MC ~~240~~
Box 22 Folder 43 1/4

Princeton - History 336

OK

PRINCETON LECTURES:

SEVERAL YEARS OF HISTORY 336. TWO SPECIAL LECTURES FOR A HUMANITIES COURSE.

f) Just one other remark. A number of people have pre-enrolled as Auditors, which is fine.

i) Actually, think there will be enough room to fit those auditors who want a conference into one.

ii) Only, will then expect you to attend and to be able to participate in discussion.

iii) If you want to do that, fill out schedule card with others. BUT LABEL IT, AUDITOR, please.

g) Now, are there questions on these organizational and formal aspects of course.

II. PREREQUISITES

1. Try now to anticipate some other questions by telling you something about the course and its present state.

a) In fact it's very much in transition state: Never been given in quite this form before and will not be given in at all this form again

i) Originated just three years ago by splitting up History 334 which had been only undergraduate course in history of science.

ii) Split it into two parts running -- with some inevitable overlap -- up to about 1750 and on from there. History 335 & 336.

iii) Obviously the split was essential. There were obviously too many sciences, developing over two long a period to be discussed in a single semester.

iv) 334 was a fine course, but coverage presented special problems. You'll get a taste both of its quality and of the problems when you read, later in this course, chapters from book that grew out of it: Professor Gillispie's Edge of Objectivity.

b) I think the split was an improvement, but Have to add that those of concerned with history of science at Princeton have concluded that it's still not the best answer to the question of how to make history of science a fully effective part of the undergraduate program here.

i) Much discussion last spring and early fall.

ii) Conclusion was that we're still trying to get too much material into too small a number of courses and missing a good deal of the discipline and excitement of the field in the process.

iii) Also, perhaps more important, trying to address ourselves to too many different audiences at the same time. Majority of audience has generally come from sciences and engineering, but also from English, Philosophy, Politics, and almost anyother department you can name.

iv) I'm convinced that history of science can be useful adjunct, at least in limited doses, for people in any field. But different aspects of it are useful, and different parts of the background can be taken for granted, for people in different areas.

v) Result is, as some of you will have seen in the Prince, we're entirely redesigning the programmas of next fall.

vi) I won't read out the new catalogue for you, but there will be a

total of seven courses in history of science, four or five to to be given each year.

vii) No longer even a pretense of a survey. Courses directed much more nearly to special periods and special problems.

viii) Some will particularly emphasize the place of science in the intellectual history of the west. Others will give more emphasis to the growing role of science as an institutional force in modern civilization, particularly since the 18th century. Still others will engage with close analysis, mostly done in seminar, of changing scientific ideas.

c) It will be aunique undergraduate program, and I think quite an exciting one, though we'll surely find things the matter with it too.

i) But it does make this course a bit of a lame duck, and I've decided -- at the risk of disappointing some of you who've read the catalogue description -- to take one fairly drastic step towards ~~xhexdiffi~~ eliminating the difficulty that's bothered me most in the past.

ii) Too many differents sorts of subject matter for a semester -- or at least for a semester which is intended to supply you not only with new information but with intellectual issues you can wrestle with both by yourselves and in precepts or conferences.

iii) Therefore announce with some regret that I'm going to leave out biology entirely, except for those of you who want to do your paper in that area. It will be back in the program next year, and I can give a better course with more elbow room for it.

2. The ground I do mean to cover is indicated, at least sketchily, on the lecture outline which is last page of document that's been distributed. I want to get back to it, but had better first talk to two sets of issues that are almost certainly on the minds of some of you.

a) First is relatively easy: Do you need 335 for 336.

i) Answer is, you don't. This is meant to be independent course.

ii) Welcome those with the earlier course, but in the nature of major programs, there won't be many.

ii) On the other hand, absurd to pretend that one can simply pick of the development of even the physical sciences as of 1700 or 1750 without some notion of what happened earlier and how it happened.

iii) Have therefore suggested on assignment sheet would do well to have a look at Part III of Mason, brief systematic survey of early modern science.

iv) I'll be dropping back to consider some important background issues that the scientists of the 17th century present to their successors.

v) Next three / and perspectives lectures will be devoted to these -- develop some problems that will be important to much that follows in the course. Only after That -- two weeks from now pick up actual science.

b) Other question is tougher, and I'm less certain of the answer because past experience gives me conflicting answers.

i) How much science do you need to have had to take this course?

ii) Want to answer, none. This is intended as a course for all comers. Except at a few points -- which I know will lose some of you but which are included for the benefit of those with more background -- the lectures and reading should supply the backgrou nd you need.

iii) But there's no use pretending that one can talk about the ddevelopment of the physical sciences during last two-and-a-half centuries without talking fairly frequently about specific bits of technical science. Like course in history of art with us pictures.

iv) Mean to mix up technical and non-technical and also the types of technical subject matter. Will offer enough choice on exams so that no single part of the technical subject matter that you'll have to know. Can substitute. Use your background.

v) But anyone who decided in 8th grade that he hated the sciences is not going to have his mind changed here. That's a bigger spectrum of attitudes and interests than I can hope to handle.

vi) Furthermore, anyone who's not had even a course in highschool physics or something resembling one is going to have to work extra hard, though it should be perfectly possible to manage it.

3. Now, once more, QUESTIONS

III. WHY HISTORY OF SCIENCE

1. Now turn from mechanics to subject itself, and try to orient you by saying something about both it -- hist of sci -- and this course.
   a) Furthermore, ~~because it's a new course and even more~~ because history is an almost new subject, will start with generalities that can perhaps be taken for granted with better established subjects.
   b) Ask, why study the field at all? What can one hope to learn? It's pretentious, embarrassingly so, but perhaps in a field like this a relevant starting point. Then turn to course itself, as I hope.
2. Inevitably the answer to question, Why study hist of sci, must be personal.
   a) My colleagues in the field would give varied answers, Many of you will, I hope, find still other answers of your own as term goes on.
   b) But my own hopes for field inevitably underlie any course I give, and I might do well to point to the main ones at this point.
      i) At least crudely they divide in three overlapping categories.
      ii) In so far as history can aid understanding at all -- a point I propose simply to take for granted -- then I'd hope history of science could aid understanding of Special characteristics of European Civilization, of Contemporary Civ., and of Science itself
   c) Just a few words about each to make them more concrete.

Not for Bates

3. First takes me back to a point ~~also~~ made by Prof. Gillispie at start of 335. Obvious, perhaps, but often forgotten.

   a) If you contrast civilization of Europe since, say, 1600 with ~~xxxxx~~ any of the great civs of ancient world of of contemp. east -- China, India, elsewhere, find comparable development in art, religion, politics, literature, music and even, until perhaps 200 years ago, in technology. But you won't find a comparable science. ~~It is the~~

   b) If there's a difference in kind between our civilization and these others, its closely related to this particular creative activity which, missing elsewhere, is so highly developed here.

   c) That should make both activity itself and way in which it developed particularly worth study. Also makes it somewhat ironic that serious study has been so long in developing.

4. My second point clearly derives from this but is somewhat different and will supply a somewhat different theme for the course.

   a) Science has distinguished European civ from all others since 17th century, at least. At least three hundred years.

   b) But it's only in this century and particularly only since W.W. II that many people have done much worrying about it.

      i) History of science itself provides prime example of change of attitude.

      ii) Fifteen years ago only about five people doing it entire U.S., and almost none of them could do full time. And no jobs.

iii) Now there are at least ten times that many, and ~~we could double it practically over night if we had trained people to take the available jobs.~~ the demand is likely to continue if we outline point emergency

iv) Many other signs in education, government, public press of same concern to understand science, come to terms with it.

b) And reason is entirely clear. [Not a Two culture problem. Seems to me very real.]

i) Not that educated people are ~~no~~ so much more interested in content of science than they used to be. Not that they're more concerned to know relativity and quantum mechanics and molecular biology than their predecessors were to know Newton, Lavoisier, and Mendel.

ii) On the contrary, in much of Europe scientific literacy used to be far more a perquisite of the educated man than it is today.

iii) Instead of concern ~~coming~~ arising from science as knowledge, it's a concern with science as power. Science the source of innovations that repeatedly and rapidly change our way of life.

iv) It's radio, television, computers, automation. It's miracle drugs, plastics, synthetics. And of course the bomb.

v) This is the laboratory transforming society, and doing so at rate without precedents in history, it's a very new phenomenon. Much newer than the laboratory or than science.

vi) In fact, there's scarcely a sign of it until about 100 years ago, at which point things begin to develop quite fast.

d) Its from this novel line of development that come many of the most difficult problems now being debated in the press and frequently in legislatures as well. Science and public policy. A new issue.

i) Silly to pretend we'll solve them here, or that they're most fundamentally historical problems.

ii) But I do suppose, perhaps just from faith, that history can contribute significantly to their understanding.

iii) Particularly in conferences. Hope to get at them a bit here.

5. Turn now to my third point which is rather different and about which I'm going to be brief and dogmatic for the moment. We'll come back to it explicitly towards the end of the course, and I ask you to keep your eyes open for it meanwhile. very shortly for the sake of my major concern. and is introduced in book five introduced early in terms of experiment.

a) Almost everyone, I suggest, gets his notion of what science is like by looking at finished scientific achievements: Newton's theory, or electrical theory, or Darwin's theory, or some others.

i) It's a natural result of science pedagogy. People learn theories in the most systematic and finished form possible. Elementary or advanced.

ii) With them they learn illustrations of the theory which provide evidence.

iii) Terribly effective, but it leads to an odd view of science. People naturally tend to think that, with some allowance for inevitable accidents and imperfections, people got the theories in the first place by the reverse process. From the evidence, the observations, to the theories.

iv) If men observed scientifically and didn't draw the now scientific conclusion, then something was prejudicing them or keeping them from behaving scientifically.

b) Both as a scientist and as one with a longstanding interest in philsophy of science, I was brought up with a view very like this.

i) Now I think it was largely wrong, and my own change has been brought about mainly by historical study.

ii) ~~Obviously~~ the process is more complex than the image I've just sketched suggests, but that's not what I mean. Instead, want to insist that it's wrong. A point I shall drop for now but come back to at least for preceptorial discussion ~~at the end of the course. By then, we'll have a bit more for evidence.~~

IV. THE COURSE

1. All that ~~of course~~ is terribly general. Let me now close briefly with a few remarks that are concretely about the course.

a) Won't outline the whole thing for you. But give you a notion of what's coming in the weeks ahead and thus a better sense of what mode of operation will be.

2. Next ~~time~~, I want to set up some major historical issues for the course and give it some structure.

a) Actually will do this by approaching some of the questions I suggeste

earlier you should be looking for. What had science achieved by mid-eighteenth century? What ideas were there about how to do science, what models of scientific achievement? What subjects seemed accessible to scientific scrutiny, and what did it mean to be scientific in scrutinizing a subject?

b) In the process of doing this will try to point you towards some of the aspects of science that are going to change most markedly with the nineteenth century, some of the things I mean to look for as we go on.

c) Reading in Hall and the Truesdale article should help to backstop this, though my own approach will be rather different.

3. Then, in three weeks that follow, want to take a fairly careful look at two representative branches of science that first reach maturity in 18th-century and that we'll follow into 19th.

a) First of these is electricity, second is chemistry.

b) In tracing them we'll get first real examples of growing power and scope of 19th-century science.

i) Change that makes character of that century very different from that of period of Copernicus, Newton, and other 17th-century giants.

ii) Ultimately will make me want to say that we've got to recognize two scientific revolutions.

4. That will bring us to mid-term exam:

a) Immediately after that want to look at changing position of science in 19th-century life, and particularly at the changes that then occur in its institutional structure:

i) This is period of ~~xxxxxx~~ professionalization of science, beginning of big proliferation of journals, foundation of specialist societies.

ii) Partly cause, partly effect of developments already examined.

b) Then one more example of transformation of physical science -- one particularly closely associated with new institutional structure for science and new demands placed on it.

c) After which, with one intervening look at a whole new set of ideas that lead to new insights in this period want to switch scientific ground and look at what's been happening to life sciences in this same period.

d) Lecture outline will show you that and also indicate the last phase.

i) Will have indicated that much of triumph, at least in physics, in 19th century is due to extension of Newtonian views into areas that couldn't be approached previously.

ii) Conclude course by looking briefly at way in which that approach finally comes to grief and ushers in a whole new approach to subject in this century.

The New Scientific Metaphysic

1. Essentialism -- The Aristotelian World-View

2. The Mechanico-Corpuscular Philosophy

   ~~Ixxxx Cartesian form~~
   Common Elements
   Cartesian Form
   Newton's emendation

COLORED CHALK

HISTORY 336 -- Lecture 2

CORPUSCULARISM

I. ESSENTIALISM -- THE OLD SCIENTIFIC METAPHYSIC

1. This morning I ~~aim at one of~~ begin a series of three lectures on the background of late eighteenth and early nineteenth-century science.

   a) In particular want this morning to discuss what I had better call the metaphysical basis of 18th and much 19th century science.

      i) Shall shortly develop the view that it was one or another form of atomism or, better, corpuscularism.

      ii) Shall also want to indicate, though mostly later, that it's immensely influential in scientific practice, even though we're often told that metaphysics and science are antithetical.

2. Difficulty with presenting this view is that it will almost inevitably seem terribly modern and also terribly natural.

   a) Becomes hard to see why its victory should have been so difficult to achieve and why people in 17th and 18th centuries found it such a source of freedom and release.

      i) So much so that they were again and again able to be totally dogmatic about it, thus stifling other approaches repeatedly.

      ii) And also hiding the extent to which an older view still lingered here and there in what they were doing.

   b) Partly, then, because the new metaphysic needs context to be appreciated and partly because we'll occasionally be concenred with some of

Must ensure time for Newton. Try cutting earlier.

the residues of the old, want to start this morning by talking very briefly about what preceded.

i) Do this even though I shall inevitably corrupt and distort the view by trying to deal with it in ten minutes. Those of you who know it from philosophy courses will be appropriately shocked. Should take weeks to explain.

ii) Condensation seems to me particularly unfortunate because it will prevent my persuading you of two things about it. It's an extremely sensible view which might well have been right, though it wasn't. Also, during its period of dominance, men managed to do some first rate science based upon it.

3. Shall call this view by a modern name, Essentialism.

a) It's roots are in prehistoric common sense and much of its plausibility and hold are due to those roots.

b) On the other hand, as a developed philosophical position it's due, more than to anyone else, to Aristotle.

i) After his work it has competitors in many areas. His authority was seldom so great as it's been said to be.

ii) But by and large it was the view best suited to science, and in the sciences it was not often challenged with success.

4. In trying to say what it is, introduce you to it in the familiar form in which it was parodied in the 17th century.

a) Molière's Doctor: Opium puts people to sleep because it has a dormative potency. Gales of laughter. No explanation because have simply paraphrased what one was asked to explain. Circular.

b) But the parady, though natural and an important element in 17th-cent rhetoric, misses the point.

i) The notion that things have potencies, or essences, or natures that makes them what they are would be unassailable if only it then required just a few of them to account for all the variety that's observed in nature.

ii) That's the virtue of the modern atomic theory as embodied, say, in the periodic table. Only 90 odd stable elements to account for all variety of organic and inorganic substance.

iii) If one needed an extra element for each substance, this view would seem circular too.

iv) As a matter of fact, it did begin to do just that in the 19th century.

v) Lavoisier, who put the notion of element in modern form, had only a few, but many more are quickly discovered.

vi) Faraday bemoans multiplication. If it goes much further, must either give view up or discover how to transform one into the other.

vii) Plausibility and utility of notion depends on their not being too many of them. They must simplify observed variety.

5. Well, for a very long time it seemed that explanation in terms of essences would produce a similar simplicity. would not need for each single thing.

a) There were three good reasons for thinking so, and I'll consider them in order.

b) First let me call everyday (or even -- ~~as well see later~~ -- quite professional) biology.

i) Species do come, particularly if your radius of observation is restricted, in distinct bundles.

ii) Cats don't shade gradually into dogs, or dogs into horses, or horses into cows. There are natural families, perceptually separate in nature. Can give a few examples to illustrate each. Seldom or never troubled Thought.

iii) Not a long step to suppose that what's responsible for this is a cat essence, "catness," a dog essence "dogness", and so on that makes each of these species what it is.

iv) That's part of where notion comes from and part of what gives it its force. Even today hard to explain this natural clustering in physico-chemical terms.

c) But there's more to it, and some of that is seen by turning from biology to geometry.

i) It takes very little experience with geometry for a clever man to reach a point where he takes in gobs of it at once.

ii) Studying the triange until he grasps its nature, he sees that sum of angles must be 180°, that lines from vertices to midpoints of opposite sides must intersect in a point, and a great deal more. exterior angles

iii) And this is part, also, of notion of essence. Careful inspection will enable you to grasp the essence or nature of a body. Having grasped it, you will be able to understand as consequences of the essence a great many things you have not at all seen in it originally.

iv) Essences, in short, are consequential. Having grasped the essence is to learn a great deal about the body whose essence it is.

d) Finally, then, I'd simply add that, of course, at the common sense level we constantly still act as though there were essences.

i) Particularly clear in personal or political relations.

ii) Knowing a man is a Republican, Democrat, radical or liberal gives one the sense of knowing all sorts of other things about him.

iii) Seeing a mouth that turns down at the corners or one that's a straight line with thin lips, is an immediate source of judgment about personality and character.

iv) Of course the more flexible among us are prepared to be mistaken, and make corrections as more information comes along.

v) But we really have no alternative, until it does, to relying on our initial intuition of the essence which makes the individual what he is.

e) Philosophically elaborated and applied to many aspects of nature, this is what operating in terms of the essences of bodies around us is like. Almost unavoidable as a start, and might have lasted for ever. Much good sci.

II. THE MECHANICO-CORPUSCULAR WORLD VIEW

1. For reasons that I do not now want even to touch upon, this whole way of regarding the world begins to encounter a barrage of sever criticism in the second half of the sixteenth century. it's increasingly replaced

   a) And in the seventeenth, particularly after c. 1630, by another which is variously known as the mechanical philosophy, the corpuscular philosophy, or just the New philosophy.

   b) This is perhaps not quite so new as it sounds, for many of its elements are borrowed from another Greek philosophy. Ancient atomism.

   c) To a great extent it steps in to occupy intellectual void left by downfall of Aristotelianism. But it steps in with a difference or several of them.

      i) Much science, particular observation and study of motion, and much mathematics has been learned since view was developed in antiquity. Can now do things with it that one could not at the start.

      ii) In addition, ancient atomism had been largely concerned with resolution of logical paradoxes.

      iii) Thus, name means indivisible, to solve problem of dividing body for ever. Smallest particles. Other problems of same sort.

      iv) Now view is much more common-sensical. Particles need not be in principle indivisible. Just the smallest divisions that ordinarily occur. DRW.

      v) Not, however, atoms of weight. Think of as clouds. These are corpuscles of corpuscles.

2. Result is a view of nature which, though hotly resisted in a number of circles, ~~some of which we'll encounter later~~, is common to most scientists from mid-17th centuyy onwards.

   a) Can summarize its main common tenents like this:

   b) Matter exists in (relatively) stable corpuscles

   c) These have only primary qualities: Size, shape, position, motion, (weight). Otherwise neutral. No color, temperature, taste.

   d) Their Motion and interaction governed by God-given laws, from which all else is to be derived. All color, heat, and so on, as well as motions of projectiles and planets.

      i) This is universe seen as a piece of clockwork, image is often explicit, and left to run with or without his constant guiding hand. ← built by God

      ii) It's pretty standard view in many circles in 17th century. Part of what makes the century one of intellectual revolution.

3. All of this will become clearer with illustration which I take from the formulation given it by the Frenchman Descartes, 1596-1650.

   a) Now better known for his methodological writing or for mathematics, but this is source of his most important contribution to the 17th century. It's immensely influential.

   b) Draw. Single corpuscle. Linear motion. Newton's first law. For corpuscles.

b) Now introduce second corpuscles. Draw. Same behavior unless they collide. Then other laws.

i) Descartes has a number of laws depending on relative size and relative velocity.

ii) Only the first is good, but this is origin of collision problem. Much work from here on. Basic to Newton's 2nd and 3rd Laws.

c) From these everything else -- entire motion and qualitative behavior of universe is to be derived.

4. Of course Descartes doesn't succeed, and in some respects what he does next is incredibly crude. But it gets worked on, and for now it's the idea that counts. Worth following a bit further.

a) Immediately encounter another aspect of his thought -- insistence that universe is full. No empty space.

b) Thus draw imagines more and more corpuscles, jostling and colliding subject to same laws, until all void is squeezed out and we have virtual motions followed by virtual collisions.

c) On this basis, though with major logical gaps, Descartes develops vortex theory briefly described by Hall.

i) Draw vortices. Within each one matter circulates in circles.

ii) Planets are aggregates of larger particles carried around in vortex and kept from escaping by impacts from above.

iii) Smaller vortices drive stones to earth, account for weight and thus gravity.

d) This is way that planetary and projectile motion are handled.

5. But that's not all. Also qualities. One illustration.

a) Smallest particles are driven to center where they churn around.

i) Thus constant vibration transmitted out by neighboring particles

ii) Draw. When it hits eye the result is sensation we call light. Descartes derives many of its properties, or thinks he does.

b) And also attempts an account of color -- corpuscular spin. Acquired for example, by contact of light with shade, as in prism example he gives.

c) Will not elaborate or follow further -- and there is much further to go.

d) But it should make clear what it means to say that objective of much of science in 17th and 18th century is, following this program, to explain all natural phenomena in terms of corpuscular mechanism governed by fundamental laws.

6. Only, let me now underline it, the machine doesn't always take just this form.

a) Many later figures, for example, allow void. Others try other sorts of particles. Still other variations.

b) But of these only one proves really radical and tremendously important at the metaphysical level at which we now are working.

c) It's due to Newton and is the notion that particles interact in other ways besides impact. In particular, there are forces which act between them at a distance, of which the ~~ex~~ most important for 17th century is gravitational attraction. But also chemical, electrical, others.

7. You know what it is, and I need not elaborate. But a few points have to be made to set up what's to follow.

a) Newton himself doesn't believe in innate forces acting between particles at a distance.

i) But can't explain ~~what~~ causes the apparent attraction and leaves it as a mathematical law to be explained ~~mechanically~~ at a later date.

b) In the absence of an explanation, however, many people don't believe him.

i) Either accept it as a God-given force not to be further explained.

ii) Or ~~fix~~ reject it as an occult property. Return to essentialism and rejection of mechanism.

c) In fact, it's fifty years after Principia in England and longer still in France before Newton's theory of gravity is taken fully seriously.

i) It's a basic change in metaphysics again and is much resisted.

ii) Some effects of that resistance we'll encounter both in studying 18th dentury electricity and also chemistry.

1) But it does take over, then search for proper forces is basis of sci work.

RATIONAL MECHANICS AS "CLASSICAL" SCIENCE

1. Technical Transformation in Scientific Revolution
2. "Classical" vs. "Baconian" Sciences
3. 18th Century Mechanics as an example

   Rationalization of mechanics.
   Celestial Mechanics
   Vibrating Strings
   Hydrodynamics

HISTORY 336 -- Lecture 3

18th-Century Mechanics as "Classical" Science

I. Classical Science and the Scientific Revolution

1. In my introductory lecture I suggested, one cannot study 18th- or even 19th-century science without looking back first to the 17th century.

a) A great deal that occurs later is conditioned by what had occurred and what had not occurred in the Scientific Revolution of the 17th century or in what's sometimes called the Age of Newton. Origins of Modern Sci.

b) But in practice, though this point is too seldom emphasized, the Scientific Revolution is an extremely complex constellation of events, and the various transformations it encompasses do not all develop in the same way afterwards or have the same sorts of effects.

c) In the three introductory background lectures, of which this is the second, I am trying to separate out three rather different lines of development whose later interactions we shall need to observe.

Most profoundly significant (BACK)

i) The first was the new metaphysical base, corpuscularism, which I discussed last time.

ii) The second is the transformation of actual scientific laws and theories. That I mean to deal with this morning, first in a general way and then taking 18th-century mechanics as a particular example.

iii) Finally, in next lecture, last of background set, I mean to talk about change in scientific method, value-system, and institutional structure.

iv) Will need all of these as we proceed.

See p. 2

This is pretty good. But --

1. First part is awfully abstract still. Needs some thinking out.

2. Last part is not very interesting. Needs to be real world and human

c) Probably good reason to speak of history of science!

i) At least invites us to look at sciences as a group, not trace modern established back. Part of phys, chem, biology etc.

ii) On the other hand, not like history of art, literature, law, etc.

iii) Must remain prepared for work independence, different supporting forces having different effects in different places.

iv) Now trying to isolate two main streams that behave quite differently.

2. Have already said that 17th (better 16th and 17th) century was period in which the sciences underwent first really major rewriting since Greek antiquity. Now ask for the most cursory answer to the question: What were these changes and in what sciences did they take place?

ROSTER OF GREAT ADVANCES.

a) Earliest science to be transformed is Astronomy. Copernicus, 1543, heliocentric system for geocentric.

i) Kepler -- first mathematical account that's as accurate as observation.

ii) Galileo and telescope. New objects, unification of terrestrial and celestial behavior.

iii) Newton, all heavens and earth under simple laws. Deviations from Kepler's laws. Comets and satellites. Etc.

b) Almost simultaneously begins upheaval which, though somewhat less drastic is ultimately as decisive in Anatomy and Physiology.

i) Vesalius, 1543, brilliant anatomical atlas from human disection by a physician. Embodied in printed book with full illustrations that can serve as map with respect to which future corrections are made.

ii) Harvey, circulation of the blood. Upsets old theory with more mechanical one that increasingly indicates new functions for old organs and new model for analysis of organs.

iii) In particular, though H doesn't see it, total change in function of lungs and breathing. ~~Point at which we'll pick physiology up later in course.~~

Term paper problem.

I made good sense of this, I think.
by ad. libbing the structure & cadences
that seemed natural.

But it left me [illegible]
for adequate mechanics.

c) In Mathematics changes are less sudden but more varied.

i) Algebra from Arab world is greatly increased in power by introduction of standard symbolic abreviations that are spread by printed book.

ii) In this form algebra makes first firm contact with geometric heritage from Greeks and both are transformed. Analytic geometry.

iii) And this is the essential preliminary to what's the greatest of all changes: Calculus which in turn reacts back on physics.

d) And of course science it reacts bakk on is Mechanics, the study of motion, greatest of all the technical transformations that occur in 17th century.

i) It's Galileo's New Science, or one of them. Not new as subject matter. Aristotle has made it central and its stayed their. But new in application of mathematics and new as model for what science can become.

ii) Previously had math only in astronomy and, less elaborately, in statics and geometric optics. Now it extends to projedtiles, pendulums, bodies on inclined planes, to the tides, to the propagation of sound in air, and to many other areas as well. In all cases as mathematical science resulting in precise quantitative predicttions.

e) Finally, somewhat less consequential changes in Optics.

i) Lenses and the eye. ii) Snell's Law of refractionx iii) N8s theory of colors.

3. That's a nearly exhaustive list of the areas transformed by 17th-century development, though not of the changes within those areas. Now notice two things about it.

   a) All of these fields are very old.

      i) Reached a high level of development in antiquity in works of men like Apollonius, Archimedes, Euclid, Ptolemy, and Galen.

      ii) They have a relatively continuous history in Islaam and the Latin west during the middle ages.

      iii) Not surprisingly, therefore, they've all got institutional homes in institutions that have a long history before the 17th century.

      iv) Mathematics, Mechanics, Astronomy, and Optics are all fields in which lectures are offered in medieval universities during the middle ages, and the number of chairs in these fields increases during the 17th century.

      v) Anatomy and physiology are, of course, just medical school subjects and the med school is even older than the University as an instit.

   b) That being so, I shall label this group of sciences the classical sciences, and I shall simply assert about them that the transformations they undergo in the 17th century are firmly based upon both the substantive and institutional heritage from antiquity and the middle ages.

      i) This is not the course in which to argue the point, but the notion that one gets Copernican astronomy, Galileo's laws, and so on just because people open their eyes is a myth.

c) Saying that much, however, already highlights the second characteristic of the list now labelled classical science.

i) Though it's a big list and represents impressive achievements, it by no means exhausts the list of sciences as they will exist in the 18th and 19th centuries.

ii) In fact, the fields not represented form a list of their own: Magnetism, Electricity, Heat which will be central parts of physics by early 19th century. Chemistry, a whole science. Geology, another one. And also the non-human parts of biology, or better yet, the non-medical parts: Botany and Zoology.

iii) This list I shall label the Baconian sciences, though I reserve my reasons for doing so until next lecture.

d) At the moment they stand here simply as a contrast to the classical sciences, and I shall therefore say only a bit about them.

i) They do exist in the 17th century, but most of them are new and all of them are scientifically underdeveloped. No great domains.

ii) Using vocabulary suggested in the book I've assigned (tho this is part of vocab that needs revision), I suggest that these sciences, unlike the classical, are still in their pre-paradigm stages.

iii) They lack a firm model or models to guide practice, and they lack a well-defined community of practioners.

iv) Not surprisingly, then, there's also a lack of homes for them,

of
an institutional base for their practice. These are not university fields.

v) Part of our problem as we continue in course will be to see how they became full-fledged sciences. originated and how then

4. That, however, is already ahead of my story for today. At the moment, having tried to show you part of reason for distinguishing them, want to drop back again to classical sciences.

a) Here my question will be: What happens to them after the 17th century?

b) Just asking the question should suggest another reason for the distinction I've introduced.

i) If one asks about the development of science in the 18th or 19th question, it makes a great deal of difference whether one asks about a classical or Baconian field.

ii) It's with the classical sciences that I'm now concerned, with that is, the sciences that had well-established paradigms before the 17th century and replaced them with others at that time.

c) Only, I shall no longer try to talk about them as a group. Instead pick mechanics as an example to stand for the whole.

i) It's not, as many of you will realize an altogether typical one.

ii) In particular, a point which needs underlining to avoid confusion, it's elaborately mathematical in ways which none of the other fields are except math itself and parts of astronomy.

d) Nevertheless, if one asks what the Scientific Revolution left to be done in the sciences it had transformed, the answer from mechanics is not atypical.

i) The way I want to put it initially is in the form of a paradox. In mechanics after Newton there was simultaneously Everything and Nothing at all to do.

ii) Looking back a hundred years after the Principia, Lagrange would say, Lucky Newton: There is only one system of the world and therefore only one man could discover it.

iii) Which is to say that nothing which could again produce the sense of cosmic excitement evoked by Newton occurs during the 18th or 19th centuries in mechanics -- Not until Einstein, in fact.

iv) On the other hand, Lagrange himself stands at the end of a full century of brilliant achievements in mechanics. This is period which includes, in addition to Lagrange himself, such men as the Bernoullis, d'Alembert, Euler, and Laplace. Names that can be reeled off this way because all of them have left their names on one or another theorem, principle, or law familiar to anyone who studies their subject.

v) Mechanics, as it exists today, is their subject far more than Newton's. And it is, correspondingly, they rather than he who make possible much that happens in the 19th century and the 20th.

5. Now ask, what is it that they do? Obviously can't give technical description for reasons both of time and of mathematical complexity. But can characterize development in terms of several main directions of effort.

II. MECHANICS IN THE 18th CENTURY

1. First of these is the effort to make sense out of the achievement that have already been made.

   a) By this I mean find a formulation of mechanics that willbbe at once more precise, more general, and more generally applicable than those given by Newton and his contemporaries.

      i) Newton's Laws, for us, are extremely general. Can derive rest of mechanics from them.

      ii) But he didn't usē them this way. His applications are almost entirely to widely separated bodies, spherical in shape, and actēd upon by a single simple force.

      iii) By no means clear how those laws should be applied, or reformulated so that they do apply to a problem like, say, the gyroscope or a compound pendulum.

   b) This is the line of development summarized so well in Truesdell's article that I asked you to read for this week.

      i) Culminates in Lagrange's Méchanique analytique of 1788, and I shall not trace it further here except to correct one impression that I think that article may leave with you, and Truesdell further (implied, explicitly in places).

      ii) Though Truesdell quite properly emphasizes how much in the way of clear and general formulation Newton left for his successors to do, he does leave the impression that that effort largely took off from the Principia as its starting point.

Stratton is ever wrong.

iii) In practice, there have been two other major lines of 17th century development that Newton has done little for or with, and one of the big problems for 18th century mechanicians is to put these together with each other and with Newton.

iv) It's really this rather than an anlytic restatement of Newton's laws that occurs when Euler writes $F_x = Ma_x$, and the other equations that Truesdell cites.

c) One of these lines of development is statics. Equilibrium of weights. Simple machines.

i) Ancient subject brilliantly reformulated in 1st half of 17th cent.

ii) But notion of force that it involves is that of weights, springs, and so on at rest.

iii) Newton's force is principally dynamical. What's passed back and forth when bodies collide. Mostly it's impulse.

iv) It's by no means clear how to put these together. In fact, the problem itself is not initially seen. Late 17th century people can still misspell & perfectly spelling not...

d) Other line is kinematics, which stems from Galileo and is brilliantly developed by Huyghens.

i) Here motions are described in mathematical terms without any reference to forces that produce them.

$\frac{a_1}{a_2} = \frac{s_2}{s_1}$

ii) Galileo draw on fall and inclined plane. Applicable to circle.



No forces, uniformly accelerated motion.

iii) Huyghens and successors making up complicated curves out of infinitesimal inclines. How to unify this with Newton?

2. This, then, is the rationalization of mechanics, but there's a great deal else. I

   a) In particular, without waiting for Lagrange to get all in order, there's immense ingenuity expended on the solution of many new problems in a large number of areas.

   b) And these efforts, unlike those at rationalization, continue into the 19th and 20th centuries.

3. One principal area of effort is celestial mechanics.

   a) Newton has derived Kepler's laws on assumption that only attraction between planets and sun need be taken into account.

      i) But all bodies attract each other and this perturbs K's orbits.

   (i) add'l ~~Kepler~~ observational accuracy.

   b) Newton's taken a stab at next level (it's till not possible to handle three-body problem generally) for moon.

      i) But it's gradually recognized that his results are bad.

      ii) Lunar theory adequate to meet observations demands immensely elaborate and ingenious math and is only worked out between about 1740 and 1780.

   (iii) talk of giving up gravity 1/r².

   c) And the problem of the interactions between the planets takes even longer.

      i) These cause both local irregularities in orbits which are handled first.

      ii) But also long term, very slow, variations in the direction and

planes of the orbits.

iii) The development of techniques to handle problems like these continues well into the 19th century.

iv) Most exciting, but by no means most brilliant result, is discovery of Neptune in 1846, just where it should be to account for failure ~~in~~ of Uranus' orbit to obey theory.

4. An in additon one gets application of mechanics to what are new or very nearly new problem, of which two particularly consequential ones are problem of flow of fluids (hydrodynamics) and problem of vibrating strings.

a) With problem of vibrating strings shall lose those of you who haven't seen subject before, but I'll also be brief.

b) In series of developments that extend throughout century and that often involve quite bitter controversy, get following stages:

i) General differential equation for string: $\frac{d^2y}{dt^2} = c^2 \frac{d^2y}{dx^2}$.

ii) Recognition that any solution appropriate to string initially at rest must have form: $y = \frac{1}{2}[f(x+ct) + f(x-ct)]$

where f(x) may be any function at all. Draw.

iii) Development over time can be found by extending function periodically draw, and then moving it in ± directions at vel c.

iv) In process, Lagrange almost gets general Fourier series, but just

fails to see what's on page before him.

5. Finally, in case of hydrodynamics, will not need to tell the Aerodpace majors present that there's notsuccess with turbulence (this problem is still immensely active) and therefore almost notresults that agree with experiment.

   a) But this bothers people less than you might suppose, and what they do manage is brilliant mathematical formulation for laminar flow.

   b) Euler, in particular caps -- though he does not end -- a long line of development by producing the general differential equation for the motion of a fluid under pressure: compressible or not, homogenious or not.

   c) In addition solves the equations for ~~xx~~ a number of important cases.

   d) A development which is, of course, basic not only to subsequent hyrdrodynamics, but also for whole mathematics of fields.

6. This is neither trivial nor easy nor dudl work.

   a) In most of the classical sciences it has important parallels during the century, though perhaps only mathematics and physiology display quite this brilliance.

   b) Terribly ingenious both for theory and because it makes available fundamental techniques ~~That~~ for other deployed in ~~The~~ Baconian sciences, most slightly, chemistry. {but right meager with Baconian-}

   c) And yet ~~not~~ unappreciated at ~~Lucky~~ level of ~~The~~ Newton. gross structural ideas, nothing at all

Baconianism

1. Baconianism as ideology
2. The Baconian program
    - A Fresh Start
    - Experimentalism -- Old theory new practice
    - Utilitarianism
    - Institutionalization
3. The Importance of Baconianism

HISTORY 336 -- Lecture 4

Baconianism

I. BACONIANISM AS IDEOLOGY

1. Today give last of the three bckground lectures, and present it under the general heading of Baconianism.

   a) By this I mean not any scientific achievement or group of scientific achievements.

   b) Nor have I in mind any really novel philosophical position about the nature and sources of scientific knowledge, though there is somewhat more of this.

   c) Rather, what I'm after now is a quite elaborate constellations of attitudes, values, and resulting programs for science.

      i) In a sense it's a propaganda movement, a new indoctrination, an ideology. New set of notions of what science is about + how to do it.

      ii) One which produces more words than consequences at first but which ultimately transforms the sciences. Motives.

2. Can perhaps make this clearer in following way.

   a) Movement takes its name from Francis Bacon, 1561-1626, who is undoubtedly one of towering geniuses of the early 17th century.

   b) i) Prominent Lord Chancelor of England.

      ii) Great essayist, stylist, and generally also prolific writer. Permanent impact on English prose style. Some people still argue that it must be he who wrote Shakespeare's plays.

This went well, but —

I had too much for
with some of early stuff — dense.
exhib. etc. — and ran out of time
at end.

b) But not really a very good scientist.

i) Rejects many of the best discoveries made in his own day.

ii) Reports as experimental fact a great deal that derives from long-lasting legend.

iii) And discovers nothing of significance on his own.

c) Nor is he a great deal better as a philosopher, though I think in this respect he's somewhat under-rated.

d) But what he does prove to be is a fine and immensely influential propagandist for a movement that was already coming into existence before his birth.

i) He becomes the chief program writer for a movement that he did not by any means create.

ii) Thus he gives his name to and becomes a symbol for a whole cluster of new attitudes and emphases in the sciences.

II. THE BACONIAN PROGRAM

1. Now let me try to epitomize the Baconian program for you, beginning with that part of it which has had the longest-lasting, though not the most important effect. I mean the rejection of all past work and the insistence on the need for a fresh start.

a) Bacon, in fact, is relatively respectful of the Greeks, but at that his evaluation comes out like this:

"It must be plainly avowed that that wisdom which we have derived principally from the Greeks is but like the boyhood of knowledge, and has the characteristic property of boys: it can talk but it cannot generate, for it is fruitful of controversy but barren of works."

b) To the scientists of the Middle Ages he cannot concede even that much.

i) For him they are contentious dogmatists and logic choppers who argue exclusively from books and have succeeded in degrading even the ancients. Angels on "head" of pin.

ii) We inherit that image, which is by no means accurate, from him and his fellows, and it is still extraordinarily difficult to eradicate.

c) Under the circumstances -- weak start further undermined by the Middle Ages -- he sees: ". . . but one course left . . . -- to try the whole thing anew upon a better plan, and to commence a total reconstruction of sciences, arts, and all human knowledge raised upon proper foundations."

d) People take this idea of a new start terribly seriously. Try it.

i) Also, believing that they have started afresh, they often give credit to the new program for developments that, in fact, have firm roots in antiquity and the middle ages.

ii) This take much credit for Newton, etc., though he is not much to do with him. Many historians have looked for fellows there.

2. Bacon speaks, however, not only of a new start but of a new foundation. His is a positive as well as a negative program. Want to look at it.

   a) In doing so will spend most of my time on an item I've labelled experimentalism.

      i) Necessary partly because this is surely most important aspect of the program from viewpoint of its effect on science.

      ii) But also because it's been largely misunderstood, I think, by historians who either take Bacon's word about its importance too literally or else dismiss this element entirely.

   b) Both groups, I think, miss the point. Should warn you, however, that what I take to be the point is not the common view of the profession.

3. Used regularly to be said and still is in some circles that Bacon invented experimental method and developed philosophy to go with it. Or, if he did not invent it, he at least propagandized for this 17th-century novelty

   a) It's absurd both with respect to experiment and with respect to philosophy.

   b) Those of the Greeks who did science were thoroughly aware that it must be based on careful and prolonged observation often combined with experiment.

      i) Aristotle himself wrote: "Lack of experience diminishes our power of taking a comprehensive view of the admitted facts. Hence those who dwell in intimate association with nature and its phenomena grow more and more able to formulate principles [which] admit a

wide and coherent development: while those whom devotion to abstract discussion has rendered unobservant of the facts are too ready to dogmatize on the basis of a few observations." (316a5-11)

ii) That's a statement that Bacon might have written, but it's from Aristotle, and it's not an isolated attitude in antiquity.

c) Nor does it vanish in the Middle Ages. In fact there's an elaborate philosophical tradition of empirical methodology that stems from Grossteste and Roger Bacon in 13th century and is a regular part of the University curriculum at a number of medieval and early modern schools.

i) The philosophical insistence that one must examine nature is not new.

d) Nor is the practice of refined observation and of some experiment.

i) Aristotle in marine biology is unsurpassed until the 19th century

ii) Astronomy is entirely dependent on observations and has a considerable instrumental arsenal for the purpose.

iii) There's been much experimentation in optics, in particular Ptolemy's attempt to measure the angle of refraction of a light ray entering water.

iv) And the medical tradition has included both elaborate anatomy and some vivisection to establish function of organs.

e) The performance of experiments is not new either.

4. Emphasis on facts like these has led people to say that there's nothing new about experimentalism in the Baconian program and to reject entirely its historical role. But this seems to me as wrong as the attitude it replaces.

   a) Misses the fact that though neither the philosophy nor the practice are new, there's an immense change in the value placed on experimentation and on the sort of experimentation that's done.

   b) For example, ancient and medieval experimentation have generally been intended to provide a concrete answer to a concrete question given in advance.

      i) Sometimes to determine a fact or law, as in astronomy or Ptolemy on refraction.

      ii) Sometimes to test a hypothesis, as when Galen ties off the ureter to see whether an expanded bladder can force urine back up the channel to the kidneys. Galileo & inclined plane.

      iii) Both are important functions. They continue today.

   c) But for the Baconians they're not the main function.

      i) For them obsrvation and experiment are principally tools for exploration.

      ii) The product they envisage is the so-called Natural History, where natural means about nature and history means list of facts.

      iii) Widespread examination of nature is to them a prerequisite to science. One must collect and collect and collect.

d) Bacon writes some natural histories himself and leaves behind a list of others that should be written:

i) Apologises for incompleteness though there 130 items on the list.

ii) Sample a few: Works VIII, p. 373 ff.

e) People follow this up. Some get written. Maybe a look in precept.

i) Usually a morass of assorted observation.

ii) But very new and ultimately useful.

5. Nor is this all that's new. Also what I can best call new standard for observation and experiment.

a) Examining medieval experiment one ~~constantly~~ occasionally wonders whether certain of the experiments cited were performed.

i) Some ought not have given results quoted, though they might have. One doesn't know enough about apparatus to be sure. Trickey: Hot & cold water freezing.

ii) On other occasions the results are fine, but one doubts whether the needed apparatus could be built.

iii) Undoubtedly lots of the experiments were pefformed, but the attitude taken towards them is often very close to that which is generally adopted now towards demonstration experiments.

iv) Not easy to demonstrate to a large audience. You cheat a bit. Added element in apparatus. Point the other way. Tell them it would have worked out if the weather were different.
Oddity is, it doesn't make much difference.

b) This tradition continues into the 17th century.

i) In many respects Galileo belongs to this medieval experimental tradition.

ii) But the Baconians reject it to the point of parody.

iii) Boyle will describe every solitary thing about his apparatus, the room, the witnesses , their nobility and credibility, and so on. Often leaving out, however, just that one thing one would most like to know.

iv) Sometimes one gets really decisive confrontations of the two traditions as when Boyle reviews for the Phil. Trans. a book by Pascal on hydrostatics. Brilliant presentation documented by many experiments illustrated with elaborate diagrams.

v) Boyle says he agrees with principles and finds them clearly explained. But he wonders at the experiments: How is a man to sit at the bottom of a twelve foot tub of water holding a cupping glass to his thigh. Where is one to find workmen who can machine the instruments Pascal shows. And so on and on.

My experience.

c) This is the plea for fully circumstantial reporting and for scrupulous honesty which is again a new attitude towards the subject.

6. And with this new insistence on quantity and standards goes one other pair of terribly important things: Bacon insists that one must not be satisfied with examining nature in the form which it takes naturally.

a) Distort nature. Twist the Lions Tail. See what happens in unnatural situations. Not the to corpuscular phil.

b) Furthermore, for this purpose, the Baconians introduce or import a great many new instruments into the sciences.

i) Anyone who doubts that there's novelty in the program should look at the list:

ii) Electroscope, Telescope, Microscope, Barometer, Thermomenter, Air pump, together with importation of whole content of the Chemical lab which has previously belonged to pharmacist, alchemist, or manufacturer.

iii) There's been nothing like this before. Instruments have been astronomical, surgical and that's substantially all.

7. It's these things and others closely correlated with them that I have in mind when I speak of importance of experimentalism in Baconian program.

a) And implicit in them and in your reading are the last two aspects of the program which I'll here simply point to virtually without discussion.

b) On Bacon's list of natural histories, you will have noticed a number of items calling for histories of the crafts. Histories of cooking, baking, dyeing, leathermaking, winemaking, and so on and on.

i) These have not previously been respectable subjects for study by the learned. They become so now.

ii) And the reason why is clear. Baconian than There's all sorts of recondite infor

mation to be had from them. Needn't start quite from scratch.

iii) And it is information that's likely to lead to useful science.

iv) One new item in the Baconian program is the insistence that science be useful. It's utilitarian, though not only that.

v) Thus craftsmen as well as their crafts become important, and that of course is part of how instruments get into the sciences. We'll see this as we go on.

c) After which I need perhaps only remind you where the instruments go:

i) Partly, perhaps mostly, into the workrooms of rich men. This sort of science is largely an amateur activity. Not in the univesities except where it's able to attach itself to the medical schools.

ii) But partly also into the collections assembled by gift and by grant at the new scientific societies.

iii) For these societies are founded to a very great extent as a response to the Baconian push. Their aim is to encourage above all the new sort of science for which there's no room in the universities. You're reading about them so to warn her.

III. THE IMPORTANCE OF BACONIANISM

1. That is as much as I want to say about the nature of the Baconian program. Now let me ask what it's good for. What does it produce.

a) Often said that it's responsible for what I called last time the substantive changes in the classical sciences in the 17th century, but this I think is largely wrong. Based on post hoc propter hoc argument

i) These sciences are already very well on their way. New attitudes are important to them, but seldom these attitudes, at least not primarily.

ii) In particular, there's remarkably little new experimentation underlying the major substantive changes that occur during the seventeenth century.

iii) That's another reason it's seemed easy to dismiss the Baconians.

2. But though easy, it's also a mistake.

a) What Baconianism does is not, at least for a long time, to transform established sciences but rather to create new ones.

b) Very often these grow out of existing craft techniques.

i) Gilbert starts as a student of the mariners compass and gets much of his earliest material from a book by a master mariner, Robert Norman.

ii) The bulk of early scientific chemistry comes from the recipes and apparatus of chemical technology and alchemy. 16th century Boyle. R.S. publications.

iii) That's two where much of the instrumentation comes from.

c) In other cases one gets new sciences largely through a joy in collecting, a natural extension of curiosity and of the horizon of science.

i) Geology and botany both come partly from this route, though mining

pharmacy also play a role here.

3. These are, of course, just the fields that I listed last time as the Baconian sciences, and it should now be clear why.

   a) About them I also said that they are highly underdeveloped in the 17th century, and the reason for that should also be clear.

      i) They're too new. They depend upon too much observation for which there's little guidance. At the start they're likely to be a considerable mess. Which they are.

   b) But I need scarcely tell you that they don't stay that way.

      i) We shall be looking at them in the weeks to come and will find that in the 18th century, from about 1750 on, most of them begin to take significant form.

      ii) And in the 19th century most of them reach a maturity comparable to that which the classical sciences had displayed in the 17th century.

   c) And by the time they do so, one other important thing happens.

      i) In a number of cases, most notably in the study of electricity, heat, and new parts of optics, they begin to merge with the classical sciences.

      ii) In particular, they reach the point at which they begin to be able to use the powerful mathematical techniques which have previously been deployed only in mechanics and astronomy.

   d) Then things really begin to hum.

COLORED CHALK

Electrostatics as Baconian Science

I. Electricity before 1600.

II. Gilbert and the Origin of Electrical Science

III. The Effluvial Period, 1600-1729

IV. Fluid Theories, 1729-1747.

V. Newtonian Electrical Theory

VI. Mathematization of Electricity

HISTORY 336 -- Lecture 5

Electrostatics as Baconian Science

I. ELECTRICITY BEFORE GILBERT

1. This morning will talk about electrostatics as a Baconian science, first we've looked at in any detail.

   a) In the process I'm going to go over almost exactly the ground covered in the Harvard Case Book.

   b) Result will be more duplication than I'll generally allow.

      i) Usually I'll either have you read on related topic or else I'll fill in between reading.

      ii) But in this first attempt at examination of substantive science, I want to emphasize certain aspects of the situation that reading doesn't make altogether apparent.

      iii) Later expect that you'll do more of this for yourself.

2. Not surprisingly, since I've already said electrostatics is a Baconian field, first thing I want to say about it is that it didn't exist as a science until 1600 and after.

   a) But if you'll look at almost any standard history of electricity, you'll find that it takes many pages getting to 1600, sometimes most of the book.

      i) Have to see in what sense my statement is meant.

      ii) Depends on a marked contrast between earlier and later period.

This went well, Though a bit
rushed at end.

Second go Thru was fine.
But partly because I took
time to point Things up.
As result, I left out last
part (IV. 4.) entirely.

b) People who begin histories of electricity in antiquity and the Middle Ages generally search ancient and medieval texts for knowledge of the field. In fact, they then come up with a good deal that we would now call electrical.

i) Many descriptions of lightening, and many others of "torpedo" or electric eal.

ii) Some discussion of amber and jet as bodies that attract chaff when rubbed, given together with discussion of lodestone and sometimes of moutain that pulls copper nails from ships.

iii) Elsewhere mention of the glow from tips of spears of Roman phalanx and some of St. Elmo's fire in ships' rigging.

Great scholarship but all wrong or [illegible]

c) All of this we now group as electrical, but this was not done at the time. These are scattered observations spread through books on many different topics.

i) So there is no body of electrical knowledge that draws these together. Only amber & jet are electrical. Greek word now amber

ii) ~~In practice~~, there's little interest in pursuing any of these isolated facts beyond themselves, nor is there a body of technique with which to do so.

II. GILBERT TO HAUKSBEE AND GRAY

1. This is situation that's decisively changed by appearance in 1600 of a book called On the Magnet by William Gilbert, or by new circumst. that produced

a) ~~A~~ new science results from study of this immensely influential book.

i) Because much that goes on here is typical too for other fields want to look at sources of the new science a bit more carefully.

ii) Elaborate a remark I made last time.

b) Gilbert himself is a physician, in fact to Queen Elizabeth I.

i) They're among the men who combine the training in scholarship to do the new sciences with the facilities needed to do it.

ii) If you watch the development of the new sciences, biological or physical, you'll find a disproportionate number of medical men involved.

c) But he doesn't simply invent the field, but instead turns to the study of an existing craft or technology.

i) This time of the mariner's compass which has revolutionized European trade during the past 200 years.

ii) Knowledge of it comes to him mainly from book by Robert Norman, a master mariner who in 1581 publishes the New Attractive, a description of various compasses, how to make and use them.

iii) Again event is of type that recurrs. Only in the 16th century that one begins to get such books. Early publications of Roy. Soc. include a number of them.

iv) And it's often study of them by figures in university tradition, or direct study of craft itself, that introduces new subjects into science.

2. About Gilbert's work itself you'll be reading, and I shan't attempt a a description except to say that it's one of the first great Natural or Experimental histories and appears before beginning of Bacon's publicat'n.

a) Do want, though, to make explicit the ~~three~~ four elements which, at least from present viewpoint, are most important to what comes next.

b) Gilbert introduces first clear distinction between electricity and magnetism, and he studies both with care.

i) Previously they'd been a single phenomenon.

ii) Gilbert emphasizes the differences: selective attraction by magnets (iron only); also screening of electrostatic effects.

c) W. This electricity-basis concerned dwarfs its electric and non-electrics.

d) Simultaneously introduces a theory for the effects.

i) Previously both were due to natural affinity of bodies with like natures (or sometimes unlike natures). Love runs the world.

ii) Gilbert retains this for magnetism -- he's not yet a corpuscularian.

iii) But for electricity introduces explanation in terms of effluvia.

iv) Rubbing arouses a sort of tentacle that's otherwise hidden in the body. These spread out from pores in the body, grasp chaff in vicinity, and return it to the body.

d) And simultaneously Gilbert invents the so-called versorium, which is the first electroscope and an early new instrument.

i) With it establishes basic techniques for detecting the effluvia.

3. This is not terribly high class physics in modern terms, but it's extremely effective.

   a) There's quite a lot of activity which takes Gilbert as its model. During the next hundred years and a bit more there's a considerable extension of his work.

   b) For example, Gilbert has introduced basic distinction between electrics and non-electrics. Bodies that will and won't be excited by friction.

      i) Successors greatly extend the list.

      ii) Also investigate effects of heating, dampness, various other special treatments on the effect.

      iii) And also much investigation of the circumstances under which the effluvia will and will not reach the object. Screening, vacuum, and so on.

   c) In the process a good deal is learned and also the instrumentation is considerably extended.

      i) People learn to build larger apparatus and to magnify the effects

      ii) In particular, by beginning of 18th century have begun to build electrostatic generators.

4. Yet, interestingly enough, there are two very elementary effects that simply don't get noticed although they must often have been seen: electrostatic repulsion and conduction.

a) Reason why seems fairly clear. Don't fit effluvial theory.

i) Effluvia are excited in situ, where rubbing goes on. They're then anchored in body.

ii) But while that's true can't electrify a body by contact.

iii) Thus repeatedly see body rebounding (even after sticking briefly) rather than being repelled.

III. THE FLUID THEORIES

1. What changes this is, I think, principally the development of larger and better instruments which magnify the effects. Unacountable accidents become more frequent and obtrusive. Someone's got to see it.

a) Which appears to happen first with repulsion in 1706 to Francis Hauksbee.

i) Start is obscure, but Hauksbee does describe feather kissing rod, then going off.

ii) Chases it about lab with large glass rod.

iii) Significant that he doesn't quite claim a new effect. It's been noticed before. Only he's now seeing it differently, as electrical

b) Initially all this makes is trouble.

i) Hauksbee explains repulsion in terms of effluvial streams, but then is troubled about attraction.

ii) Can do either, but scarcely both though people try.

c) Situation remains obscure until 1729 when Stephen Gray discovers unexpectedly that a rod rubbed in one place will attract a feather to a rod stuck in a cork at one end.

i) This is discovery of what we'd call conduction, though it takes a bit to see it in those terms.

ii) Electrification will move from body to body in some cases. That's what happened to feather that touched the rod.

2. At this point whole situation in electrostatics changes drastically. It's our first revolution.

a) Distinction between electrics and non-electrics is replaced by that between conductors and non-conductors.

i) Cuts almost same line among materials, though not quite.

ii) But seen the effects very differently.

b) Simultaneously gives a new tool for electrifying bodies.

i) Don't have to be able to rub bodies to charge them. Can lead electricity to them.

ii) Much more sensitive experiments become possible. Suspended pith balls can be detectors. Beginning of development of electroscopes.

c) And electricity itself becomes a fluid, something that will flow through conductors.

i) Attractions and repulsions are now due to "atmospheres", draw a sort

of electrical vapor that hovers around and accompanies the fluid.

3. ii) Two charged bodies repel because their atmospheres push them apart. Similar mechanism for attraction of uncharged body, absorbt.

3. Not surprisingly, this new view of the field and the accompanying new experiments make possible a lot of new discoveries of which I here pick out just two:

a) First is discovery, by the Frenchman Charles Dufay in 1733 that there are actually two sorts of electricity, vitreous and resinous.

i) Hard to discover if one has to detect an attraction between two rubbed rods, one of rubber and one of glass.

ii) Almost inevitable if one can conduct a test charge to a pith ball and then bring up a charged rod.

b) Second discovery is the Leyden jar, 1745/46, by several people at once.

i) If you can conduct charge to bodies and store it there, would be amusing to try storing it in bottle of water. Several simultaneously.

ii) Draw spark from water, fire from water, great demonstration.

c) Several of the men who first try it are, however, almost killed.

i) Go through motions. Gigantic shock.

ii) Apparently, water is a real absorbent for electricity. Wonderful storage tank.

IV. THE NEWTONIAN PERIOD

1. But if this is a triumph, and it's widely hailed as such, it's also beginning of another radical change, and one that comes quickly.

a) The puzzle. Put jar on table and approach gingerly. No shock at all.

i) The unravelling, principally by Franklin from 1747.

ii) Need two coatings. Charge not in water at all.

iii) Instead, draw, it's a condenser.

iv) Now people think of jar not as storage tank, but as convenient way to build a condenser whose principals are best illustrated with parallel plates.

b) But to get that far need also to change one's notion about electricity once more.

i) Attraction's can't be due to atmospheres. They're known not to act through glass.

ii) Instead must have here a real action at a distance, like gravity.

iii) This, I think, is heart of Franklin's contribution: attractions and repulsions occur between particles of electricity separated by space.

iv) Call this the Newtonian model applied to electricity.

2. It's another transformation, and even more effective than the earlier ones. Will note a few effects but examine only two.

   a) Straightening out the whole network of effects we now call charging by induction.

      i) Previously seen as due to leakage of atmosphere, a special sort of conduction. PROBLEM HERE.

      ii) Now seen as redistribution of charge in conductor due to action on that charge by electrified body.

   b) Seeing this much, can also again design new instruments, particularly important one in this case is the so-called condensing electrsoope, an immensely sensitive detector of charge. Very important to next step, the battery.

3. There are other steps of the same sort, but what turns out to be more important than any of them is that the new Franklinian view makes it possible to do what people had been trying to do before: make electricity a quantitative and ultimately a mathematical science.

   a) People had looked before for the electrostatic force law.

      i) In a variety of ways. Typical draw was plate connected to generator placed under pan of balance.

      ii) Get numbers all right, but nothing that gives any recognizable regularity.

b) Recognizing that action is at a distance between tiny particles provides the clue to the introduction of system here.

i) Eliminate inductive effects

ii) Make measurements on small charged bodies at a distance one from the other.

iii) This is what Coulomb does in 1785 using apparatus specially designed for the purpose.

iv) Get's inverse square law and is justly celebrated for doing so.

v) Nevertheless, it's symptomatic of what's gone on to make it possible that the result surprised no one.

vi) In fact, two very good electricians had already announced that the law must be of this form because electrical attractions could be shown to behave in several important ways like gravitational ones.

4. That remark, however, points to what I take to be the most important development of all.

a) When it reaches this point, electrostatics is at last in a position to use the mathematical apparatus that's been built up for use in Newtonian mechanics.

b) Only Now electrostatics, a Baconian science, begins to merge with the older Newtonian group.

ii) Only it takes a while before the people with the mathematics m. make contact.

ELECTRIC CURRENT, 1791-1825

~~Triumph of~~ "~~Newtonian~~" ~~Electrical Theory~~

STET

~~I. Mathematization of Electrostatics.~~ P.S. de Laplace, 1749-1827
S.D. Poisson 1781-1840

II. The Battery, a new problem.
Luigi Galvani, 1737-1798
Alessandro Volta, 1745-1827

III. Electromagnetism, a new direction
H. C. Oersted, 1777-1851
A.M. Ampère 1775-1836

IV. Newtonian Electrodynamics
Wilhelm Weber, 1804-1890

CHAPTER

~~E. T. Whittaker, History of the Theories of Aether and Electricity, vol I.~~

Qi

2 - Rods.

Need for grid (ideas.

Mechanization.

How Cost stack.

Must BETTER
THAN
BUT STILL NOT PERFECT.
PREVIOUS CT
PERHAPS NOT INTERESTING
NEEDS ADJUSTMENT
FOR
L.P.W. Hall
Reading

History 336 -- Lecture 6

The Electric Current -- 1791-1825

I. Mathematization of Electrostatics:

1. At end of last lecture I briefly described Coulomb's formulation of Newtonian electrical theory.

   a) Given (draw) two charged bodies, way to handle total force between them is to consider the charge as composed of points. Apply inverse square force law to each pair of points. Sum for all charges.

   b) It's this approach, action at a distance between charged points or charged atoms of electricity, action governed by a known force law that I have in mind in speaking of this view as "Newtonian." Term used by a few people.

   c) We'll see it emerging again later in ~~this lecture and~~ next lecture. It's not just a view for electric charges, but a whole way of looking at how to set up problems. A paradigm. Applicable to current as well as charge. Also to chem.

      i) But get there by a long excursion into current electricity, and I want first to look at a late chapter in electrostatics, from outline last time.

2. With Coulomb's formulation, as completed around 1795, the science of electricity or at least of static electricity is clearly ripe for mathematization.

   a) Partly simply because we've got a quantitative mathematical law of attraction and repulsion, but even more because the conceptual scheme which involves the law closely parallels that of Newt. mech.

THIS CAN WORK.

BUT STRUCTURE IS TOO OBSCURE. I LOST MANY OR MOST OF THEM.

i) Substitute charge for mass and use same force law, and the whole mathematical apparatus of Newtonian gravitational theory can be applied to electricity.

ii) Furthermore, there's one part of this theory, developed particularly by P.S. de Laplace, 1749-1827, which is especially suitable

iii) Mathematical theory of tides and of atmosphere. These are fluid bodies which move in response to attractive inverse square forces until equilibrium is obtained.

iv) Thus an elaborate body of math technique almost perfectly suited to electricity as Coulomb has left it.

c) ~~Thus~~ Electrostatics is ~~roughly~~ Terrain the first of fields in which you get a relatively full merger of the new Baconian sciences with the classical science of mechanics as it has developed during 18th cent.

i) First step, which is all I want to show, is S.D. Poisson in 1812.

ii) He's teacher at the Ecole polytechnique in Paris, an institution I want to name now for later discussion.

iii) A very large part of the early mathematization of the Baconian sciences goes on here, and there's good reason why it should. Brand new sort of institution of a sort that provides a model for many others during the 19th century.

d) That, however, is for later. Now just a glance, for those able to follow it, of what get's done.

b) This paper of Coulomb's in first of series published over a period of about five years in which he provides a particularly clear presentation of electrostatic theory and simultaneously shows how, with a torsion balance, to measure the amount of electricity ~~xxxxxxxx~~ of a given body or density of charge on surface.

i) Apparently at this point, 1785-89, everything relevant to mathematization has happened to electrical theory.

ii) Nothing further until Poisson in 1812 picks up this work and applies to it techniques developed for mechanics by his teachers Lagrange and Laplace.

iii) Lagrange, 1777, useful to treat gravitational forces in terms of function: $V = -m_1/r_1 + m_2/r_2 +$ Then: $F_x = -\frac{\partial V}{\partial x}$. Etc.

Not for "potential"

iv) Laplace has shown that this satisfies famous differential equation:

$$\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2} + \frac{\partial^2 V}{\partial z^2} = 0$$

v) Now using Coulomb's model and substituting -q for m, Poisson says that problem of charge distribution on conductors is to find solutions of diff. eq. which are constant throughout interior of conductor so that there will be no net forces.

vi) For one case Laplace provided solution. For another he works it out beautifully but laboriously himself.

b) This I suggest is sort of thing that's got to be learned for mathematization of a science.

i) Long way still to go in learning better techniques. Handle more elaborate problems.

ii) Brilliant work ahead by Gauss, Green, Kelvin and others.

iii) But basic step is here. From this point the brilliance is, in a sense, mathematical rather than conceptual.

ins won't try to follow further the actual math development.

Wh. Heller: Theory of Aether & Electr. vol I

III. THE BATTERY AND ITS AFTERMATH

1. Line of development just sketched takes care of pretty much everything discovered about electricity during preceding centuries. Would be the completion of the science except that:

   a) Just before mathematization begins, just after Coulomb's work but quite unrelated to it, get a totally unexpected discovery that sets off a whole new direction in electrical research.

   b) Invention of battery -- current electricity -- due to work of Galvani and then Volta.

   c) It's one of those cases in which an apparently <u>accidental</u> discovery starts a science off in a whole new direction.

      i) Won't stay with it long, but this aspect is worth examination. How does battery come into existence?

2. Story actually goes back to year 1780. Galvani, a doctor and med school professor, is working on effect of electricity on muscular contractions.

   a) Frogs are experimental animal. Electrostatic machine is source of electricity. By now they re relatively standard equipment.

   b) Leg twitches when machine sparks across room. This is the initial accident.

   c) Followed up -- spark them with lightening and various other sources.

   d) In course of this work ~~that~~ leg's observed to twitch in apparent absence of electricity. Hanging on metal hook, etc. Draw

e) Galvani concludes to special electrical fluid. Discharged from nerve to muscle by metallic path. LEYDEN JAR ANALOGUE.

f) O.K. That's the accident or rather pair of accidents tho still not the electric battery. What's one to say about it? RECURRENT PHENOM

i) I've deliberately told story to set up only answer I think situation permits.

ii) Accidents of this sort happen only in sciences when and if situation is so well prepared that they're statistically probable.

iii) Or rather, when they happen sooner, they're ignored. Don't seem significant -- just dirt effects. Body of experience with equip is not available to make it clear that something odd has occurred.

3. Where then does battery come in?

a) This is from follow up to Galvani's discovery by Alessandro Volta of Padua.

i) He's one of leading students of electrostatics. Electrophorus and condensing electroscope are both his. Latter plays role in what follows.

b) Much experimentation follows finally convincing him that no animal is needed, just two dissimilar metals. Late 1790's. DRAIN ☐

i) Results in long and very bitter fight with Galvani who insists there are purely animal effects.

ii) Both right except in analysis of particular situations.

iii) Volta's success makes it harder to discover neural electrical effects.

c) Then, 1800, Volta discovers how to multiply the effect. The Pile. Series connection.

i) Announced in famous letter to Sir Josph Banks, President of the Royal Society. Great sensation. Everyone dashes out to try it. Volta is lionized.

ii) And all sorts of new effects emerge very rapidly. By 1805 someone or other (mostly English, however) has found: electrolytic decomposition and electroplating, arc and hot wire lamp, new elements by chemical decomposition. Various more obscure effects

iii) It's from this time that the attempt is seriously made to develop electrical theory of chemical affinity. Berzelius in Nash CaseBK

iv) Fairly typical of what happens in aftermath of discovery of brand new effect. Another sort of result. This time instrumental. Hope to speed science.

But work now follows in all directions.

4. Now ask how these effects are understood, and again get answer that can stand for other fields besides. Now is not like electrostatics

a) With electrostatics there's a long groping pre-history before theories of any real power or fit are arrived at. The initial analogy is mechanical impact, and it's not very revealing.

i) Here immediate analogue is to electrostatics, more particularly to Leyden jar and if proves a good deal more illuminating tho it ultimately requires a good deal of revision.

ii) Jar being discharged and then immediately replenished. ~~Only real disagreement is whether chemical action is needed for replenishing~~ ~~Two schools on this with gradual victory (very) for chemical view~~ contact view dominant for some time

5. Two illustrations of outcome of this way of looking at things. One subtle and important only as illustration, the other consequential.

   a) When we draw chain of batteries, we draw cell connected to another cell. When Volta and followers draw them they see half-cell as basic units, i.e., the two disimilar metals and conductor in between. Thus it's liquid that's conductor.

      i) This has a number of consequences for experimental design and for theory of accompanying effects.

   b) Which can be summarized at high level with remark that attention is directed to the jar and away from the external circuit. The wire is simply extension of the liquid; it's what discharges the jar.

      i) It's the charged jar, the static phehomenon that people mostly think about, even tho there interest is for what happens when it's connected.

      ii) Looking at this literature, after count to any current has not yet been conceived.

6. And this has still further effect, as follows:

   a) It's been suspected for some time that electricity and magnetism must be somehow related.

      i) Both attractive and repulsive. Once confused with each other.

      ii) Magnetized needles are found after lightning strikes, etc.

   b) Now people look in earnest by before + used by again. But still electrostatics.

      i) But in wrong place. Plus and minus ends of battery are N & S of magnet. Hang gigantic batteries from ceiling is typical attempt

ii) Almost no one here needs to be told that it doesn't work.

IV. OERSTED & AMPÈRE

1. With result that most people give up. Only known exception being the Dane, Hans Christian Oersted.

   a) His perhaps excessive conviction that the effect must exist now seems to have arisen mainly from his deep immersion in German Naturphilosophie, a generally romantic and often antiscientific view of nature, which emphasizes the organic metaphor and emphasizes the unity underlying diversity of all natural phenomena. We'll see it again in other places. Then the single force of which both electr. + magn. are manifestations.

   b) He doesn't give up and finally, apparently with some intervention of accident, finds that it's not the static battery but the ~~xxxxxx~~ dynamic action in the circuit that shows the magnetic effects being sought.

   c) This is result he announces in 1821, and again there is an immediate sensation. Draw.

      i) Partly it's a totally unexpected sort of effect, even for those who have expected resemblance. Partly because the Reb exp. knew could not work.

      ii) Perhaps even more important, it drastically changes the way many people look at battery action. Focus of attention shifts from battery and static analogue, to the circuitry and current itself.

      iii) Notice this in distinction introduced by Ampère who actually goes much too far. In your reading, but cos- do watch.

      iv) Tension effects vs. current effects. Two totally different.

key to next steps and it's

d) This shift is largely the work of one man, A.M. Ampère, and it's immensely consequential. One more in the several revs we've been examining this morning.

i) Falls into two parts. One qualitative,

ii) The other quantitative: Newtonian current theory, which I'll begin with next time.

2. Ampère in Paris, again at the Polytechnique, hears of Oersted's work immediately, and is greatly shocked.

a) But principal reason he's shocked is that this breaks with another theory, again by Poisson, which explains magnetic action as due to a fluid quite different from the electrical one.

b) Realizes, however, that if Oersted's right (a fact which he quickly confirms) then there can't be two distinct types of fluid but only one.

c) Either electricity is a magnetic effect or magnetism is electrical in origin.

i) He opts for former and confirms it before end of year in series of striking demonstrations, performed before Acadmie des sciences

3. Many of you will have seen them in a physics course:

a) Draw. Parallel wires. Attract for current in same direction, repel for opposite.

b) Helix. Behaves just like magnet. Full duplicate.

c) There are others, but these will do. Look what's happened.

i) These are all experiments on the circuit, changing arrangement of wires.

ii) Battery is just an off-stage instrument. In a sense it's unnecessary. It's the current that counts.

iii) There's a basic break with the Leyden jar discharge picture, and one about which Ampère is entirely explicit.

iv) It's a break that's away from, rather than towards, the picture of the electric current most of you learned in school.

v) But it's a source of much progress nonetheless.

4. Close with three examples, all from Ampère and mostly in the reading (but you'll miss them if you don't look).

a) Insists that current effects are a totally different class of phenomena from electrostatic.

i) Effects of tension vs effects of current. In reading.

ii) And key experiment: Measure tension of battery with electrometer. This is key apparatus from electrostatics, all that's been available. Grows with number of cells, and so on.

iii) Now put wire between poles. No more tension. (We'd say it's a short, no voltage because of battery's internal resistance. Ampère says, no, it's effect of a different sort.)

b) As a result, he banishes all the electrostatic apparatus and concepts from study of current. Current is primitive concept.

i) Only legitimate instrument is a new one. Deflection of Oersted's needle. This is what measures the current. Galvanometer.

c) Finally, sees current as something going on in its own right, indep. of battery.

i) There are permanent magnets in nature. Earth is one of them.

ii) Must be due to permanent currents.

iii) Starts by draw thinking in terms of permanent current sheet around bar of hard iron.

iv) But rapidly, with an assist from Fresnel, switches to a view that has long an influential history from this point.

v) Molecules with current circulating around them. Draw. Net effect is current sheet because interior currents cancel.

Electrical Theory, 1821-1845

1. Mathematization of Current Electricity

2. Unification of Charge and Current Electricity

   Michael Faraday 1791-1867
   G. S. Ohm 1789-1854

3. Triumph of Newtonian Electrical Theory

   Wilhelm Weber, 1804-1891

History 336 -- Lecture 7

The Electric Current -- 1821-1845

I. REPRISE

1. Am quite aware that I lost a number of you part way through last lecture.
   a) Hope to pick up details as needed in next conferences and won't try here.
   b) But do want, very briefly, to clarify main structure of last lecture, for much that I shall be after this morning is closely related to it.
2. Remarks on mathematization of static electricity should not have presented problems, nor those on discovery of the battery or pile.
   a) My next point, the first that will be important here, was to suggest that most early analysis of the battery takes the new instrument to be a sort of self-charging Leyden jar.
      i) What we call the current in seen as a sort of repeated discharge.
      ii) The external circuit is not a unit of conceptual analysis.
      iii) And the instrumentation for the field is exclusively that of electrostatics.
   b) That's a situation that's changed quite rapidly be Ampère in the immediate aftermath of Oersted's discovery of the action of a current carrying wire on a magnetic needle.
   c) Ampère's principal conclusions, insofar as we examined them last time, were:

Has pulled things together so
well.

i) Though battery at rest is an electrostatic machine, yielding well-known effects, one gets a totally different range of phenomena when one connects an external circuit. Tension vs current

ii) These effects occur in the circuit, on which attention is now concentrated, and they are to be examined with the new instrument which Oersted has made possible, the galvanometer.

iii) The battery is no longer a central concern to the man working on the electric current. It's off stage for laboratory work, and it's not always needed at all.

iv) Permanent magnetism, including the earth's, are to be understood as due to currents which continue indefinitely without batteries or other source of tension or voltage.

v) Get now a molecular model that's going to have a long and varied career. Draw. One molecule, two, three. Net surface current.

II. MATHEMATIZATION OF CURRENT ELECTRICITY

1. In a number of respects, particularly the conceptual divorce of static and current electricity, these steps are regressive.

   a) Will see more of that later, for one of principal object of this morning's lecture is to see how electrical theory reunites the two fields.

   b) But Ampère's viewpoint is also vital to electrical theory, for it provides him with the basis for the first mathematization of the current, a rapid and very powerful development which earns him the

Not molecular model. But current as wdsp.

title of "the Newton of Electricity".

2. Ampère's demonstrations, some of them examined last time, have typically justaposed (draw, straight wire and loop) ~~have typically justaposed~~ two wires each carrying a current, and then asked how the two interact.

   a) But Ampère also asks about the quantitative magnitude of interaction and gets quick answers in period between 1821 and 1825.

   b) Procedure is this. Conceptually divides each circuit into current elements (draw) and asks how each of these acts on each element of other circuit. Then adds all of them up.

      i) This approach is what I meant when I said we'd soon be back to Newtonian model in a new context.

      ii) These current elements are like atoms of matter or of electricity interacting. It's Newton's approach in gravitational theory and the Franklin-Coulomb approach in electricity.

      iii) Only here the division ~~is~~ maybe purely in the mind. There's no permanent ~~physical~~ element at each spot. Ampère does think that current flows. There aren't atoms of current. All of which makes the model no less Newtonian.

         ↳ May however be Tricky ↳ effect of current on wire.

3. And thinking about the problem of interaction in this Newtonian way turns out to be extraordinarily powerful.

   a) With a few simple hypotheses about current confirmed by experiment, Ampère derives a general formula for the force between current elements. Hypotheses are:

i) Reversing direction of current reverses direction of force.

ii) Current behaves as vector quantity: i.e., draw, at distance from bent wire, net effect is same as current flowing from end to end of wire.

iii) A couple of other hypotheses no more elaborate, plus an experiment to determine one constant and Ampère can write down:

$$F = \frac{i_1 i_2 ds_1 ds_2}{r^2} [\mathrm{Cos}\epsilon - \tfrac{3}{2}\mathrm{Cos}\theta_1 \mathrm{Cos}\theta_2]$$

where ϵ is angle between ds_1 and ds_2 and θ_1 and θ_2 are angles between respective current elements and r.

iv) Don't care at all about form, but do care you see it as Newtonian.

v) And ask you to take my word for the fact that it's extraordinarily successful. Add current elements in actual circuits and get with precision the forces between complex circuit forms.

4. But if you need not bother about the formula itself, you should recognize one other thing about it. It's disappeared entirely from physics.

a) Still have something called Ampère's Law which permits you to get the same results, but its form is very different, and is only very indirectly due to Ampère.

b) And the reason this can occur is important.

i) When Ampère records the hypotheses necessary to derive the formula, he omits one which he actually uses repeatedly.

ii) Assumption that force between current elements is in direction of line between them. Push and pull like gravity.

iii) Almost inevitable Newtonian assumption; needn't even be spelled out.

iv) But it's absolutely impossible to check. There are no such things as current elements to be experimented on. Always have whole circuits. Total forces.

v) And for whole circuits there are other ways of getting the same results.

vi) For computation of total force they're equivalent, but not for other aspects of electrical theory.

c) Ultimately this whole approach to electric current theory will have to be given up, for reasons that I'll come back to when dealing with field theory later in the course.

i) Meanwhile, I want to follow the evolution of this tradition a few steps further.

ii) Before doing so, though, I had better say that I now enter into an area that has not yet been much studied. There's more guesswork in what's to come then in ground previously covered.

II C UNIFICATION OF STATIC AND CURRENT ELECTRICITY

1. To avoid confusion try to say at the start where I'm going:
   a) Really two topics, historically related but logically distinct.
   b) First is the elimination of Ampère's categoric distinction between static and current electricity. Current as charge in motion.
   c) Second is the need, once that step is taken, of unifying Coulomb's Law with Ampère's, not have two totally different sorts of effects.
      i) Actually, by the time it occurs there are three effects that have to be unified, for a brand new discovery has been made in the interim.
2. As to the unification of electricity, there are a number of routes to it. Different force in different places. Can't weigh them against each other. Look at three main ones.
3. First is simply the <u>prima facie</u> implausibility of any separation as complete as Ampère's.
   a) Get both tension and current from the battery. Get electrolytic dissociation from static generators if you set it up right and crank for long enough.
   b) Though many people follow Ampère's basic viewpoint, there are always people trying to show that all electrical phenomena are the same.
      i) Charge in motion, vs. charge at rest.
      ii) Most nearly definitive researches are those of Faraday in early 1830's. Break's not sharp, but many people coming around.

4. A second set of problems carries people in same direction, and the people involved are often the same. Trouble with Electrostatic theory of battery.

   a) Basic idea (draw) outlined last time was that battery cell was two metals in contact. Liquid was just to connect between them.

   b) But as experience with these devices accumulates, it's increasingly noticed that there is chemical action, not just electrical, in liquid. That particles of metal are transfered. Ultimately, the metal gets used up.

      i) Thus great efforts put into dry piles. No liquid. No chem action. Adherents of original theory say the action in piles previously developed is just side effect, can be eliminated.

      ii) But at least a few people point out that if you eliminated them, you could get something for nothing. Movement of magnet, etc., at no expense.

      iii) Increasing group comes to see battery as intrinsically chemical. Thus tend to draw it differently. Draw. Chem action is seat of effect.

   c) But this is also, as previously mentioned, period in which people are trying to analyse chemical combination in electrical terms. Oppositely charged atoms combine.

      i) The chemical theorists, though troubled to know exactly what happens in liquid, do see it as charged particles moving through fluid under influence of tension from contact of different metals.

      ii) Don't get all the way, but they're underway.

5. This route might have done it by itself except that, before it's at all well worked out or widely believed, something else happens.

   a) George Ohm introduces in 1826 the law that bears his name.

      i) Won't tell you the story of the discovery which is elaborate, and you all know the law: $I = V/R$.

   b) But notice what it does, relates current to two parameters, one an electrostatic characteristic of the battery, the other largely due to external circuit.

      i) Thus current and electrostatic parameter firmly bound together, one measured with electrometer, other with galvanometer.

      ii) This is the unification.

   c) At least it will be when people take it seriously.

      i) But that's a long way off. Ohm has trouble getting published. Much criticism and even more neglect.

      ii) In England, at least, it's almost impossible to find anyone referring to Ohm or using the law for fifteen or more years after its announced.

   d) Simply doesn't fit electrical theory when it's announced. A more careful study of this development would point out the quite radical way in which a number of electrical concepts have to be changed in the course of its assimilation. Particularly need new concept of resistance.

      i) But it comes. Can't get on without the law.

IV. NEWTONIAN THEORY OF MOVING CHARGES

1. But as it comes, get still another problem.

   a) While current and static electricity where distinct, it was no great source of discomfort to have two Newtonian theories for electricity, one for static charges one for current.

      i) But when the two are seen as one, this point becomes a likely source of discontent.

      ii) Nothing like this for gravity -- a total change of force law as matter goes from rest into motion.

   b) Not a bit clear when people begin to feel uneasy about it, for once again a still worse problem emerges before this one has developed at all far.

      i) It's a consequenee of another truly great and novel discovery: Faraday, electromagnetic induction, 1821.

      ii) I'll be talking about Faraday when we come to Field theory, and the phenomenon itself is one you must all know.

      iii) Here concentrate on just one of the forms recognized by Faraday: Draw two ~~xxxxxxxxxxxxxxxx~~loops, one carrying current other not. Move one relative to the other and get current. Or turn first current on or off.

2. Now there's nothing in either Coulomb's static or Ampère's current to suggest any such effect. Won't fit in at all.

   a) This rather more than problem of unification seems to have suggested

next step.

i) Qualitative suggestion made in paper published in 1845 by G. T. Fechner, figure some of you will know for his important role in the development of quantitative psychological expt.

ii) Quickly made fully quantitative by by his colleague Wilhelm Weber.

2. ~~Qualitatively~~ Idea goes Draw two parallel wires.

a) Charge on each interact according two Coulomb's law. Draw chgs & r.

b) When charges are in motion there's a further force between them, one that depends on both relative speeds and accelerations. But even so directly scientifically useful, it plausible

c) Speed may be thru wire, thus current interaction as in Ampère's law.

d) But may also be by virtue of motion of wire. That also produces motion of charges and thus additional force term.

e) Subject to two further hypotheses: action along line of centers, plus current consists of equal ~~xxxx~~ and opposite charges flowing in opposite directions with same speed -- get all phenomena then known from following formula.

$$F = \frac{e\,e'}{r^2}\left\{1 + \frac{1}{c^2}\left[r\frac{d^2r}{dt^2} - \frac{1}{2}\left(\frac{dr}{dt}\right)^2\right]\right\}$$

↑ Coulomb ↑ ↑

3. Again a formula you needn't know, but realize this about it.

   a) Though now totally displaced, it does give a full quantitative account of all known interactions between conductors carrying charges at rest or in motion, so long as accelerations are small.

   b) Thus, for wide class of problems, it's entirely equivalent to later equations of Maxwell's.

   c) Furthermore, does this in a form that's still fully Newtonian and that combines all previous Newtonian forms.

   d) Not surprising, therefore, that this formulation remains a rival for Maxwell's until the later 1880's and 1890's.

   e) However badly displaced since, this is by no means a trivial approach to science.

Requisites for Revolution in Chemistry

I. Institutional change

II. New Chemical Theory: esp. Affinity & Phlogiston

III. Pneumatic Chemistry

~~IV. New role for [illegible] Weight~~

Development; Triumph; Failure.

GET LAVOISIER ARTICLE

HISTORY 336 -- Lecture 8

Background for the Chemical Revolution

I. INTRODUCTION

1. Begin this morning a series of four lectures on development of chemistry from the 17th to the late 19th century.

   a) Because the subject is vast and because the reading is particularly good, I'm going to weave lectures in and out of topics covered in reading.

   b) In particular, this ~~week~~ morning will lecture on background for chemical revolution ~~now~~; then ~~assume~~ consider the revolution itself as described in reading; and then lecture on the manner in which what happens to chemistry through L's work sets up the next major stage which is contained in work of John Dalton.

2. Topic itself I can best approach by reminding you that chemistry is one of the fields which, like electricity, is a member of my list of Baconian sciences, fields that scarcely existed before 17th century.

   a) But chemistry is not quite like electricity, for in this area there had been a great deal known.

      i) Many particular reactions.

      ii) Vast amount of apparatus and many processes.

   b) Generally, however, these are practical craft techniques and recipes. Or they belong to mystical tradition of alchemy.

      i) In the West, at least, neither has been respectable or studied

O.K. But can't do
Weight at time.
Consider cutting down or
institutions.

In 1968 I lagged in my delivery.
Got only thru ~~pharmacology~~ Therap.
~~chemistry~~. It's good stuff though
& I'm not sure I mightn't
benefit up and get thru

Note also:

Sulphur (Acid + Phlorg) $\xrightarrow{\text{Comb.}}$ Acid

is way to prevent cost
of reactor acid fits to adlib
& acid alkali reactn.

for learned study.

ii) Body of chemical technique and knowledge only enters into scientific tradition -- becomes respectable and begins to integrate with other sciences -- in 18th century.

c) And this comes about through two somewhat different routes.

II. INSTITUTIONALIZATION OF CHEMISTRY

1. First of these I had meant to leave almost entirely to your reading in Boas, and must be extremely brief with even though you can't get hold of the book.

   a) Call it institutionalization of chemistry and might also call the habilitation of chemistry.

   b) This begins in mid-sixteenth century and (in its first important form) is pretty well complete by say 1730 or thereabout.

   c) Comes about through two main routes.

2. First of these, ~~about which I'll have less to say for the moment,~~ is the new respect payed by learned men of the 16th and 17th centuries to techniques of craftsmen.

   a) Part of Baconian movement, ~~and part of story of~~ new instrumentation.

   b) In Chemistry it shows through a number of studies of chemical crafts, done by people with university training and widely circulated.

      i) Just one example: G. Agricola, De Re Metallica (1551). Book on mining technology including assaying, acid production, etc. Important both for spreading chemical knowledge and geology.

      ii) One of many books of the sort, though perhaps most famous since it was translated by a former Pres of U.S., late Herbert Hoover.

      iii) Important to us as characteristic genre and because it points to one major source of chemistry. Mining. Becher & Stahl, authors of phlog theory, are both mining chemists. Important german home.

3. Other route is not technology but medicine (actually medicine has characteristics of both).

   a) Until 16th century main medical remedies have been herbal, not chemical. That changes during 16th century against much resistance. Get an important and continuing school known as Iatro chemists, medical chemists.

   b) From this point ~~on~~ until well into 19th Century most contributors to development of chemistry are either pharmacists or doctors, and their labs are either their shops or closely related to medical schools.

   c) Again just two examples of this close knit brotherhood and its develp

      i) Jardin des plantes, 1626. Royal herbarium (also clled Jardin du roi) which very early acquires chair for public chemical lectures which continue from 1720's with little interruption.

      ii) Give you just one name in this long line, G. F. Rouelle, 1703-1770. Pharmacist whh holds the chair and is Lavoisier's teacher. When Lavoisier whose interest has been first arroused by geology determines he must learn some chemistry, the place available to him is not the university or even the medical faculty itself, but the lectures of Rouelle at Jardin.

   d) Other example is even more important in breadth of influence and is strictly medical. Shall again attach it to names though you'll need only those that show up elsewhere too.

      i) Franciscus Sylvius (1614-72), famous medical professor at Univ. of Leyden who opens there what is Europe's first chem. lab.

ii) With only a few intermediaries chair passes to Hermann Boerhaave, 1668-1738, who is simultaneously one of Europe's most famous doctors, and one of its leading chemists and teachers of chemistry

iii) People come to Leyden from all over Europe and many medical schools are reformed along the Leyden pattern.

iv) Including Edinborough which, within a generation, takes over the lead in many aspects of European medicine carrying chemistry with it. Here leader is Joseph Black, 1729-99, who studies with a man who'd been Boerhaave's pupil.

v) And Black, of course, is the physician who's famous for the concepts of specific and latent heat as well as for fundamental analysis of the way in which fixed air, carbon dioxide, enters into chemical reactions.

vi) Might add for local interest that it's not only Edinborough that follows the Leyden model. American chemical tradition starts in much the same way. The Penn med school, America's first great one, is also set up by men who studied at Leyden, and they bring chemical research back with them.

4. All of which should make more concrete for you the development of a larger research tradition in Chemistry out of a previous craft and alchemical tradition.

a) Suppose its importance is obvious. A place to do it and a group to do it. It's respectable subject with respected practitioners.

b) Perhaps equally important. It's now published in works designed to be read and understood. Great Chem text trad. from Jardin. Boer's t

III. CHEMICAL THEORY

1. That's first line of development that I take to be vital to Chem Rev. A second one is development of chemical theories.

   a) Here must be careful. There've been plenty of chemical theories before. Most of them, in one respect or another, an outgrowth of the Aristotelian theory of matter. Some quite elaborate.

   b) Yet I think it's fair to say two things about them. Reasons for holding them are not generally chemical. They're in part logical, as ancient atomism had been. In any case, change of phase and simila crude results of everyday processes are what they account for.

   c) So they're little grounded in facts of chemical experience. And conversely, they do very little for that experience. A man may be aa chemist and embrace one of the prevalent theories of matter. But the dta to theory ratio is very very large. Mostly he operates with recipes.

2. Now be clear that this situation doesn't change dramatically until after Lavoisier and Dalton. Even then it remains true in much of chemistry, particularly in the organic realm.

   a) But the late 17th and the 18th centuries do witness growth of ~~two~~ chemical theories ~~both of~~ which do, unlike most of their predecessors, prove capable of producing order where there had been little before.

2b. First of these, about which very little can be said when more is [illegible] (over)

3. ~~First~~ 2 of these, which I shall call by name it receives only late in 18th century, is Elective affinities, and actually is first sketched by Newton in one of the famous Queries at end of his Opticks.

BOYLE – BACONIANISM.

COLOR INDICATORS.

ACIDS & ALKALIS.

NEUTRALIZATION, SALTS.

a) Elective affinity means selective power of attraction, and what one finds in Newton and then greatly elaborated in 18th century is following sort of thing. Chem. forces between compounds.

i) Salt coheres initially because of mutual attraction of salt particles. Dissolves in water because salt particles are more attracted by water particles than by each other.

ii) Metal dissolves not in water but in acid because latter does have a strong enough attraction to undo its coherence.

iii) But one metal can knock another out of solution, for example iron replaces copper or copper silver, because iron is still more strongly attracted to acid than silver is.

iv) Thus replacement reactions and replacement series become a standard tool in many parts of 18th century chemistry. Long lists are drawn up. Even more sophisticated ways of looking at reactions. Things react always more together. Reducents.

v) Doesn't always work, there's much criticism. But it's a very useful reaction schema which leads to much additional understanding.

vi) Well before Lavoisier a number of people are also extending it to double displacement reactions. (A B) + (C D) → (A C) + BD.

4. That's ~~first~~ second of my 18th century theories. Second, which also goes back to beginning of the century is Phlogiston theory.

a) Product of German mining chemists, Joachim Becher and G. E. Stahl, 1660-1734. Latter is one to remember, for he gives it its developed form and its known through his work.

i) Origin is of some imprtance for essentially this is a theory of ores and of oxidation reduction reactions.

b) This is a theory you've all heard of before, but I'd be surprised if you'd heard much more than nonsense about it. I'll try to cut quickly through the tangle.

i) In its original form, which may actually be very very old, phlogiston shows great kinship to the occult principles of alchemy and of some of the Aristotelian theories of matter.

Phlog is a principle, an essence. It carries properties with it.

ii) But Stahl is corpuscular chemist in many respects like Boyle and Newton. In his form theory makes juncture with Newtonian chemistry. For example, introduced to France in 1723 in book called New Course of Chemistry According to the Principles of Newton and Stahl.

iii) In this form its got many uses.

cc) Basic reaction is, of course: Earth (ore) + phlog (from coke)--metal

i) This is already leading but more goes with it. For example, relative heterogeniety of ores and homogeneity of metals. Thus a metallizing principle.

ii) Again, it's substances rich in phlog which burn. Thus explains why burning occurs. Actually see phlogiston getting away.

iii) And what happens when burning takes place is confined volume. Contraction of volume. (Ruin the spring of the air). Limited absorbtion of phlogiston, thus flame goes out.

iv) Or, one last but particularly important application. Have here also a theory of acids.

v) Like the earth or ores, acids are relatively elementary bodies. Can produce compound substances by phlogisticating them.

vi) Thus we speak of burning sulphur to get the oxide which in water is sulphurous acid. For 18th century chemist we've actually deprived the compound sulphur of its phlogiston and gotten back to acid. SAME THING WORKS FOR A NUMBER OF OTHER ACIDS. Carbonic.

Sulphur (Acid+ϕ) → Acid (carb.

d) Which may already give you the idea that what we've got here is not just foolishness.

IV. PNEUMATIC CHEMISTRY

1. But that still doesn't show you the greatest triumphs of the theory which come virtually together with its demise through its applicability to the study of gases, virtually a new branch of chemistry in the 18th century.

a) This is an immensely complex story that I'll have to leave largely to the reading but that I want nevertheless to tie to the lines already being drawn. More than anyother development, this one sets stage for Am Rev!

b) Beginning by noting that people who develop gas chemistry are mostly people we've already encountered in the 17th-18th century experimental scientific tradition. New instrumental tradition. Try anything. Birds in air. Burn. Water in vessels.

i) Begins with Boyle and his air pump in 1660's. Includes Boerhaave who again uses pump in chemical studies. ~~Almost simultaneously involves Stephen Hales whose work you read bits~~ about as a Newton ~~in scientist in Cohen's book~~

Successive "take" Plants & [illegible] vol. of air

FAST

The Chemical Revolution

1. Pneumatic Chemistry as the key
2. The Problemx of Weight Relations
3. The Nature of the Chemical Revolution

THEORY IN CHEM. TEXTS PRE LAVOISIER
GENESIS OF THE TRAITÉ ELÉMENTAIRE, 1789
ROLE OF CALORIC THEORY
A NEW CHEMISTRY

CHALK

GET Dalton, Ly
Case book
LKN
Thinking

HISTORY 336 -- Lecture 9

The Chemical Revolution & Oxygen

ANNOUNCEMENT - TUESDAY CONF. TO WED NIGHT. MY OFFICE
AUDIT CREDIT ON BASIS OF FINAL O.K.

I. Pneumatic Chemistry

1. Talked last time about a number of developments in 17th and 18th centuries that prepare way for the Chemical Revolution

   a) Open this morning with last such element, one that actually sets the revolution up more than any other.

   b) It's development of pneumatic chemistry, chemistry of air and gases.

      i) Complex subject which I'm going to treat extremely briefly.

      ii) But there's much about it in your reading. My primary purpose is to tie it to elements we've already been looking at in way reading does not.

2. First thing to notice is that, unlike other developments we've discussed, the phenomena of pneumatic chemistry are brand new in the 17th century.

   a) Furthermore, they're very much a product of the new concern with instruments.

   b) First figure is Robert Boyle who builds one of the very early air pumps.

      i) In typical Newtonian fashion tries everything. Flames, animals, wheat, and, some chemical reactions. Metal in acid. Gunpowder.

      ii) Immediate successors in 18th century are Stephen Hales, a Newtonian who's discussed in reading and also Boerhaave.

1 Cor is perhaps the pastoral.
But it goes fairly well.
Could be one exception.

ii) Their work, which is done by about 1740, develops the first of the basic equipment needed for collecting gases.

iii) And simultaneously makes it clear that air can get taken out of circulation in chemical reactions. Hales speaks of Fixed Air. Air that's lost its spring and its volume. Previously air = elastic.

Diff gases "fixed air" do have for CO_2

c) But it's only around 1755 in work of Joseph Black that you get two further steps that are vital. Hinted at by Hales, but not grasped.

Air's elasticity

i) Air is active ingredient. Something that combines with another ingredient to give a new product.

ii) And even more important. Not all airs are alike or are just impure versions of each other. Hints of this before but Black pins it down.

iii) A test for "fixed air" (our CO_2) which normal air won't pass. Lime water CaO,

d) From this point things go very quickly, particularly in work of Henry Cavendish, 1731-1810, and Joseph Priestley, 1733-1804.

i) Cavendish isolates hydrogen as a gas distinct from other airs.

ii) Priestely isolates and tests a number of gaseous oxides including those of nitrogen. Also, tho misidentified, oxygen.

iii) In the years just before Lavoisier's work begins, new gases are rapidly being released and studied.

2. At the start the main impact of this work is very nearly to confirm the phlogiston theory once and for all.

   a) Fixed air is phlogisticated air. What one gets from burning or respiration.

   b) Oxygen dephlogisticated air

   c) Hydrogen is pure phlogiston, matter of fire which burns with no ash. Notice that it's gotten from a metal, leaving an earth. It fits.

   d) Also, it often guides new research. In particular, one of the routes to isolation of oxygen is by an elaborately contribed experiment which successfully isolates the fire-air that's combined with phlogiston (~~fire-air~~) to give heat.

3. But any of you who know just a little chemistry will realize that with these techniques and the relevant tests in hand, one is not going to handle the variety of gases that now are found with just basic air plus phlogiston.

   a) One particular problem will arise from the fact that fixed air and nitrogen, both left behind by burning, don't pass the same test and can be had separately. Only one leads to Nitrogen oxides.

   b) There are other similar problems besides.

   c) Thus not a bit surprising that work of Lavoisier and its fruit, the oxygen theory, should come within a decade of Cavendish's work and even more closely on the heels of the pioneering work of Priestl.

4. Certainly this is the crisis.

V. NEW ROLE FOR WEIGHT

1. ~~But when the revolution comes it turns out to involve~~ On the other hand, in work of Lavoisier, there's still another element, and a particularly puzzling one. Use of weight relations.

   a) As many of you already know, Lavoisier is sometimes said to be the man who discovers conservation of matter in chemistry.

   b) But this is absurd, for it's clear that everyone who has ever discussed a chemical reaction has believed in that. In a sense, the weight of matter.

2. Come closer if we say he showed that weight is conserved in chemical reactions -- that weight of reagents is same as weight of products.

   a) Certainly he assumes this to be the case, and it plays a vastly important role in his research. From the very start. No one's moved this before.

   b) On the other hand, though it's important, it's ~~hard to see just~~ not clear what's new about it, for many earlier chemists -- including both Boyle in 17th and Black in 18th -- have utilized the balance to determine whether matter has been added or lost during the course of chemical reaction.

   c) Terribly hard to put one's finger on what's new in L's treatment of weight relations, and it's interesting that in this area he himself makes no claim to novelty. Another one of those impt. discoveries that was never discovered. Like oxygen.

3. Nevertheless, it seems to me clear that a longstanding line of development does culminate in his work to give his own use of the balance a power that it's not had before.

a) Partly what's occurred is that increasingly during 18th century the balance has become a standard instrument.

i) More and more chemists use it as a matter of course and make regular records of weight.

ii) A part of the new instrumentalism and new standard of reporting.

b) Other part of it is that weight increasingly becomes the standard way to measure quantity of matter, something that it has not regularly been before. Volume. But this prove only w.r.t. liquids.

4. Last point is sometimes hard to see, but can perhaps clarify it by reminding you that for many people in the 17th century and earlier weight was not, any more than color or temperature, a primary property of matter.

a) Thus even though matter was conserved in chemical reaction, weight might change just as color did and also state of aggregation.

b) What changes this is, I think, more than anything else the gradual spread into other fields of the Newtonian view of matter as possessing an intrinsic gravitational attraction.

c) If it does, then the balance measures the extent of this attraction, and thus the amount of matter in the body.

i) On another view, for example the Cartesian view, the balance has no similar significance.

ii) Vol not weight is measure of what conserved.

III. WHAT IS THE CHEMICAL REVOLUTION

1. At this point I want suddenly to skip a central part of the story, for it's fully covered in your reading.

   a) Part I'm jumping over is actual development of oxygen theory of combustion.

      i) You all know what it is, and I can't add to the case history.

   b) Instead, want to assume the theory introduced and then ask why people call what results "The Chemical Revolution"

      i) Part of answer you know. For those chemists concerned with gases and combustion reactions, the overthrow of the phlog. theory is shattering.

      ii) Priestley continues to fight for it until end of his life. Many others are slow to come round.

   c) But phlogiston has been a local theory, restricted to a few types of reactions.

      i) In any case, Oxygen is not far from being negative phlogiston.

      ii) The pneumatic chemists were bound to be upset, but phlog has been local theory, and pneumatic techniques were not wide spread.

      iii) Remembering that L gets called the father of modern chemistry, and that resistance is not just to oxygen theory but to the "French system of chemistry", one want to ask what can have gone on.

iv) Why did chemists at the time and why have historians since felt that the entire field turned a corner at this time?

2. That's a tougher question than it sounds, partly because it's ~~almost never~~ seldom been asked.

a) I'd taught the Chem Rev a good many times before it gradually dawned on me that it couldn't just be the oxygen theory.

b) Under those circumstances, not surprising that there's no commonly accepted answer.

i) What follows is again my suggestion of an answer rather than accepted gospel.

ii) But must, I think, be a part of story.

3. What I want to suggest, then, is that, though phlog theory was local theory applicable only to certain class of reactions, its inverse, the oxygen theory, rapidly spread out to transform all of chemistry.

a) What one gets as a result is a chemistry more generally ~~philosophical~~ theoretical than any that's existed before.

i) More than that, it's a chemistry that, for the first time, is quite firmly based ona physical model, one which makes a difference

ii) With Lavoisier chemistry and physics come closer together than at any time again until quantum theory in twentieth century.

iii) As I'll ~~xxxxxx~~ suggest next time, it's work of Dalton, though only slowly felt that begins to drive them apart again.

4. Place where the shift first shows clearly is in Lavoisier's Elementary Treatise on Chemistry published in 1789

   a) In a number of respects this looks much like the elementary chem texts that were used when I was in school and college and unlike anything that's existed before.

      i) Add that it doesn't look a bit like books you've used, at least in college, whole switch to early introduction of quantum models, molecular orbitals, and so on, is since I studied field.

      ii) At the elementary level it's probably biggest switch since L.

   b) Pre-Lavoisier chem text has relatively standard form.

      i) Introduction that opens with a definition of chemistry. It's the art which teaches how to separate bodies into elementary

constituents and build them back up again. Sometimes adds fabrication of useful products as its goal.

ii) Introduction then continues to say what these elementary principles are. Vary in number -- anywhere from 3 to 5 and as the century goes on there get to be more. Elementary earth, oil, salt, sulphur. Clearly understand though that these are not real earth but earthy principle, etc. Essence of earthiness.

iii) But we never get down this far in lab but only to relatively earthy body etc. In short, our stable chemists corpuscles are highly compounded.

d) All of this may take as many as twenty pages, and its ordinarily the entire theoretical section of the book. After that we continue:

i) To a lengthy section on chemical instruments -- furnaces, flasks, retorts, measures, etc.

ii) And then to a long series of recipes about, say, the various substances to be made from mercury, from sulphur, and so on.

iii) In short, once the introduction is passed one has mainly a cook book.

iv) Perhaps illuminated here or there by a locally applicable theory, phlogiston or affinity. But usually not even much of that. These are reserved for advanced books that have not so much bearing on the nature of chem as a whole.

5. Now Lavoisier's Traité elementaire of 1789 turns all this ~~nether~~ on its head, though in ways that L seems not initially to have intended and ~~that~~ relate only tangentially to the oxygen theory, or at least to its mod form

a) In fact it evolves over more than a decade, and we have enough scraps to permit conjectures about its evolution.

b) Initially was to be simply an advanced book on new gas and combust chemistry presupposing normal elementary knowledge.

c) But kept having to revise bits of other parts of chemistry so resolve for the fuller and more elementary mode.

i) But that again starts out along a pretty classical line. In the early 1780's it treated first reactions involving acids, then alkalis, then metals. Presumably it would have included a chapter on airs for the oxygen theory.

ii) Only as he progresses from draft to draft gas theory keeps moving forward and providing the model for the whole rest of the book.

6. Or at least it provides the model when taken in close conjunction with Lavoisier's developed version of the caloric theory of heat. which is -- ~~here I'm in categoric disagreement with Prof. Gillispie -- far more than an expression of mathematical conservation laws plus a residual category to which the principles can be attached. You'll come much closer in modern terminology if you think of caloric as being a perfect gas.~~

a) Now look a bit at how this works out in the Treatise.

b) Opens with a preface on need for reform of chemical nomenclature, and how appropriate names will help us discover relations between things. Remember old product terms. Now ingredient terms.

c) Then goes immediately to a physical theory of gases in opening his text. Puzzling that Kopp for new book. I've asked you to read it. Di Bacco

i) Caloric is matter of heat; needn't commit ourselves to its existence to show experimentally that it acts as follows. Play Boscovich

ii) Attracted to particles of matter but mutually repulsive. Thus atmospheres.

iii) This enables us to understand expansion (begin with equilibrium of solids) and also states of aggregation)

iv) L even insists (and ~~I think~~ its first time it has happened) that all ~~xxxxxxxxx~~ simple substances can in principle exist in all three states of aggregation.

d) And now looks what's happened:

i) As a result Gases not a separate chemical species but a state of which all species are capable.

ii) Change of phase is separated from/~~xxxxxxxxxxxxxx~~ chemical reactions once and for all.

(Nii) Chem. authors are those involving the cases. Therefore

iii) Gas reactions become type for all other reactions because what happens to central particles can happen with or without the large caloric sheathes that are typical of gases.

6) So now we can proceed to chemistry/~~xxixxgxxxixxxixxxxxxxx~~ with change of phase banished and gas reactions a model.

a) That's what L does:

i) Two sorts of cores for atmosph air. Oxygen and nitrogen.

ii) One of these is active. Follow its combination with sulphur, phosphorous, etc. to produce acids.

iii) Then with the various metals to produce oxides.

iv) Then with hydrogen to produce water

v) Then various reactions of hydrogen.

b) And so on to reactions of bases, formations of salts, and other inorganic reactions.

i) Recipes showing up only here and there where essential. Not many in toto.

ii) Whole instrumental section dismissed to part III where it seems very tacked on. Traditional

iii) No longer a recipe book, but a guided tour -- organized around type chemical reactions -- through the world of the main simple chemical substances and their reactions.

iv) One here learns, as from the older books, what chem is about, but one learns it at an abstract, not a concrete level.

v) It's determining what these central kernels are, and how they combine one with the other, and what they produce

c) This [illegible] I think the real rub for most chemists.

BIRTH OF CHEMICAL ATOMISM

1. The Novelty of Dalton's theory
2. The Problems Presented by Dalton's Theory
   - Proust-Berthollet Controversy
   - Physical vs. Chemical Forces
3. Dalton's Route to the Theory

ADMISSIONS OFFICE

HISTORY 336 -- Lecture 10

Birth of Daltonian Atomism

I. LAVOISIER'S CHEMISTRY AS PREREQUISITE

1. This morning I mean to talk about the development of Dalton's atomic theory and its reception.

   a) As in the case of Lavoisier's work, however, there's a great deal about this in your reading, and I shall again duck in and out.

      i) Intend that this lecture make sense whether you've yet read the Dalton material or not.

      ii) But warn you that to get the whole story you'll need to put the two together.

2. Dalton figures in most elementary chemistry texts as the man who ~~invented~~ introduced the ~~chemical~~ atom into chemistry.

   a) But this is clearly wrong. Chemistry has been corpuscular since the seventeenth century.

   b) On the other hand, as I've repeatedly pointed out before, corpuscularism has not, on the whole, been much use in chemistry.

      i) The corpuscles are particles of elementary earth, phlogiston, or what you will.

      ii) Lots of them in the bits of iron, gold, sulphur, or what you will. They're not particles of the de facto ingredients of chemical reactions. The stuff that's in bottles on lab shelves.

This is too thin. Need more
style.

c) One therefore comes closer if one suggests that Dalton is the man who takes atoms to be the atoms of these laboratory substances, of oxygen, iron, sulphur, gold, and so on.

i) Yet even this misses the point, I think, for as my last lecture should have made clear, that step is really taken already in Lavoisier's Traité élémentaire.

ii) His book get's rid entirely of the old chemical principles that provide the basic, and not very consequential, chemical philosophy of the older texts.

iii) Without insisting that they need be elementary, he lists the chemical elements as actual laboratory substances plus light and caloric. With the acceptance of his work, the elements become for the first time the standard products of chemical analysis.

iv) And they are atomic in form. Thus the joint core plus caloric model from last lecture. Draw.

d) It's not quite so modern a picture as I'm indicating.

i) Still vestiges of the principles. Oxygen is a principle of acidity. Still retained in German word for the gas, Sauerstoff. Notion that oxygen is what makes things acid is eliminated only with difficulty by Humphrey Davey who finally convinces people that you're not going to get it out of hydrochloric acid.

ii) There are some other similar aspects to Lavoisier's theory.

iii) But the basic step has been taken. Chemist's do think in terms

of relatively permanent corpuscles of lab substances.

3. If that had not occurred, we would not have Dalton. This mode of post-Lavoisier thought is an absolute prerequisite for what comes next.

   a) But it still leaves the question what there is for Dalton to add? Isn't the job already done? To which answer is:

   b) What's still left to do -- and what's in many respects the most important job of all ---is the recognition that one can introduce all sorts of additional order into chemical data and predict at least some new chemical reactions if you suppose that atoms combine in simple whole number ratios.

      i) Thus smallest particle of water is one hydrogen, one oxygen.

      ii) Carbon oxides are CO, CO_2,; Nitrogen N_2O, NO, N_2O, etc.

   c) And what's important about this, of course, is that it greatly limits the range of possible combinations.

      i) Thus laws of fixed and multiple proportions become standard in chemistry only with this work.

      ii) And as soon as you've got them, you've a new criterion of the adequacy of analytic techniques.

      iii) If you've got two different compounds of Carbon and Hdrogen in which products don't yield these simple whole number ratios, then you've either got a mixture of oxides in one compound or you've got impurities.

d) The period from 1810 to 1840 is therefore a period in which one gets gigantic improvements in chemical analytical techniques.

i) Knowing that certain sorts of results are incompatible with fixed and multiple proportion, chemists learn to separate mixtures of compounds and to eliminate impurities from substances that they'd previously thought to be chemically pure.

ii) There's an important shift in chemical data on composition by weight. An important sort of shifting approach to data.

iii) And a very great simplification in the way one can think about compounds.

4. That's Dalton's contribution. A very simple idea with immense consequences. Makes the atom a functional tool of the chemists in a way it had never been before.

a) But it leaves a puzzle: Why was it so hard to take this next step?

i) Why not Lavoisier or one of his immediate successors? Lack of relevant data.

ii) Or, if that seems artificial because the period isn't very long, why was the idea so much resisted when it came? It was, as reading shows.

iii) Or to put the question still another way to which I want later to return: Why is it so natural that the theory came from a man who was no Chemist? Who then had to fight chemists to get idea accepted?

b) General point being, though L's work is prerequisite and next step looks small, another rev. is required to achieve it. Why?

II. DALTON'S PROBLEM.

1. Fundamental answer to this question is, I take it, that Dalton's theory is entirely incompatible with affinity theory, and the whole related way of regarding reality.

   a) Remember, according to affinity theory salt dissolves in water because water particles pull salt particles more strongly than they pull each other.

      i) Same analysis accounts for displacement reactions, e.g., iron's replacing copper in solution.

      ii) Both are chemical reactions. So is alloying. Glass making. Etc.

   b) But if these are chemical reactions, then Dalton is simply wrong, trivially so.

      i) Line between physical mixture and chemical compound has to be drawn in a quite different place to permit Dalton's being accepted.

      ii) There had been a line before, and it was drawn using many of the same examples used today. Iron filings and sulphur. Others.

      iii) But it's not much use in the intermediate cases (which we'd now often recognize as genuinely intermediate), and these have largely been classified as chemical since they depend upon affinities between unlike substances.

2. Just how severe the problem is can be seen with a look at a famous controversy that occurs just before Dalton and that his work finally settles.

a) It's known as the Proust-Berthollet Controversy, after the two very good French chemists who were the main protagonists.

   i) It opens in 1796 with a paper by Proust and continues with no agreement until Dalton's success settles it.

b) Proust's point throughout is that when particular compounds are made, whether by nature or in the laboratory, they always contain exactly the same proportion by weight of their ingredients.

   i) It's been known, or perhaps taken for granted, for some compounds before, but no one has suggested that it's general.

   ii) Proust analyses samples of substances, particularly copper oxides, from many different places and also compares them with oxides he prepares himself. Always the same proportions.

   iii) For him the law is general. Entirely so.

c) Berthollet, who has been doing brilliant work in an attempt to rescue affinity theory by analysing other factors that effect reactions, says it's crazy.

   i) Copper takes up oxygen continuously within certain limits. Can watch color change. Same holds for lead and many many other reactions.

   ii) There are cases like Proust's, but they're special. They depend on special characteristics of the reaction and are not characteristic of reactions in general.

d) Proust comes back and says, No, there are two oxides of copper, what

Berthollet has is various different mixtures of the two compounds which we'd call CuO and CuO_2.

i) Berthollet says, what do you mean it's a mixture? They're held together by the same fordes. What's your distinction?

e) From this point the argument goes on inconclusively, and I won't try to follow it further. SOME OF YOU MIGHT DO IT FOR PAPERS, particularly the philosophers, but you'll need French.

i) It's a perfect case, though, of two men and their adherents talking through each other.

ii) They mean different things by mixture and by compound, though neither of them is able to give ~~quite~~ clear criteria. Can only

iii) One is tempted to say the whole battle is over words, purely semantic.

iv) But if so, then semantics makes more difference than we're usually ready to concede.

v) Whole notion of what's chemical is tied up here.

vi) Proust's view, which is ultimately accepted because it's also Dalton's, makes a tautology out of what for Berthollet is an unacceptable law.

f) Add parenthetically that with Proust's victory, Berthollet's theory theory is entirely discarded, which is unfortunate because law of màss action has been central ingredient. It has to be done again.

3. The possibility of that sort of argument should show you what I have in mind in suggesting that accepting Dalton means redefining chemistry or an essential element of it.

   a) Add that if you consider the really difficult case of alloys, you'll see that the problem is entirely non-trivial. Here no either-or mixture-compound distinction will work at all.

   b) With this you may also see something still more important that I alluded to last time.

      i) One reason Dalton's work and Proust's seems so very very implausible is that no known sort of physical force can explain this kind of behavior.

   c) If an atom draw attracts one atom of another sort it ought to be able to attract still others, two, three, four.

      i) If it also coheres with atoms of its own sort, you ought to be be able to get aggregates of any proportions you want.

      ii) True of gravitational forces, ~~xxx~~ electrical forces, magnetic forces as treated in the period. And so on.

      iii) The point is certainly not seen immediately, but the acceptance of Dalton's work does create a basic cleavage in the detailed models accepted by chemists and by physicists.

      iv) Cleavage which widens through the century and is only bridged (and then against much resistance) after 1926 with the quantum theory of valence.

III. DALTON'S ROUTE

1. This should answer question why it was so hard for chemists to see what Dalton saw or two accept it.

   a) But that leaves the question how they came to see it it at all.

      i) Answer suggested by Structure of Scientific Revolutions is because there was a crisis in chemistry for which Dalton provided solution.

      ii) But I don't think that answer works here. Proust-Berthollet controversy is not evidence for crisis.

      iii) This is a different sort of case, and book should be adjusted to take it into account.

   b) Come much closer if one says Dalton's theory is imported into chemistry from outside.

      i) Dalton's not a chemist when he developes the theory and it's some time before he sees that it has important applications to chemistry.

      ii) A fact which, incidentally, fits with the biographical detail that Dalton is very nearly forty when he develops the theory.

      iii) Breaks with tradition this radical are seldom made by men of this age. When they are, it's generally because they've only very recently entered the field in which they produce revolutionary change.

      (a) Lavoisier. and Thirties... is another case in point.

2. Let me show you what's involved more clearly by going over in a somewhat different way what's said about the beginning of the theory in your reading.

   a) This isn't quite compatible with ~~it~~ reading, but based on a later version by the same man, so you can revise your impressions accordingly.

   b) i) Essentials of the story go about like this.

   b) Until sometime in 1803 Dalton was unconcerned with chemistry.

      i) Had contributed on a number of topics -- including incidentally the description of color-blindness which had never been recognized before.

      ii) Main and most consistent interest had been, as reading indicates, meteorology. Here he made extensive observations and published his first book.

   c) Atomic theory, in fact, evolves out of problem encountered in meteorology.

      i) Air contains at least three elastic fluids -- oxygen, nitrogen, and water vapor. ~~Heavy particles settle to bottom~~.

      ii) Since their densities are different, their proportions should vary with height at which sample is taken. Heavy settle do bottom

      iii) But that's not confirmed by observation. How come?

3. On this question Dalton develops a number of theories which you'll encounter in your reading. Theories of mixed gases, 2 basic ones plus mods.

   a) Also a very important additional problem and tool. Turns from the absorption of gases in other gases to the absorption of gases in water.

      i) Many experiments and an odd result. The simplest and lightest gases are apparently the least absorbed in water.

   b) In 1803 he concludes that the effect must depend on size and weight of the ~~xxxxxxx~~ gas particles.

      i) To get information on that subject -- something no chemist has at all sought -- he goes <u>for the first time</u> to existing chemical data.

      ii) And, of course, what he does with it is just what no chemist would conceivably have done.

      iii) Introduces the simplest assumptions compatible with getting the information he needs.

      iv) It's at this point that one-to-one, one-to-two, and so on enters as combination ratios. From them, of course, Dalton does get both size and weight ratios.

      v) Uses them in his discussion of the solubility of gases in water, still with no notion that he's done anything to or for chemistry.

      vi) All early studies of gases & liquids are of gas mixtures & absorption. Even early ones are out of date.

4. ~~Hard, in fact, to tell just when~~ No actually clear-cut point at which it does become chemical, but it's somewhat slow.

   a) Partly due to work of chemist, Thomas Thomson, who talks with Dalton in 1804 and is impressed. Then presents it with a more chemical cast and begins to use it.

   b) Perhaps even more due to Dalton himself who, after 1803, increasingly runs out of the data he needs and begins to do chemical experiments himself.

      i) In the course of these increasingly finds himself using the theory to control the experimental results. Particularly Methane & Ethylene.

      ii) Or anticipating conclusions that other chemists could not have foreseen.

   c) By 1806 or thereabouts Dalton is fully involved in chemistry, has become a chemist, and is exploiting what is by then a genuinely chemical theory.

      i) But it didn't begin that way, and if it had, it would have come only later.

IF COURSE IS GIVEN AGAIN MUST ADD ONE LECTURE IN THIS BLOCK, CUT ELSEWHERE

1. PROBL. of Sci & TECHN. — General Survey
   — Analysis of Probl
   — Industrial Res

2. Steam Engine as Example

3. COTTON INDUSTRY AS EXAMPLE

[4. Electrical Industry as Example?]

Foundation of Organic Chemistry

I. ~~Re~~lated Maturation of Organic Chem.
   Relation to Chem Rev
   Combustion Analysis ~~→~~ to 1838 ~~c~~.
   Prob of Atomic Weights

II. Positive Approaches:
   Radical Theory
   Type Theory

III. The Breakthrough
   Valence theory -- 1852 ??
   F. A. Kekulé, 1829-1896
      Tetra-valent carbon, 1858
      Benzene ring, 1865

WENKER POB RING

ON SIDE BOARD / CHALK?

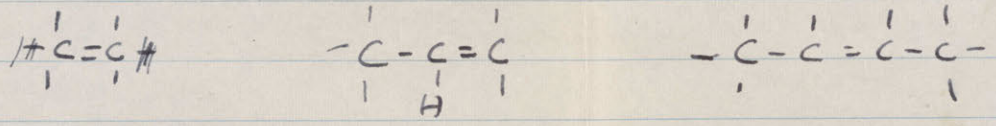
EXAM Thursday
Two Essay questions.
Close.
To begin with an exam

Alkanes: Hydro Carbon Series

CH_4	C_2H_6	C_3H_8	C_4H_{10}
Methane	Ethane	Propane	Butane.

Alkenes:

C_2H_4	C_3H_6	C_4H_8
Ethylene	Propylene	Butylene

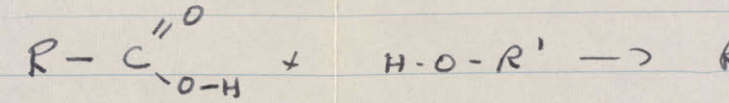


~~Alcohols~~ Alcohols
~~Acids~~ are formed by substituting OH for H

~~Acids~~ Ether by attaching second radical for H in OH group.

Main acids by substituting COOH (Carboxyl $-C(=O)-O-H$) for Hydrogen.

ESTERS ARE FORMED FROM ACID AND ALCOHOL BY ELIMINATING WATER.



Dolby:— The irrelevance of individual process to sociological
base.

HISTORY 336 -- Lecture 18

Development of Organic Chemistry

I. LATE MATURATION OF ORGANIC CHEM

1. Last week, both in lectures and in reading, we traced chemistry from a highly developed set of crafts to its evolution as a science and examined two major steps in its maturation.

   a) First the reorganization of chemistry on a theoretical basis by Lavoisier and his contemporaries; second the introduction of the atom as a significant basis for chemical theory by Dalton.

   b) Last stages of that development, lasting from first decade of the century until almost 1860, are covered in first block of reading for this week.

      i) Propose to leave them for the reading and turn instead to the examination of one last aspect (last for us) of chemical development, understanding of organic compounds, those associated with living tissue.

      ii) Important to notice that all the chemical development we've dealt with so far has been based on study of inorganic reactions, and it's this part of chemistry alone that has matured.

      iii) When Dalton develops his atomic theory, organic chemistry is still virtually in state it had been in two centuries before.

      iv) And it does not catch up with level to which D brough inorganic chemistry until just about 1860.

It's not too bad. But I talked
poorly & ran too short of time.

II. LATE MATURATION OF ORGANIC CHEMISTRY

1. Have already indicated that science of chemistry has little impact on chemical technology until the maturation of organic chemical theory, a maturation that scarcely occurs until before about 1860.

   a) Help to understand what occurred if we start by asking why so late?

   b) Not that people didn't work with organic materials earlier. Distinction ibid is modern.

      i) Brewing and soap go back to antiquity. Alchohol (Arabic root) is from late middle ages.

      ii) Recipes for a number of fermentation processes are standard in 17th and 18th century chemical texts. Animal fats, vegetable oils, etc. are discussed.

   c) But its in these recipes that old chem texts look most like cook books. No leads here to classification of products, to tracing reactions, to theoretical order. No phlogiston or affinity theory for this realm.

      i) Reason is clear enough. Most organic substances are relatively unstable, particularly to heat treatment, the standard chemical tool.

      ii) Ordinary chemical operations of day change nature of substance. But change occurs slowly. Rate and nature of result depends critically on details of process. In any case, rarely get only one product. Even today typical yields are 50% or lower. Few reactions go all the way even under best condtions. Always other messy products to be removed.

d) Thus only way to find initial order is totdivide organic materials down to their elementary components. Only then get reproducible results capable of giving real order.

i) But this means overwhelmingly to carbon and hydrogen. Often these are only elements involved.

ii) Secondarily it means oxygen and nitrogen. Some sulphur.

iii) But these are all gases or they appear first as gaseous oxides (Carbon dioxide, sulphur dioxide) in analysis.

iv) Solid substances or permanent liquids: iron, gold, mercury with which so much of early progress in chem theory is involved scarcel enter.

e) But that means even the beginnings of chemical order in organic realm must wait until men know how to handle gases, identify, trace them in and out of reactions as elements in composition.

i) That's the work of Lavoisier. It's the heart of the chemical revolution, worked out with inorg. substances.

ii) Means really that in an important sense couldn't have begun to discover regularities in organic realm until after about 1780.

iii) In practice it's a bit after 1800 before systematic onslaught in this area gets underway.

2. But the chemical revolution is only parts of what's required. It does enable one to frame the questions in the organic realm, but not to answer them. One runs immediately into special characteristics of organic materials.

   a) Inorganic compounds, those chemists have learned to study, generally contain two or three elements, and these can combine in only a small number of ways. H_2O or H_2O_2. CuO or CuO_2. Variety is due to large number of elements.

   b) Organic compounds use very few of these, but those few are combined in vast number of different ways. Variety of products is very much greater, but the cost is a great many atoms and a big difference made by small differences in composition.

      i) Fifteen to fifty or more atoms is typical. Quinine (deeply involved in first discovery of synthetic dyes) is $C_{20}H_{24}N_2O_2$.

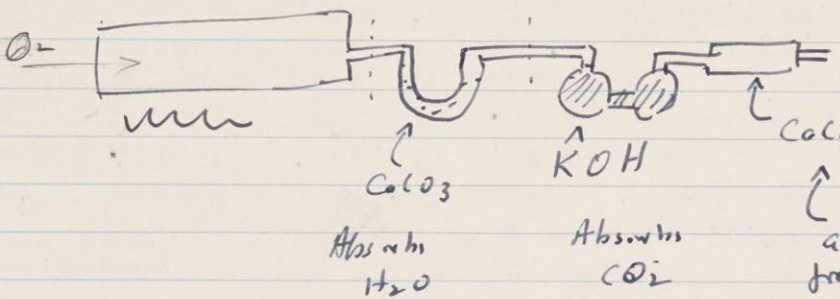
      ii) To pin down compositions like that one needs far more accurate techniques than those responsible for chemical revolution.

      iii) These have a continuous history from Lavoisier himself through Dalton, Gay Lussac, Berzelius and a number of other men you've not met before.

      iv) Culminating in technique of Combustion analysis in form developed by Liebig around 1838.

   c) Liebig, it might be said, is the first of the giants in this field and the man who almost single handed trains the whole next generation of organic chemists in his school at Giessen.

Liebig's 1838 Comb. Analysis



More detail for S, N, etc.

i) And it's really only from about this date and in the hands of Liebig and his pupils that one begins to get reliable analytic data with which one can write consistent molecular formulas.

d) ~~ii)~~ Or at least from which one could write consistent formulas if one had consistent atomic weights.

iii) One characteristic of this period that makes it simultaneously so tough and so fascinating to handle the research literature is a problem you encountered early in term.

iv) ~~Wikkxhydro~~ Water is written HO by some, H_2O by others. ~~HO.~~ ~~HO~~ Inconsistency crops up elsewhere too. Thus with Hydrogen as one, get all combinations of C 6 or 12, oxygen 8 or 16. Consistency of analytic data is not consistency of analytic formula.

d) That's a situation I propose immediately to forget about for purposes of lecture. I'll suppose consistent formulas in modern form.

Wendge

i) But you must keep it mind for it's part of what determines timing of subsequent development.

ii) Order enters organic chemistry not with relative weights but with relative number of atoms which are prerequisite to seeing structure.

iii) But that in turn depends on resolving the residual inconsistency in atomic weights in inorganic chemistry.

iv) You already know from previous reading that this comes with Cannizzaro at Karlsruhe in 1858.

v) But this is just the period in which the basic concepts of structural chemistry emerge, particularly in work of Kekulé.

vi) They don't result from this final cleaning up of inorganic chem, but they couldn't have worked without it.

II. THE POSITIVE APPROACHES

1. So far have talked mostly about special problems that held organic chem back of inorganic, that made two fields different.

a) Now try more positive approach. What techniques were developed to bring order to this incredible mass of messy material?

b) Part of answer I've already given name to. Analytic techniques.

i) But though that's requisite, it doesn't do for organic chemistry what it does for inorganic.

ii) Suppose one does get accurate molecular formulas. If there's no simplicity to them -- if numbers of atoms run high as they do -- then no simplicity beyond the composition by weight is introduced.

iii) Need to know something about which molecules can exist, which not. Need some sort of classificatory scheme, grouping into natural families, to bring order.

c) For this a number of different approaches are tried, each of which helps with partial order and suggestions for next steps, but none of which initially does the job.

2. Not surprisingly, the first of these (idea is actually Lavoisier's) is taken directly from inorganic chemistry. Attempt to build organic by analogy: See begin of electricity.

   a) Called radical theory, a radical being a complex of atoms that enters together into organic reactions as a single element would in inorganic

      i) One of earliest and easiest to follow is the cyanogen radical which behaves as chlorine in reactions.

      ii) CN is radical; $(CN)_2$ is cyanogen gas, cf. Cl_2; HCN is acid cf. HCl. KCN is potassium cyanide, cf. KCl.

   b) This much is noted in 1815 by Gay Lussac. Becomes consequential in 1830's with growth of organic analyses, when a lot of other radicals are invented.

      i) Etherin, C_2H_4; Benzoyl, $C_{14}H_{10}O_2$; Ethyl, C_2H_5; Acetyl, C_2H_3.

      ii) In each case combinations of these radicals as a whole with Oxyg., hydrog., water, chlorine and so on give a variety or a family of organic compounds.

   c) Does a good deal, but quickly runs into troubles.

      i) Compounds like alchohol and ether, which are readily prepared one from the other, often show up as compounds of different radicals, making it hard to see their relations. (Thus do get classification but not always reactions).

ii) Conversely, a single compound, alchohol, may equally well be written in terms of a number of different radical theories:

Thus for modern C_2H_5OH, have $C_2H_5O \cdot H$ (Hydr. combined with oxide of ethyl); Also $C_2H_4 \cdot H_2O$. (Etherin plus water); also $C_2H_3O \cdot 3H$ (from Acetyl)

d) The mess is clear, but so are the fruits. People do learn to see recurrent carbon and hydrogen groupings, and that's basic to what happens next.

i) In particular, it teaches people to see clusters of atoms as relatively permanent, going into reactions together.

ii) Thus one mode of organization whiph people begin to use in the 1840's is series that diffe# by a unit: Alkane Sonci. Hydrocarbons.

CH_4	C_2H_6	C_3H_8	C_4H_{10}	(Diff. CH_2)
Methane	Ethane	Propane	Butane	

iii) Even more significant is the other main approach of the '40's which again grows from same way of seeing clusters and which for first time really does introduce structure as implicit organizing principle.

9. This is the so called Type theory. Metaphor is still to inorganic chemistry, but radical theory is now turned on its head or inside out.

a) Instead of analogue being between atom in inorganic reaction and group of atoms in organic radical, its between the layout of the formula in an organic and inorganic compound. One goes from one

product to another by substitution within a formula-type or within a given structure.

b) There are a variety of types, Water Type, Hydrogen Type, Ammonia type, and still others.

c) I'll give you just a ~~type of~~ taste of the water type to show you what's involved. Those who know some organic can go further relatively easily.

i) Type $\left.\begin{matrix}H\\H\end{matrix}\right\}O$. Ethyl Alchohol $\left.\begin{matrix}C_2H_5\\H\end{matrix}\right\}O$ and other alchohols with other substit.

Di-ethyl Ether $\left.\begin{matrix}C_2H_5\\C_2H_5\end{matrix}\right\}O$ and mixed ethers, etc.

Acetic Acid $\left.\begin{matrix}C_2H_3O\\H\end{matrix}\right\}O$ And an acid anydride by a second sub of same radical, an ester by adding C_2H_5.

d) With this you can go a long way.

i) Some of early dye chemistry is done with type theory.

ii) But it stops short. There aren't enough inorganic types.

iii) More important -- there's no relation between radicals -- nothing that does C_2H_5 and C_3H_7, etc., and also C_2H_3O but not other forms.

e) These pieces come very quickly in years between about 1852 and 1865.

III. STRUCTURAL THEORY

1. First of these is valence theory, and it's odd.

a) Generally attributed to British chemist Frankland in 1852, but in an obvious sense it's been there all along. Many people have been using it without quite calling it that or recognizing generality.

i) For example, there's also been double water type: $\left.\begin{matrix} H_2 \\ H_2 \end{matrix}\right\} O_2$. This is needed to substitute, for example, SO_2.

ii) For that matter, idea is very close to surface in idea of chem equivalent and multiple proportion.

iii) But Frankland does get it out in its full generality, and it becgins to go to work.

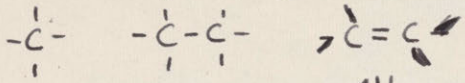
2. And this is what's required for next step which is taken by German F. A. Kekulé (1829-1896) in 1858.

a) Simultaneously says must treat carbon as always having valence of 4 which it displays most clearly in methane and carbon tetrachloride.

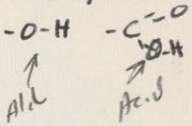
i) And adds key step, can see that it does this elsewhere if we admit also that it can combine with itself to use some of this valence.

b) From which point one can build up/~~the~~/known organic compounds from first principles -- atoms:

many



Also substitutions of groups, also controlled by valence: OH, COOH



c) Biggest single remaining step is the one also taken by Kekulé in 1865. Benzene ring.



3. At this point basic tools for description and ordering and relating all organic compounds are in hand. Organic has caught up with inorganic.

   a) And actually, when you consider what's involved, it's been remarkably quick.

   b) Here one sees, perhaps for first time, a rather modern pattern. New area opens up. Many many people rush in. Half a century later all its main concepts are layed out.

MC 240
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Princeton – History 336

OK

SCIENCE IN INDUSTRIAL REVOLUTION

I. Problem of Science and Techology

- In general
- In Industrial Revolution

II. Steam Engine as an example

- Ancient ideas
- Belated Application
- The pattern of improvement

History 336 -- Lecture 12

Science in Industrial Revolution -- Steam P'wr

I. INTRODUCTION

1. This morning I want to introduce a set of problems into the course rather different than any I've talked of before.

   a) ~~In examining electricity have~~ To this point we've talked a good deal about development of science as knowledge:

      i) In both chemistry and electricity we've dealt with science as set of ideas leading to increased understanding of detail and increased ability to predict detail.

   b) But science, at least today, is clearly a source of more than knowledge. It's also a source of power over nature.

      i) New products, new means of communication, new weapons, new ways of life.

      ii) In short, of knew technologies.

   c) Basic question at the moment is, how did it obtain that role and when?

      i) Put differently -- we've already noted that both chemistry and electricity have imported roots in prior craft technologies.

      ii) Want now to ask, when did they begin to pay their debt? When did Bacon's hopes for ~~the new~~ sciences come true.

2. This is not a usual topic for history of science course which tend to emphasize science as ideas exclusively.

   a) I shall stick to that pattern in part, for I'm going to give this aspect of the course far less time than it really demands.

   b) But I don't think it can be omitted entirely for two reasons.

      i) First, whenever the sciences may have begun to pay their debt to technology, there is a debt.

      ii) As lecture on Baconianism may indicate, sciences have repeatedly borrowed from the crafts, and that pattern didn't stop in 17th century and probably hasn't stopped now.

      (iii) Also, support for science has often come from people who thought it useful.

      iii) One needs at least a taste of the technological enterprise just because it's been so important to scientific development.

   c) Second reason is simply my social conscience.

      i) I think there's no problem of much more contemporary urgency than that of relations between science and technology.

      ii) Nor are there many areas in which more misunderstanding is prevalent.

      iii) General tendency, most marked in discussions of support for the space program is to treat the two enterprises as one.

      iv) Historically there's a good case to be made for the position that they've generally been quite separate and often in direct conflict

v) The conflicts between them seem to me particularly important -- though I don't propose to discuss them here, and reserve them for conference -- because I suspect that the conflicts are still there today in a somewhat disguised form.

vi) They may hurt subsequent development in both spheres. We need to see what these enterprises are like.

3. Now back to my original question: When did the sciences begin to repay their debt?

a) Put in that form, there's a very usual answer which, though now largely discredited among scholars, continues to exert a considerable influence.

i) As a particular case study of our problem, it's worth a look.

ii) To be continued in reading, and will have much discussion at conference. Let me introduce it here.

b) The period which we've just run through twice, first in studying development of electricity then of chemistry, also includes one of the earliest and most rapid steps towards modern industrial societyl

i) It's the Industrial Revolution which occurs first and most quickly in England centering in the period 1760-1820.

ii) In technology and productive techniques these are decades of rapid and reiterated innovation in agriculture, textile machinery, iron & steel fabrication and utilization, and steam power.

iii) Socially, its a period with immensely quick increase in population, with great development of factory system, centered in urban(izt'n) areas, many of which had previously been no more than villages or towns, but which are now needed to house what is virtually a new class, the proletariat.

c) Don't propose to survey this ground which many of you have been over elsewhere, but will give you a few figures just to indicate how quick and big the development is:

i) In 80 years from 1750 to 1830 population of Britain rises from 6 1/2 to 14 million. (Note that it's right in the middle of this period that Malthus writes his famous Essay on the Principles of Population discussing built in limitations on prosperity and population due to limitation on means of subsistence.)

ii) Increase is not, however, by any means uniformly distributed. Goes largely to the new industrial towns. Manchester from 1750 to 1800 grows from less than 20,000 to 95,000, and is still expanding rapidly.

iii) ~~Supporting~~ Feeding this population calls, of course, for a transformation of British agricultural technique. Achieved partly by increasing size and efficiency of farming, partly by new crops and rotation, partly by mechanization, and partly by gigantic improvements in livestock.

iv) Of which just one illustration. Between 1710 and 1795 calf breeding is improved so much that average weight of animals sold at British market increases from 50 to 150 lbs. Figures for oxen, sheep, and other important animals are comparable.

Ox 370-500
Sheep 38-80

vi) And of course what goes with all of this is an astronomical increase of manufacture, particularly in textiles, which at first barely keeps up with population but then makes Britain manufacturer for the world. Export in 1750, 1790, 1800 goes from $~~80~~ 65, to $100, to $210 million, and doubling in last decade is still only beginning of rapid rise.

4. These figures, which you need not remember, are simply striking indices of social and economic transformation, the transformation which we now equate with the phrase "developed country". For general history these cutting use important

a) I don't want to pursue description of Industrial Revolution further but instead deal with one very prevalent answer to question, Where did it come from?

i) Answer often given is that transformation is somewhat belated by-product of Scientific Revolution of 17th century.

ii) Sometimes even suggested that reason it centers first in England and is exported from there is that Britain is the country of Bacon, of Boyle, of Newton.

iii) On this view, what the Industrial Revolution represents is first great example of that now familiar pattern of advance: laboratory or theoretical discovery, to application, to industrial and social transformation.

iv) Began ~~at~~ toward the end of the 18th century and continued that way ever since.

b) To which I want to say, quite dogmatically, NONSENSE. Virtually nothing which occurs during the Industrial Revolution is properly described as the application of prior scientific discovery.

i) For the very simple reason that, in the areas where the ~~central~~ innovations occur, there isn't any science sufficiently developed to apply.

ii) This ismost obviousl of all in the most central areas, textiles and agriculture. Will be reading about textiles and have even | choice to get back at me.

How little science can be done with elk. & wool.

iii) What's required and deployed in the development, for example, of the new spinning and weaving machinery that transforms the textile industry is gigantic mechanical ingenuity, great skill with tools, and much practical acquaintance with possible building materials and ~~xxxfx~~ techniques of fabrication.

iv) Not surprising, therefore, that men who make the innovations are shop foremen, carpenters, metal workers (in one key case a barber)

with no exposure to science and no acquaintance with scientists.

c) In agriculture pattern is substantially the same:

i) Innovators are farmers and stock breeders willing to try new techniques and to make systematic records of results.

ii) Almost none have scientific training nor is it clear what good such training could have done them. Science isn't there.

iii) On the contrary, in a number of important cases it is they who feed necessary information to the scientists rather than vice versa.

iv) One essential step in Darwin's development of theory of evolution is prolonged inspection of stock books of breeders who have transformed livestock and flower gardens. It is they who show him what selective breeding can do and rate at which change can occur. The data goes into the Origins and into another of of his major works.

v) Mendel's breeding experiments have partially similar background, from a long flower breeding tradition, and in more detail Bee keeping

vi) This is route from technology to science which we've seen before in 17th century and which can be traced to antiquity where lever and pumping equipment are highly developed in crafts before they are subjected to scientific scrutiny.

d) Elsewhere in Industrial Revolution pattern is slightly more equivocal but basically the same.

i) One area of particular progress in Industrial Revolution is metallurgy, particularly of cast iron and steel.

ii) But there's not the slightest evidence that the chemical revolu- plays any role at all in bringing these changes about, even though it grows out of a study of oxidation-reduction reactions.

e) Story of the application of chemistry to industry is one I want to examine in more detail next time, but it comes largely after the Industrial Revolution.

i) For balance of this lecture want to sketch briefly another case -- of new technology -- that of the steam engine.

ii) If not the same in its purity as the case of textile machinery, it tells a good deal of the same story. Marxism is wrong.

iii) It's a major source of economic advance which owes comparatively little to scientific invention and discovery. Marxism is wrong.

f) If you get nothing else from this lecture, I'd like you to take away the fundamental notion that most of the pressing social and economic problems the world has faced to date have been solved without the aid of science.

i) I have no reason to suppose that will not continue to be the case.

(ii) Tendency to approach contemporary problems by looking first for needed science seems to me crippling.

II. THE STEAM ENGINE

1. In an odd and extremely interesting way the story of the steam engine begins in antiquity.

a) During the Hellenistic period (after about 300 BC) there's a

strange tradition of designing on paper, and sometimes of building, odd mechanical toys and games.

i) To me many of these resemble Rube Goldberg devices. They're of no practical importance, but they are fun.

ii) Just what this tradition was about -- where it came from, why pursued -- nonne has yet clearly made out.

b) But it does result in a number of machines run by steam or hot air.

i) One that usually gets called the first steam engine is the Aelopile. Draw.

ii) Another, more revealing, is the temple door opener. Describe.

iii) The most important of all is a device known as Hero's fountain, Draw.

2. I find these devices interesting in three respects that deserve underlining

a) They're not practical machines, and not a response to a social need. Necessity is not the mother of these inventions, and I don't know what is.

b) Ultimately, however, they're undoubtedly influential in fulfilling social needs, for the first steam engines derive directly from these designs.

i) The ancient fun and games tradition is recovered in 16th century Europe, and again evokes much interest.

ii) You'll shortly see first engines taking off from them.

c) Third point is just that, if scientific understanding of nature is needed to produce these devices, it's an extraordinarily elementary one that might as well be called common sense.

i) What's needed for these is much ingenuity and some experience with materials.

ii) Both useful in science, but by no means coextensive with it.

3. The next step in the development of these devices comes only at the very end of seventeenth beginning of eighteenth century.

a) It is a response to social needs. Of two sorts:

i) Mining is in trouble because they can't go to deeper levels because of flooding. One mine in Cornwall uses ten waterwheels each twenty feet in diameter and barely holds its own.

ii) Few mines are near enough water. Wheel size small limit. Better pumps needed.

iii) In addition they're needed for city water supplies, both drinking water and fire control.

iv) Seventeenth century is a period of rapid expansion of major cities, due to the early enclosure movement. Fire of London.

b) As a result several people, principally Captain Thomas Savery adapt the ancient toys to practical neds.

i) His is called Water Commanding Engine, ~~patented in 1702~~ released on anuunwary public in 1702. Tried unsuccessfully earlier.

a) It is an extension of Hero's fountain. Draw.

b) Though somewhat given to vapor lock and though dangerous when pushed to far, they do work.

i) One engine installed in Kensington actually raised 3000 gallons per hour through 58 feet and used only a bushel of coal a day.

ii) A larger one delivered 50,000 gallons per hour.

c) They did begin to be very widely deployed. There was an industry and an export market. In a few locations these engines get used throughout the century.

4. But once this point is reached, a new developmental pattern starts, one typical of technological development.

a) There is an industry and thus an established market, & going technology.

i) In addition, there's a group of experienced craftsmen who know the techniques and the needs of their fields.

ii) As the last innovation begins to display it's special problems and limitations, these are the men who produce further innovations to eliminate them.

b) In the case of the steam engine next innovation comes almost at once.

i) It's the Newcomen Engine. Draw. Which can be kept at surface of mine and will pump through far larger distances. No explosion danger.

ii) First working engine set up in 1712.

iii) They spread very rapidly. By mid-Century ever major mine in England has installed one and they're being exported all over the globe.

6' cylinder with 9½' stroke. 3 15' diameter boilers.

iv) In Newcastle, where coal was cheap, there were 57 of them operating by 1767, and the last of them was kept in operation until just before World War I.

v) They result in the doubling of the depth of mines and in opening ~~xxx~~ up many new locations.

vi) In short, they're an integral part of the transformation of mining practice during the Industrial Revolution. A necessary part of the background for the metallurgical aspects of the Industrial Revolution.

5. The fame of James Watt, both real and mythological, has, of course, obscured the fact that it's really the Newcomen engine that's the important innovation for the Industrial Revolution.

a) But that doesn't make Watt's engine less important, it turns out to do a job quite different from the Newcomen engine and to open up a whole new range of applications.

b) As you'll discover in your reading, Watt's engine begins as an attempt to improve the Newcomen engine.

i) Particular effort is to save the fuel that, in Newcomen engine, is used to reheat the cylinder on each stroke.

ii) If successful, it will save fuel and replace N in regions where

coal is expensive.

c) Watt's terribly important idea for a way to do this is the separate condenser.

i) Draw. Step 1. Condense outside the cylinder.

ii) But then might as well make sure cylinder stays hot, so put a jacket around it and keep live steam instead of air above the piston. Then whole apparatus stays hot.

iii) But as soon as you've done that, then you might as well drive from and condense on both sides. Double actiing engine. Symmetri strokes.

iv) And with this step have an engine that, for the very first time (MANTOUX IS WRONG) can turn wheels.

v) Thus factories, then trains, then boats. The really big push though almost entirely in nineteenth century. Late stages of Industrial Revolution or out of it entirely.

~~6xxThisxisxwhatxIxhavexinxmindxinxspeakin~~

6. This pattern of ingenious improvement of existing technology responding to demonstrated needs but creating unforeseen possibilities has, I think, been the most fundamental pattern of technological development.

a) You'll see more of it in your reading, both on steam and on textiles.

b) What this account does, however, less than justice to is what's really tough about it, where the ultimate in stubborness and ingenuit goes.

c) That's into getting the bugs out. Getting a machine that can actually be manufactured and can compete economically.

i) Watt, who starts optimistic about his great idea for a separate condenser, discovers that his problems have only started.

ii) It's the next stages that drive him up the wall and his partners into bankruptcy. Scarcely have them with ni appeals. Bank as orthy.

iii) Give you just one example that's in, but not clear in, the reading.

iv) Problem of Water sealing.

1964-65

~~19th~~

19th Century Chemical Industry

I. Heavy Chemicals -- Inorganic Industry

Main products & their origins

Equivocal Relation to Science

II. Dyestuff synthesis

~~xxxWxxHofxxxxxx,x1818-88~~
Royal College of Chem. 1845
A. W. Hoffmann, 1818-88
W. H. Perkin, 1838-1907
Mauve, 1856, and ~~xxxxxxxxxxx~~ other new colors

III. New Industrial Patterns

German dominance
Rise of Industrial Research

HISTORY 336 -- Lecture 21 13

Chemical Industry in 19th Century

I. THE INORGANIC CHEMICAL INDUSTRY -- "Heavy Chemicals"

1. Intend this morning to talk about the development of significant chemical industry in the 19th century.

   a) Will concern myself principally with the organic industry, for it's this in which the markedly new relation between scientific research and technology show: Here's where you see the scientist in industry.

   b) But want first to say something about the older chemical industry. This is organic industry -- what's known as heavy chemicals -- and by mid-19th century its big industry.

2. For this industry the three products which are mainstays prove to be: Sulphuric acid; soda; bleaching powder.

   a) Latter is needed for improved textile industry resulting from Ind. Rev. Previously have bleached cloth preparatory to dying by spreading it out in sun, soaking in sour milk, and other devices.

      i) Takes much time, sunlight, and milk. Finally Scottish mfg. send partially bleached goods to Holland where there's more milk.

      ii) Partially solved around 1760 by sulphuric acid bleach and then permanent solution from about 1800 with chlorine bleach. Latter is international standard and basis for industry.

   b) With Soda (i.e., Na_2CO_3) situation is different. This is not a new industrial material. Used since antiquity for glass, soap, leather

This is not right.

I need more circumstantial detail. This need to integrate with other incidental stuff.

Partly This, I did it deliver it well. Too much time on I. Not enough elsewhere

Second Time Run, went fine. Ever done for some odd 16 at end.

and has also some role in some dying processes.

i) But in late 18th century two things happen at once. Previously made from wood ash and plant ashes. Deforestation cuts down supply and ups the price.

ii) At same time the demand is steadily expanding.

iii) What happens in 19th century is process for synthesizing it. Particularly successful development from about 1815 of process patented in 1789 by Frenchman named Leblanc.

c) Against this background need for sulphuric acid on major scale explains itself. It's important for preparation both of chlorine and of Soda. By mid-19th century mfg of sulphuric acid is used as index of economic health.

d) First in France and then in England the mfg of heavy chemicals becomes very large industry in first half of 19th century.

2. That brings me to the question I've asked in this course before. What had development of science to do with these changes and this growth.

a) Say at once that answer must be far more equivocal in this area than in any we've previously examined: agric., textiles, metallurgy, even steam.

i) At the very least have to notice that many doctors are involved in the innovations that make chem ind possible.

ii) Leblanc is one. Roebuck, who develops lead chamber process for sulphuric acid is another. These are men who've had some contact

with medical chemistry and with science more generally.

iii) In addition, in France and particularly during and after the revolution there's much consulting done by emminent chemists -- Lavoisier and Berthollet among them -- about relative merits of various chem processes. T

iv) They do suggest certain improvements and tho its not clear than any of these is very decisive, its clear that significant interaction continues.

b) v) That must be one reason why the field of heavy chemicals is one in which France is generally ahead of Britain at start of 19th century and are only gradually surpassed.

b) Yet having said all of that, it's still unclear just what ~~the role~~ The effects of chemists and chemistry was. In the absence of a new and more sociological study, not quite clear what to conclude.

i) Sulphuric acid, for example. Key improvement is lead chamber. But this is physical and only physical expansion of old process conducted first in ~~xxxxxxxx~~ clay, then glass. What's tough is actually rivetting the lead sheets. French can't do it. Must import workmen at first. But chemistry is same as ever.

ii) Leblanc process is tougher. Chemists have discovered before his time a few ways to make soda in laboratory. But they're not commercially practical. His novelty is introduction of lime-stone. But no one knows why he did it. Best guess is that it was a misunderstanding based on false analogue to smelting. No apparent guidance from intellectual processes of chemists.

Wait do it. Your problem

iii) Bleaching powder least clear of all. It's Scheele, famous Swedish chemist who discovers chlorine, and its French chemists who follow him up who notice it bleaches and may have industrial use.

iv) But the man who tames it and makes it safe and economical enough is a bleacher, Charles Tennant, with no known training or interest in chemistry.

3. So I suggest, tho with a good deal of reserve, that even in first half of 19th century contact between laboratory and industrial chemistry is of only secondary importance.

a) Does produce occasional new prodcuts and occasional improvement of process.

b) But its random and often accidental. There's not the chemical knowledge or theory to make it a conscious process.

c) As late as 1850 Chemists aren't yet able to be deliberate improvers of industry.

II. THE COMING OF THE DYE INDUSTRY

1. That's the situation that changes so drastically through the organic chemical industries, particularly the dye industry, after about 1870. Now trace that route.

a) Not too surprisingly, it starts in a relatively familiar pattern -- an accidental discovery made in a chemistry laboratory. ~~whose outcome unexpected.~~

b) Say something about the accident in a moment, but first the lab. for

it's a new one, and its novelty helps illuminate what happens later.

2. ~~Probably~~ need not now reiterate the list of new institutions founded in England to teach science in the wake of the Industrial Revolution: they include the Royal Institution (which soon doesn't teach), a number of so called Mechanics Institutes, and (an outgrowth of the Institutes) the first two colleges of what becomes the University of London.

   a) Because of these and other institutions there's more chemistry taught in Britain than there had been before -- but it's by no means an unqualified success.

      i) These are all of them lower class schools and designedly so at a time when class lines are strong.

      ii) They aim to train workingmen, factory formen, or men hoping to to rise to factory forman.

      iii) They're not intended to train engineers (Britain's very late in getting any idea of engineering training -- polytechnique model never does take here), and they rarely do train scientists.

   b) As a result the teaching is generally of a quite low level. Advanced training is still not routinely given, and most of the group that comes has little leisure or desire for it. The new chemists who emerge do so in part by accident.

      i) And most of them continue on non-organic problems like those which had occupied Davy, Dalton, and others. In this area Britain is particularly far behind.

c) Now early in the 1840's Liebig, whose scientific emminence is by now unbounded, visits England and inspects both educational and industrial facilities.

i) Immensely critical of both. Says you need an institute like mine at Giessen.

ii) A number of his former students and some local industrialists take this much to heart. Try for crown support, but failing it start an institute by private subscription.

iii) No one to direct it in England. Ask Liebig for recommendations. One who finally accepts is his student and assistant, A. W. Hofmann, 1818-88, who arrives in England in 1845 and by summer of '46 has a lab going and over 60 students doing advanced work under his direction. Success brings promotion: ROYAL COL OF CHEM

3. This is institutional context within which first practical synthetic dye emerges. Happens this way.

a) While working under Liebig, Hofmann has been assigned to analyse the components obtainable by fractional distillation of coal tar. Has worked particularly on aniline and secondarily on benzine, two very important fractions in view of what's to come, and has done first rate research.

i) When he come to England he and his students continue in same general line and are still at it in 1856. No coherent unit use. Tars is an industrial lab.

ii) That's year in which one of his students, W.H. Perkin, tries to synthesize quine by two different quite well reasoned but totally

unsucessful techniques. (First total synthesis isn't until 1944)

b) Would be just another days work except that cleaning up his equipment with alchohol gets a purple liquid yielding purple crystals.

i) This he suspects may be a dye. Tries it. Has result tested. Thinks he's got something.

ii) Against Hofmann's vehement advice (he's known you can get colors this way -- has used them as tests)-- and he knows the special problems that stand in the way of mfg.) Perkin quits school to develop product.

iii) So does his little brother. And father, a contracter, sinks the family's small savings into equipment.

c) In fact it's a crazy gamble. Costs are impossible to estimate in advance. He has to design non-existent sorts of equipment and find people to build it, in area previously not industrialized at all. Also needs mordants, techniques for even application to cloth, and so on.

i) Only this proves to be one of the extremely rare cases in which the gamble works and quickly.

ii) Within just under two years after the initial accident the new dye, Mauve, is commercially on the market.

iii) Many manufacturers are initially unwilling to use artificial product, but French pick it up (declaring patent invalid in process because misdated) and make it high style. Then its the rage in England.

d) This is the dye Mauve, or Analine purple. It starts a whole new industry.

4. You can guess the next steps except perhaps for their rapidity. It's the Columbus and the egg story.

a) Knowing that dyes can be made from coal tar derivatives, people with any knowledge of chemistry try to have an accident themselves: random reactions with slightly changed reagents.

b) Both in France and in England a great many are found. A number turn out to be identical. Others impractical.

i) But at London Exhibition of 1862, less than five years after first commercial production of mauve, twenty-nine European firms, mostly British and French, are willing to exhibit new dyes.

ii) Many are transient, but five are staples of the early industry.

iii) And at Paris exhibit five years later there are at least eleven more. Such were dyes that these have been.

iv) Demand is great, competition fierce, prices are down already by a factor of ten in some cases. But total coal sales are already up by factor of three in same five year period.

c) Given the role of fashion in textile industry and also the discontent with the very restricted palate which vegetable and animal colors had permitted, the future is assured.

5. But so, by now, is an important change in pattern of the chemical industry.

a) Most of dyes produced by 1860's have been produced by entirely empirical means.

i) Men who did it had to be chemists, tho not necessarily highly trained ones. But surely had to know how to prepare the reagents and what reagents were likely.

ii) But ~~xxxxxxx~~ beyond that they'd simply try and try until they found a combination that would work.

Nicholson b) But then, in the early 1860's, one British manufacturer who has also been a student of Hofmann's brings his old master a sample of one of his dyes and leaves it with him to see what will happen.

i) Hoffman gets interested, analyses it, then turns to a number of the other analine dyes. Finds related patterns or structures.

ii) Reasons that if these changes of structure change the color, specifiable other ones should also. Rapidly turns out three new dyes deliberately and a fourth, even more important, turns up as residue in one of his reactions.

iii) Here is something very close to deliberate design of new colors.

iv) And it is followed by what is almost exactly this -- the successful synthesis of Alizarin, the active ingredient of madder which has been the main vegetable dye. Perkin & Bayer indep.

v) Now can produce Madder itself and also new families of alizarin related dyestuffs.

1. The ability to do this sort of work would be important in any industry, and is crucial in the dye industry.

   a) Patents are unreliable because alternate processes will produce results. Secrecy won't work when competitors can analyse your products.

      i) Best way to stay in market is to keep producing new colors, or new ways of dying.

      ii) That's what becomes the basic industrial pattern. Duplicate everything your opponent does and go him one better with new products.

   b) But this can't be done without chemists in industry or closely available to it.

2. Which has two decisive results: First of which is that -- though in 1860's the two leading dye producers have been France and England -- by mid-1870's the lead has passed to Germany and Switzerland.

   a) Complex causes but the phenomenon itself is clear.

      i) 1863 Hofmann is persuaded to return to Germany. Here he is promised a laboratory and staff of his own on a scale that's become typical in Germany since Liebig but that no one in England is prepared to meet.

      ii) Simultaneously a number of other German chemists who've come to England and helped in dye industry go back.

iii) And they're really scarcely replaced. Not until the first world war does Britain really wake up to what's occurred and begin to support chemical research on scale that's common in Germany by 1870.

iv) Partly they're secure in an industrial tradition that has not needed scientists. Partly engineering itself is infra dig. Both Perkin and Nicholson retire early and devote themselves to private and pure research after making their own fortunes.

b) Nor is situation better in France. Individual great chemists. But few lab facilities and these are not for advanced students.

i) It's the Germans not the French who have continued and expanded the tradition that dates from the Ecole polytechnique.

3. That's the first pattern of change. The second -- initially restricted to Germany -- is a whole pattern of new relationships between industry on the one hand and University and Polytechnic institutes on the other.

a) First part of the pattern is now familiar attempt to seduce (or should I say, gain the cooperation of) the Professors of the principal research institutes.

i) Consulting fees and royalties.

ii) Equipment and stipends for students if they'll work on dye related problems.

iii) Promises of jobs for students and general attempt to establish a special inside relation with a research institute.

b) This is already going in the 60's. It continues important today. But it's not quite enough.

i) Chemical industries need also academic chemists, men with doctorates, on their staffs. By mid-70's they're hiring them in ever increasing numbers.

ii) Some of course for quality control and for production improvement. Some to analyse products put out by competitors. But also an increasingly sizable core group that's pledged to look for new colors, and later new drugs, and other new products. Problem:

c) It's a brand new pattern but again grows very fast.

i) Bayer firm in Germany hires first Ph.D. in about 1875. 1 1885-15; 1885-24; 1890-58; 1896-104.

ii) Same firm in 1891 opens ~~first~~ 1 1/4 million mark building designed just for research. 3 stories high, three years to build, model for all of Germany.

4. Perhaps silly to stress it, because it's so familiar.

a) Spreads from chemistry to physics and from there even to math. Can't drive from here to New York of Philadelphia without passing a nubmer of industrial research laboratories. It's not special. Most scientists work in such laboratories.

b) But eighty years ago it was brand new. Existed only in chemistry. Nothing intrinsic to science about this institutional locus. In fact, there are even some who feel strongly that it's doing science harm. There are strains in the fabric.

Professionalization of Science

I. Context for Institutional Change

II. Scientific Institutions in 1750

III. Beginnings of Change

Sources
In France
In England

IV. Concommitant Changes

HISTORY 336 -- Lecture ~~11~~ 14

19th Century Professionalization of Science

I. RETROSPECT

1. Want this morning to discuss one additional aspect of science that relates ~~elsewhere~~ to certain of the problems of technology and industrialization raised last time.

   a) Call it professionalization of science, and have in mind principally a considerable transformation of scientific institutions that begins in late 18th and continues through much of 19th century. Book is ready. I week to set up.

   b) Before approaching it directly, however, think it useful to look back at ground already covered and try to notice where it fits in.

      i) Some of developments we've already examined are products of the new professionalization, others are sources for it.

      ii) A brief and overly schematic retrospect will set stage for consideration of new set of novelties in 19th century science.

c) Particularly want [illegible] people because [illegible].

2. Early in course I introduced distinction between classical and Baconian sciences. Remind you of it with schematic drawing that falsifies details, but highlights several important trends.

   a) Draw. First group, particularly math, mech, astr., anat, phys. reaches high level in antiquity, continues thru middle ages, and is radically transformed by sci rev of 17th century. Then continues on developing from its newly relayed foundations.

This was quite well. But I didn't get to rest down or like

2nd Time this was awful. But largely because I collapsed. Again didn't get to rest down. But could have.

b) Draw. Second group, particularly chemistry, electricity, heat, geol, botany, zoology are products of Baconian natural-historical emphases of 17th century, often from crafts. Little substantial progress in that century, but come of age after 1750 and merge (partially) with older group after 1800.

i) One sign of this merger is the very significant introduction of techniques of higher mathematics into fields that had previously beenentirely qualitative.

ii) We've seen it electricity only, but it's far more general.

iii) One more example next week, thermodynamics, but there's still more. Work of Fourier on heat, and other work by Laplace and Poisson. Fresnel on wave theory of light. Still other work on accoustics and elastic media. (Nec. diff btwn ~ approach of 18th & 19th century done (pmath.)

iv) Continues during the century to produce what's really a new field, Physics. Deceptive because ~~some of~~ its concerns are very old. But it's only when it spreads from mechanics and celestial theory to include experimental fields like sound, electricity, heat, and so on, that it takes its present position among the sciences.

v) Residues of this older picture still endure at a few European universities, some of them prominent. Mechanics and the other mathematical parts of physics in applied math, experimental parts in physics departments, not always easy to combine the two.

vi) Dominance of Germany in 19th C.

3. Finally, draw, there's a third line, technology, againsstarting in antiquity and marked by periods of innovation in middle ages and again in 18th century.

   a) Initially separate from both the others, tho there's continued feed from technology to science throughout our period.

   b) This two merging in important, tho incomplete, ways with science line late in the 19th century.

4. Taken together these development -- new maturity of Baconian science, mathematization of new fields, ultimate new basis for technology -- justify our talking of a second scientific revolution in 19th century, a transformation of many sciences with a number of parallels to what had happened two hundred years before.

   a) Furthermore, that parallel exists not only with respect to substantive transformation and not only with respect to introduction of math theory into new fields, but also in a third respect that parallels 17th century.

   b) I mean development also of new scientific institutions which to a considerable extent provide a basis for both the merger of classical with Baconian science at beginning of century and for increased feed to technology at end of century;

5. It's instititutional transformation whose main lines I now want to sketch.

II. INSTITUTIONAL BASE OF SCIENCE AROUND 1750

1. Begin by collecting remarks scattered through older lectures and reading to remind you of institutional base for science in mid-18th century.

   a) Begin with one of the classical sciences, astronomy.

      i) Chairs in a number of the main European universities, some medieval in origin, others added slowly since.

      ii) Also, government and ~~military~~ naval observatories which provide employment for many men not in universities.

      iii) Astronomy is a field one can learn in school and practice there or in a research establishment.

   b) Situation in mathematics, which INCLUDES MECHANICS, is about the same.

      i) Again have university chairs widely dispersed.

      ii) And also positions in a number of the national academies. Not Britain which has no payed research positions: But Paris, Berlin, St. Petersburg.

      iii) Here again available training and jobs.

   c) And of course the situation is the same in the medical fields, anatomy and physiology.

2. Turning from classical to Baconian sciences, the picture is very different

   a) A few of them, particularly chemistry and botany, get support from medical schools for their relation to pharmaceuticals.

i) But almost all the men who, like Boerhaave or Black, do chemistry at medical schools also are teachers of directly medical subjects.

ii) And for every one of them there are several men like Rouelle, Scheele, Cavendish, and Priestley.

iii) First two are pharmacists who learn their trade as apprentices beginning at tender ages. Experiment by themselves on their own time.

iv) Cavendish is a noblemen of independent means who supports his own work. Priestley is a minister who writes ~~even~~ much more on theological philosophical, and political topics then on the sciences, and who also largely supports his own research.

b) In the study of thermal phenomena, electricity, and others of the sort there's even less institutional base for studies.

i) Most of the men who contribute to Baconian science are in one way or another amateurs.

ii) The one exception is provided by an ~~x~~ gradually increasing number of university chairs in natural philosophy.

iii) But these courses tend to be simply general physical science at a quite low level. No advanced work, no associated laboratories either for teaching students or for research of teachers.

iv) With a very few exceptions, the men who hold these positions are not significant contributors to scientific development.

III. 19th-CENTURY TRANSFORMATION

1. After the middle of the 18th century this situation begins slowly to change, first in France, then (a generation later) in England, and finally in the early 19th century in Germany which moves rapidly and leads Europe by 1850 or shortly afterwards.

   a) Initial effect is an increase in the knowledge and teaching of classical science, particularly mathematics and mechanics.

   b) But in France, at least, there's also a gradual increase in institutional niches for Baconian sciences ~~also~~, culminating with the foundation of the École polytechnique in last decade of the century.

      i) And this new stature for fields like chemistry and electricity and other experimental sciences is gained also in England, ~~and~~ Germany, by us. during 19th century.

   c) I want here to sketch quite different patterns of development visible in France and England, leaving German pattern to reading where it's quite fully dealt with.

2. But before turning to description, I shall say just a word, if a very general one, about why the change went on. Necessarily speculative, for the phenomenon's been little studied. But here even guesses are of use.

   a) Partly, of course, the rise of the Baconian sciences is due to their own internal development. With increased scope and power of these fields they seem to clamor for a status like that of math and mechanic

   b) But undoubtedly far more important as background for this whole transition is a conviction we dealt with last time:

i) Rightly or wrongly, it's widely felt throughout Europe that science can and should be useful to industry and the state.

ii) The sorts of initiative that produce the new institutions seems to come again and again from governmental or private sources concerned to produce more of a more useful sort of science.

iii) We've got here an institutional by-product of Ind Rev.

3. In France the initiative comes from government, and it's in France that such initiative is first felt.

a) Reflects a still older pattern. From beginning Academy Royale des Sciences has been an organization with duties to the state. Members are payed, unlike those of R.S., but also have duties to inspect patents, advise the government, and so on. More and more is made of this as 18th century goes on.

b) Last week's reading in Guerlac describes the developing situation in chemistry.

c) Place where the intervention of government is even more forcefully felt is military education, particularly the training of military engineers.

i) Several new schools founded of which one of earliest and most important is probably the Ecole du gènie, Mezière, 1748.

ii) Main emphasis in math, mechanics, design. A number of important scientists teach here and others get their training here.

iii) Emphasis on these subjects also increases at other military schools. Both Laplace and Lagrange hold their first teaching poistions in military schools. Lagrange artillery school. Lapl ger

d) During second half of century spread is measurable if slow, and then, with outbreak of French Revolution in 1789, begin a series of events which transform French science in a number of respects.

i) Despite some notable anti-scientific movements here and there in the revolution, it's widely held that France needs its scientists for survival, and they're put into service as never before.

ii) Famous mathematician Monge comes from Mezière's and becomes Minister of Navy. Lazare Carnot, father of Sadi whose work in thermo I'll discuss next week, becomes Minister of Army and "organizer of the victory." He's military engineers trained at Mezières and a scientist of some distinction in his own right.

iii) Your reading in Gillispie's articles gives you bits of the deployment of chemists in the service of the state.

e) But Revolution does more than bring scientists to Paris. Also provide the political discontinuity necessary to accelerate institutional reform. Happens to a number of institutions. Speeding trends already apparent.

i) In particular, Jardins des plantes becomes in 1793 the Musée d'histoire naturelle, and staff is greatly expanded to 13 major professorships, two in chemistry, and much additional facilities.

ii) From this point on for several decades it's the leading Eruopean center for both botany and zoology.

f) Even more important is founding in 1794 by revolutionary government of a brand new school, Ecole polytechnique, 1794.

i) It too is discussed in your reading and I'll say little about it here. But some points need underlining.

ii) Object is to train engineers. Partly military as before, but also considerable recognition that France is far behind in industrialization. Courses on machinery, steam engines, other such subject -- INCLUDING CHEMISTRY -- play major role in curriculum.

iii) Effect is partly what's desired, great engineers tho not much industrialization for which there are other barriers.

iv) But mostly it trains great scientists.

v) Initial faculty includes Lagrange, Laplace, Monge, Berthollet, and other famous names. Probably greatest academic assemblage of scientific talent ever, given amount of talent around.

vi) Curriculum includes math, mechanics, but also experimental physics chemistry, agriculture. First time Baconian and Classical science have been taught together.

vii) Products include Ampère, Fourier, Fresnel, Sadi Carnot, Poisson, Gay Lussac, and others, many of whom later teach there. Notice this is JUST THE GROUP that first produces the new math-phys of the early 19th century. All of them products of this brand new sort of instit.

g) Not surprisingly then this is school, really the first scientific school that becomes model for Europe.

i) When Liebig wants to learn chemistry comes to Paris and Gay Lussac lab. Goes back and founds his own at Giessen in 1826. Then Engl

ii) When young William Thomson, better known as Lord Kelvin, having completed a brilliant mathematical education at Cambridge wants to compete for a chair at Glasgow, father says, here we're more practical. Go to Paris and learn experimental technique too. Again he does so, and afterwards the work he does is basically in both experimental and math tradition, combination not really seen in England for a long time.

1845

iii) U.S. model. Rensselaer poly. Worcester polyt. Lawrence & Sheffield.

4. First decade of 19th century marks high point in French science. Napoleon militarizes Ecole polytechnique and a gradual decline begins. But model has some what spread.

aa) Turn therefore to England about which I'll say less since the novelties that emerge are far less consequential.

i) What's important is that the same drive is indicated, though this time coming from a different source. Not government but private initiative.

ii) Emerging largely not from established centers like London nor from the old universities, Oxford and Cambridge, but from the new industrial centers that have been so instrumental to the Industrial Revolution.

b) During 18th century Royal Society has become largely a gentlemen's club. Non-scientists significantly outnumber scientists, and reform which begins in 1820's is scarcely completed until mid-century.

i) Meanwhile, however, a whole new group of societies has begun to emerge in the provinces.

ii) Oldest ones are hard to date because they've informal beginnings, often from pre-existing medical groups.

iii) But can spot their coming of age with beginning of publication:

Black in Ed Trans — Trans. R.S. Edinb. 1788, Mem. Manch Phil Soc, 1789, Trans. R.S. Dublin, 1799. — Dalton in Manch Mem

iv) And in decade 1812-22 get new societies at Shefield, Leeds, Yorkshire, Liverpool, and many other new centers.

b) What goes with this movement and helps to display its character is an important effort towards workingmens education:

i) Partly the foundation of a number of travelling lectureships directed to shop foremen and others with main emphasis on science.

ii) Partly also an effort to establish a number of so-called Mechanics institutes initially in the same centers as the new academies.

iii) These are schools intended to supply the same workingmen with more systematic education.

c) Perhaps not surprising that neither of these attempts is very succesful. Educational level is low. Audience tends to drop away.

i) Little evidence that significant scientific work or technological came from people who started through these schools or lectures,

ii) They're gradually abandoned in early decades of 19th century.

d) But as they are, the courses that have been offered in Mechanics insti increasingly show up in universities.

i) Not Oxford and Cambridge. Except in math and astronomy they're scarcely affected until the 1870's. Last of all.

ii) But the Scottish and provinicial universities, which is where much good British experimental science is first done.

iii) And, beginning in 1825, at the newly founded University of London, which from the start has strong scientific curriculum.

iv) It's in institutions like these that British experimental scientists are employed and trained for some time.

IV. TWO CONCOMMITANTS

1. That shows you at least the beginning of the movement for scientific education and the creation of new places where sciences is done.

a) Other end was mentioned briefly in last lecture. Just as Oxford and Cambridge are being reformed in 1870's science, which has not long been in universities, begins first steps out again to industrial research laboratories. Movement still very much with us.

b) But I'll leave it to the reading to ~~connect these up~~ and instead close by pointing to two other developments that are occuring at same time.as ones I've just examined.

c) They're the formation of specialist societies and the proliferation of journals, including specialists journals, which begin also at end of 18th century.

2. Can't say very much, for it's quickly just a list of names, but want to give you the flavor. Phenomenon which transforms 19th century shows perhaps most clearly of all here. Up to ~~this~~ mid-18[illegible] it was Nat. Sci. or local ones for all Sciences.

   a) Linnaen Society 1788 -- 463 members by 1820
   Geological Soc. 1807, Wernerian Society 1808
   Royal Astronomical Soc. 1820
   Chemical Society, 1841

   Br. Ass.

   Similar patterns in other countries together with new all-embracing organizations like BAAA, 1831.

   b) Or journals.

      i) To this point almost only outlet for scientific publication has been publications of the various national academies: London, Paris, Berlin, St. Peterburgh.

      ii) But beginning about 1780 and increasing rapidly after about 1810 a great many new journals, both general and specialists spring up.

      iii) In France, for example,
      1773, Journal de physique, General science but private and quick
      1789 Journ. de chimie
      1802, Ann. du musée d'histoire naturelle
      1830, Bull Soc Geol.
      1836, Journ. mathematique
      And this is actually small selection among relatively impt ones.

3. This is real index of progress/[illegible]

ANNOUNCEMENTS: DMantovx papers.

1) Must reshuffle lectures. Doit by Tu. conference. Doit drop #20. Wave Theory. Enough is in reading

2) My Tuesday conference. Will meet next Tuesday instead.

ORIGINS OF THERMODYNAMICS II: ENERGY CONSERVATION

I. The Work of James Joule, 1818-1889

II. The Work of Hermann von Helmholtz, 1821-1894

III. Reconciliation with Carnot
William Thomson (Lord Kelvin), 1824-1907
Rudolph Clausius, 1822-88

III. Reactions.

Origins of Thermodynamics I: The Constraints 1824

I. Caloric Theory of Gases:

II. ~~the~~ work of Laplace & Poisson

II. Precedents from Steam Engineering

The Problem

"Mechanical Effect"

Expansive Working

Cagnard's engine

III. ~~Generality of the Theory~~ Practical Outcome.

[SADI CARNOT: 1796-1832]

Chalk

HISTORY 336 -- Lecture ~~12~~ 15

Origins of Thermodynamics

I. INTRODUCTION

1. Have ~~recently been talking about the transformation of~~ repeatedly emphasized importance of merger of classical and Baconian sciences in early 19th century. ~~These are perhaps not really old fields -- 17th century -- but they've received a good deal of systematic effort by 1800.~~ Shall have talked most recently of institutional reconstruction leading w.r.t. it.

   a) Now want to ~~examine~~ manner in which same movements ~~in the Sciences~~ that we've been looking at give rise to what is, in effect, a brand new science.

   b) Have in mind thermodynamics, a field which by the end of the century or even by about 1860 has gained the appearance of a sort of meta-science. Can to role it now plays

      i) Supplies regulatory principles applicable in all fields: heat, motion, electricity, light, chemistry, presumably biological also.

      ii) These of two sort: one which appears later states that in all changes in nature a parameter called energy shall be conserved.

      An earlier one which, once revised to permit the conservation energy, states the direction in which all changes must occur excepting only those that can be fully reversed.

2. As you'll see easily, these are overarching generalizations. Broader in scope and more purely philosophical in texture than any that at least the hard sciences have produced before. For many people in late 19th & 20th, they're

FIRST PART IS NOT GOOD ENOUGH AND MY DELIVERY WAS LAME

II + III ARE O.K. AND THEY WORK, I THINK.

IV. I REALLY DIDN'T GET TO.

2nd Year.

Tried to cut first part but
did lobbed it any way.

Not too bad but slow start
plus incomplete fluency week.
I rushed beyond bodily and
did nothing O.K generally.

a) Thus, ~~when~~ revolt against Newtonian mechanism occurs late in the century, particularly in Germany, thermodynamic generalizations will ~~often be taken~~ as the models to which all science should conform.

i) They apply to mechanical processes but are not thought to be dependent upon them. Mechanics is just a special case.

b) And by the same token, their generality and their depth, they spill over outside of the science proper more than any other developments in the physical sciences in the 19th century.

i) Extrapolation from core of thermodynamics leads to notion of heat death. Gradual equalization of temperature everywhere in the universe after which there'll be no more way to use energy.

ii) This becomes topic for public discussion on a quite large scale.

iii) Even more important, the view of process and of time direction implicit in thermodynamics is carried over by a number of men to processes in which physics as such has no very obvious applicability.

iv) Most famous example, but surely not unique, is in work of American ~~philosophers~~ historian, philosopher, and belle letriste, whose well-known autobiography and whose philsophical writings on history see thermodynamic processes as underlying historical change and as leading in some ways to same leveling processes that are seen in notion of heat death.

3. Yet this is only where thermodynamics comes out. Its origins, which for the moment particularly concern me, are quite different.

a) Not an overarching or regulatory science, but the science of heat.

b) Not fundamentally philosophical in orientation, but ~~largely~~ practical ~~even~~ engineering. never ... with modern theories science.

c) It's these two aspects of situation want to ~~xxx~~ consider this morning through work of Sadi Carnot ~~and~~ background for it. (or more particularly the)

II. MATHEMATICAL CALORIC THEORY

1. ~~One part of background is, as I've already suggested, the developed theory of heat~~. Start with background in term of heat as developed in early 19th century

a) At this point no one will still be surprised to learn that in France the subject becomes highly mathematical in early decades of 19th century.

i) Two figures who do most to make it that are, again not surprising: Laplace and Poisson, of whom the second is a teacher at Ecole polytecnhique when Sadi Carnot studies there.

ii) Will try very briefly to sketch the sort of work they do.

2. Laplace's theory, which he developes in the years 1821-23, starts from a view of the nature of gases and of caloric very close to the one I sketched in discussing Lavoisier's Elements of Chemistry.

a) Draw particles with caloric sheaths. Add radiant caloric in interst.

b) In a gas, pressure is due to mutual repulsion of caloric atmospheres. Amount of caloric is just sufficient to maintain equilibrium with radiant caloric supplied by ambiant reservoir or heat source.

+ Charles'

c) With this model he derives Boyle's Law and a good deal else, in a relatively rigorous manner.

d) Won't attempt to follow his own derivation -- involves elaborate integrals, evaluation of edge effects, and so on. Would take whole lecture. Uses gravitating fluid with $1/r^2$ force

e) But for those able to follow can show briefly the sort of things that's involved. Provide an intuitive taste.

3. Consider just internal pressure. On diaphram. Watch only 1 cm^2 draw.

a) Short range force so only particles in little volumes on each side are involved.

i) Immediately: $p \propto c^2 \rho^2$.

b) Now ask about maintaining equalibrium with radiant caloric. It's density I write as $\pi(t)$. Can only depend on temperature since it's just density that determines how much gets into particles of thermometer.

$\pi(t) \propto$ amt falling on sec.

i) But then must have for equalibrium: ~~$\pi(t) \propto c^2$~~ off $\pi(t) \propto c$ (amt available to throw off one atom) x ρc (amt available to do the repelling. (Remember $\pi(t)$ is amount falling on single atom.)

c) $p \propto \rho \pi(t)$, or $p \propto \pi(t)$ and by gas thermometer $\pi(t)$ is simply t. We have Boyle's law. + Charles'

4. Laplace goes on from this point, but I won't try to follow further. Instead taste of the rather different approach taken by Poisson immediate after Laplace's work appears.

a) Poisson is sceptical about the detailed model. Instead simply takes Boyle's Law as given experimentally: $pv = kT$

b) Caloric theory enters via an equation of state: $q = f(p,v)$ Not true in wider theory. It's not obvious from.

c) And Poisson simply manipulates these much as one would in contemporary thermodynamics:

d) Won't do it here, ~~for~~ those who know partial differentiation can do it for themselves and for other it will be total gibberish.

i) But tell you how. Express C_p and C_v as partial derivatives of f.

ii) Set ratio equal to ~~a constant~~ γ, known to be constant from expt.

iii) This gives partial differential equation whose solution is:

$$q = F(pv^{\gamma})$$ f is arbitrary function

e) Which is ~~simply~~ well known statement that in any process in which no heat passes into or out of gass but in which temp is allowed to change then pv^{γ} is constant.

i) Standard law for adiabatic processes, now however derived on quite different basis. Hadn't been dealing a calling by implied assump.

ii) People are often surprised to note it's got nothing to do with kinetic theory or conservation of energy tho ~~derivable from them~~. usually dealt with there

5. ~~Well~~, This line of development doesn't stop here, but that's as far as I shall follow it. Should indicate that it's a powerful technique capable of detailed comparison with experiment, even though theory is one long sinnd discarded. Particularly, it enables advances & is a normal effect of good & great.

   a) And it supplies much of technique Carnot needs for analysis of heat engine.

   b) What it supplies is the laws, working material.

III. ENGINEERING PRECEDENTS

1. But it doesn't supply by any means all. At the Ecole polytechnique Carnot is also exposed to another line of development whose history has until the beginning of the 19th century been quite separate.

   a) This is actual steam engines, and the concepts developed to analyse, describe, and design them. This has problem. The preface.

   b) But its use. These also supply Carnot with elements essential to his work.

   c) I'll illustrate with three. Two quite clear, the last more speculative.

2. ~~By~~ For the first, which may well be the most important, I have in mind what I have to call here the Concept of Work. More often in this period it's called Mechanical Effect or something else of the sort.

   a) It's measured by amount of weight raised through how many feet. Actually product of weight times height.

   b) In almost exactly this form it's been the practical measure of engine effectiveness since very beginning of 18th century.

b)

b) Patent is for Expansive Working. Device to save fuel. Idea as ff.

i) Draw piston and explain.

ii) Draw pressure graph.

iii) Total effect is av. press x piston area x stroke.

iv) Thus finds use 1/4 of coal, get somewhat over 1/2 effect. Think got.

c) But this is almost exactly analysis that Carnot himself uses in computing the effect except that:

i) He completes the cycle. Gets engine back again.

ii) He allows for cooling during rapid expansion.

iii) And these are in part found elsewhere.

4. These aspects of background are, I think, clearly established. In fact, Carnot cites them in his famous memoir.

a) There are others of the same sort, but I'll avoid them.

b) Instead give you as last of engineering examples one that's far more speculative. Tho I'm its discoverer, I'm no longer quite sure I believe it.

i) But it's much too good to leave out.

ii) Could play a big role.

iii) And almost certainly played a small one. I'll tell you about it.

5. In early 19th century, France is still importing British engines and building few of its own.

   a) But British engines are not altogether suitable for French application. Too big.

      i) French aren't building big factories. Capital seems not to be available. Typical pattern is small shop, and one far from coal fields.

      ii) Big engines not economical and a series of prizes are offered by the government for smaller engine design.

   b) Many designs submitted and two of them are reported in the textbook on machines that Carnot uses. Examine one.

      i) Draw. Heated reservoir. Archimedean Screw. Turn to pump air down, heating it en route.

      ii) Bubble up and turn inverted water wheel.

      iii) Measure effect and then couple back. It goes on working.

   c) This is a strange engine, but it's also a terribly exciting one, at least to me. For it contains a number of the conceptual features that seem so novel when one discovers them in Carnot.

      i) Draw his two reservoirs and piston. As most of you know C's own ideal engine is one that's repeatedly described as taking heat from hi temp. delivering it to low, raising weight. Nothing else.

ii) Any engine, we now know, can be analysed that way, but it's not easily seen. This one has to spoken of in those terms.

d) Again, Carnot repeatedly speaks of heat engine as like a waterfall. Heat goes from high to low and turns wheel. That's an active concept in his thinking out engines.

i) Again hard to find in actual engines. Had been thought a metaphor, but it's here.

e) Finally, at least for present purposes, there's a hint here of the rest of Carnot's argument.

i) He shows his engine to be best possible engine by showing that if there's better engine, it can run his backwards, as a refrig., so that two together will do work without abstracting heat. Ruled out by perpetual motion prohibition.

ii) But this whole notion of coupled engines and of pump run backwards is built in here.

f) For Carnot it may have proved immensely suggestive. And some of it is invaluable in real engineering problems.

IV. SOME CONSEQUENCES FOR CARNOT

1. About Carnot's own elaboration of the engine cycle, I shall ~~here~~ today say nothing at all. Qualitatively it's well discussed in the reading, and ~~you can make the further ties yourself. Quantitatively it's so close to modern argument that those likely to follow me have either had it or will soon.~~ I'll come back to it in a week.

2. Instead, just a few closing words about what this analysis does and does not produce -- for the moment chiefly what it does not produce.

   a) And what it does not produce, at least for a long time, is significant improvement in engines.

   b) Carnot produces a number of conclusions relevant to engine design, but they turn out either to be negative or have been anticipated.

      i) For example, one of his most important theorems is that one cannot improve theoretical effectiveness of an engine by changing working substance: From steam to air, or alchohol vapor, or some permenanet gas.

      ii) But that's only a negative conclusion. In anycase, there have been attempts to build air engines, explosive powder engines, and others. No satisfying results. Attempts beginning to lapse.

   c) Another important conclusion: Maximize effect by increasing temp. interval between boiler and condenser.

      i) That means working at highest possible pressure. But, that again, is already being done. Limitations are practical, boiler strength to avoid explosions.

   d) Or still another conclusion, again of much theoretical importance.

      i) Maximize effectiveness by making sure that heat never passes directly from hot to cold body without doing work.

i) Partly means good insulation. But that's being done and was even before Watt on Newcomen engines.

ii) More significant, it means cool steam by expansion in cylinder to condenser temperature. Don't let hot steam into cool condenser.

iii) But this is also being practiced, though with different rationale

iv) Multi-cylinder engines.

3. These are typical, both for this case and other earlier ones.

a) Important prescriptions from scientific study, but they turn out to be embedded already in engineering practice.

i) Like Kepler and the wine casks.

b) On the other hand, what also typical of this case is that, though no practical improvements result (at least not before transition to steam turbine), there's a major increment to science.

i) As I suggested at start, techniques developed by Carnot can be applied to all sorts of physical and chemical phenomena besides steam engine.

ii) In these applications, they're major gain for scientific theory.

iii) Will see them in this role later, but must first consider the other main thermodynamic principle. Conservation of energy.

i) Savery advertises engine to pump so many gallons so many feet per hour.

ii) Smeaton working on either water wheels or engines/ compare mech effect produced as function of stroke, diameter, etc.

iii) Watt actually does experiments on the power of the horses he is replacing and designs engines accordingly.

c) Anyone concerned, as Carnot most definitely is, to examine engine effectiveness, must use this measure. Carnot does.

d) All of which would be of little significance since it's a pretty obvious measure except that no concept like this occurs anywhere in the literature of theoretical mechanics at this date.

i) Not in Laplace, not in Lagrange, Nor in other works from which mechnics is taught.

ii) Separation so complete that when de Prony, inventor of dynamometer and teacher at E.p. writes on machines he uses it as basic. In almost simultaneous text written on mechanics, there's not a mention. Two separate traditions.

3. Second thing Carnot gets from this tradition is technique for computing mechanical effect for an actual engine stroke.

a) Many sources, I'll illustrate from a patent of Watt's that Carnot quotes at length. He really knows his engine literature.

HISTORY 336 -- Lecture ~~13~~ 16

Conservation of Energy

I. INTRODUCTION

1. Continue today with subject introduced in last lecture: development of thermodynamics or of theories about conservation and utilization of energy.

   a) Last time considered background for emergence of Second Law, particularly the background for work of Sadi Carnot ~~as this occurs in your reading~~. to which I'll return next Tuesday.

   b) But as most of you know, don't get either thermodynamics or what we would now call Second Law from this until it is emerged with an initially incompatible generalization: First Law or energy conserv. Problem: All edonic to condenser. Draw.

   c) It's the development of that conception and its merger with a revised Second Law I want to consider this morning. & next lecture

2. From the reading you'll discover, if you haven't already, that it's a subject of gigantic complexity. historical

   a) Many men take essential steps.

   b) In all the history of science, this is perhaps the classic case of simultaneous discovery. One that helps us understand what's meant by recurrent generalization: Scientific discovery must fit the time, or The time must be ripe.

   c) But it's just this aspect of the development that's most considered in your reading. I'll therefore take it for granted here and try

Kin went quite well, the last part was rushed.

2nd Time Through I was badly short of time.

IN '67-68 the Javelin sky was well, but I took too long, had to hum Helmholtz a great deal and send with short receptor.

instead to give reading extra meaning by taking a different approach.

i) Discuss in some detail the development of the research that leads to energy conservation.

ii) Using two figures in particular for this purpose: James Joule and Hermann Helmholtz.

iii) Unlike many of the others involved, each of them got the generalization in an essentially complete form.

Bit good for paper. →

iv) Yet their approaches could scarcely be more different, so that between the two they illustrate in detail much of what's involved for the entire group. Different starting points. Great convergence.

II. JAMES JOULE (1818-1889)

1. I start with Joule, partly because his work is the older in its origin, and partly because it's the more straightforward and will show more clearly what energy conservation is for those who are rusty.

2. Joule himself is the last, or so I now think, of the great self-educated physicists. Scottish. Pattern typical for England in this period: Faraday, Dalton, Davy

   a) Son of a wealthy brewer, privately educated, briefly tutored by Dalton in chemistry. But no higher education and none beyond this in science. Typical pattern for Britain. Not for France.

   b) And just as education is privately gained, so is his scientific career privately supported. Father finances laboratory in whch he works throughout life. Never does much for Brewery.

c) Typ

3. Nevertheless, Joules route to energy conservation begins from an emminent practical problem.

   a) Beginning in 1837 at age 19 and continuing until 1841, Joule tries by a series of experiments on electromagnets and motors to improve the electric motor so that it will compete with steam engine.

      i) Finally in 1841 reports in despair: Best Cornish engine raises about 1,500,000 lbs for 1 lb of coal. His best motor does only about one-fifth as much work for pound of Zinc. Zinc's much more expensive. Little likelihood that difference of that magnitude can be made up by sort of change of magnets, etc., he's been trying.

      ii) Notice, here, how close this origin is to Carnot's and note also that it gives both men from start the practical engineering unit of effect.

4. Carnot procedes straighforwardly, however, while Joule's direction suddenly changes late in 1840, apparently as result of discouragement.

   a) Probably still hoping for a breakthrough, he turns his attention from the motor to battery. Particularly to heat generated in battery and elsewhere.

      i) Again, ~~clue~~ change may be because of much prior work on reducing heat loses or friction in other machines, but that's far from clear.

   b) Rapidly comes up with $H = RI^2t$ law. He's not alone, but it's original with him and many learn it from him.

c) If they do, they learn the whole of it. He checks it for heat generated inside battery as well as in wire. For heat generated in electrolytic tank, and other elements in circuit. In whatever way

d) No way around it. Apparently amount of heat generated, like it or not, depends strictly on nature of battery and of circuit.

5. Which leads directly to next step, by: Can also get heat from reaction that occurs in battery without intervention of external circuit.

a) Joule tries to see how much. Elaborate experimental procedure leads to conclusion that he gets just the same amount by direct combustion reaction involving same chemical reactions.

b) Thus, Eraw, electricity is essentially a way to distribute the heat around circuit. Doesn't create it.

c) Or conversely, which is closer to Joule's view. Chemical heat is really electrical in origin. In chem reactions, too, it's electrical particles that pass and generate heat according to same law.

d) Thus exact balancing of chem & thermal effects. For us - special case of energy conservation

6. And now a strange thing happens.

a) Tries the same balancing of chemical and electrical heat effects with electrolytic tank in circuit, and is initially satisfied.

b) But numbers aren't as good as he's had elsewhere, and goes to work on this, and gradually realises he's not allowed for one effect.

i) Makes a difference whether gas is evolved or whether it stays bound in solid form or in solution.

ii) Mechanical condensation makes a difference.to heat relations.

5. And this seems to be the observation responsible for converting (though not quite right away) an electrical theory of heat into a theory about energy or mechanical effect. Draw

   a) Joule now (1843) puts motor back into circuit and does heat experiments again.

      i) Finds he gets less heat generated if motor does work and in proportion to amount of work that's done.

      ii) Or runs motor as generator and finds he gets more heat for given expenditure of chemicals in battery.

      iii) With same proportion again. Given mechanical effect is equiv to fixed amount of heat.

6. This puts the whole story in his hands, and I therefore won't follow it further.

   a) What Joule sees he has found is that given consumption of chemicals can produce heat directly, or produce electricity that will in turn produce all the heat, or produce electricity that will produce less heat but do equivalent work. Or can leave battery & chemicals out.

   b) Checks it out on other processes. Heat by condensation. Water through pistons. Same value.

   c) Finally, in 1847, designs famous paddle wheel apparatus that's in all physics books but that's got nothing to do with discovery. Only a way to get accurate values.

   d) But his contributions here are made.

III. HERMANN VON HELMOHOLTZ (1821-1894)

1. If Joule's work had been taken seriously when written, there would be little more to the story, for most of the others come later. Except Meyer.

7 a) But, in practice, very little attention is payed. This strikes at heart of accepted theory, and the experimental techniques involved also strain existing technique. INCOMPATIBLE WITH CARNOT Further problem. Ohm's Law.

i) Joule has great trouble getting Royal Society to accept any papers until after 1847.

b) This allows later figures to enter in essential ways, though even they don't have an easy time of it.

i) In particular, Hermann von Helmholtz, other main contributor, has to publish his paper on Conservation of Force (1847) privately

2. Joule appears to us as a man who starts on a narrowly practical problem with gigantic experimental ~~school~~ skill and gets led almost inadvertently to a metascientific principle of vast scope.

a) Helmholtz, in marked contrast, seems a man who starts with the metaphysical principle and then discovers how to use it.

b) By the time the two men are through, they've covered much the same ground, though never entirely. But they've covered it in almost opposite order.

c) To see just how far this goes need just a bit of Helmholtz's biogr.

3. Son of a moderately well-known highschool (Gymnasium) teacher of philology and philosophy.

   a) Father's actually a minor figure in Naturphil circles and friendly with some more important one. Naturphil. being the dominant phil. movement in German in early decades. Dominantly anti-scientific. Thought [illegible] some right ideas,

   b) Son on other hand shows marked mathematical and scientific leaning and simultaneously rebels against father's phil leanings.

      i) In the event he turns out to be a leader in the first or almost first group that deliberately and with explicit proclamation attempts to lead German science out of path of Naturphilosophie and belief in underlying organismic forces to a rigorous physics modelled still to a great extent on Newton's.and that of France.

      ii) Those who've read Ernest Jones' great biography of Freud may remember early discussion of impact of Brucke on Freud. Well, Ernst Brucke, Emil du Bois Reymond, Helholtz form almost a club together who vow to illustrate and defend a new movement in German science. This movement is what Freud, a gen. later, is raised.

   c) In general way it's a mechanistic movement, to be opposed to the organismic one previously dominant. Only ordinary phys & chem forces

      i) But if it's mechanist and thus Newtonian, it's a Newtonianism filtered through the philosophy of Kant. Despite [illegible] basic phil. stuff. Partially, and it's a good thing.

      ii) Both substance (matter) and cause (close to Force) are seen as inate categories imposed by the mind on appearances. They're subjects of a prior synthetic judgments.

iii) Substance is conserved. Force governed by inverse principle of adequate cause.

iii) This whole view provides principles of unification as well as problem structure that runs through much of H's research.

4. That's ahead of my story, however.

a) Helmholtz wants to do math physics, but family hasn't the money for requisite education and signs him up for medicine. Army training. Does his further math and physics reading on the side, but does it magnificently.

b) Rapidly rises to prominence and joins research laboratory of leading German physiologist, Johannes Müller. Here joins Brücke & De Bois Reym

i) Müller, too, is a leading exponent of new German scientist. With Chemist Liebig, he's real pioneer of German experimental scient.

ii) But he's also something of a vitalist. Man who believes in special non-phyisco-chemico forces at work in living organisms.

c) This is point where he breaks with his three juniors. Much of their early research is directed to proving him wrong on this.

i) Helmholtz's, in particular, is concerned with problem of animal heat, ~~about which you'll be reading after vacation~~. Old problem shift is dus pute.

ii) Wants to show it can all be accounted for in terms of chemical effects involving ingested foods. (Notice tie to Joule and heat in battery.) Not an original viewpoint but one he pursues with particular conviction.

iii) Own more special research involves heat generated in muscles and also electrical stimulation of them for action. Thus electr

5. In these researches the general insistence on balancing cause and effect is altogether clear as is H's insistence on physico-chemical explanation.

   a) But it's only heat, whose conservation is actually dealt with, and it's still less than altogether clear what generalizes the conservation notion from heat and chem effects to motion, electricity, and so on.

      i) One hint in 1845 paper on muscular heat is that he's been impressed by parallels between radiant heat and light. Thinks radiant heat must be oscillations in a medium, thus mechanically generatable, e.g., by friction.

      ii) This, in any case, is the view that he now goes to work on attempting to deduce it for all physical phenomena from first principles.

6. This is program of famous 1847 paper. On the Conservation of Force

   a) Opens with principles. Science views external world through two basic abstractions, matter and force, neither seen separately.

      i) Matter with permanent properties in primitive form is chem elements.

      ii) All change, dynamism, is due to forces between them and these forces must act along line of centers. Sufficient reason.

      iii) All science is reducible to deductions from this, given force law.

Formula by Bayer & Weber.

7. Basically, of course, it's just the Newtonian program but now rather differently set up and emphasized. Forces on exhibits & Their use right.

a) The similarity, however, is such that from this point on Helmholtz's paper actually reads in structure and argument like an intermediate level physics book.

i) Not to his discredit. Nothing's read this way before. It's brilliant and new.

ii) But too familiar for much discussion. Will only sketch.

b) Starts in mechanics. No perpetual motion. Results in $mgh = \frac{1}{2}mv^2$.

Force a power to force & work.

i) Recognizes left hand side as measure for machine and refers to work of Carnot and its success.

$\bar{F} \cdot f(r)$

c) ii) Also more elaborate version for general central forces.

c) So far it's old stuff except for motivating drive and even that can be found in eighteenth century among Leibniz's successors. But he now goes on to apply it areas not available to Leibnitz et al.

i) Electricity, STATIC. Work bringing charge up to where it exists seen as storage of energy, like work done against gravity above.

ii) Ditto for magnetism.

iii) And ditto for electric current, battery generation, with heat, etc. Substantially arguments used by Joule but now in reverse order.

iv) Also treatment of heat itself. Joule's own experiments and some

others as well.

v) Curious problem here. H uses some of J's results. In afew cases in essential ways. But doesn't seem to recognize how much of what he, Helmholtz, is saying is already in Joule.

vi) May well be just that whole attitude of two is so different that in this material they talk somewhat through each other.

vii) Finally c.w. reduction.

d) In any case, Helmholtz has done the job. Traced energy through a number of cycles and showed that it's basic measure is either work or kinetic energy.

i) Again we're back where Joule left us.

III. RECONCILIATION WITH CARNOT

1. Only, as most of you realize, it's not where Carnot left us.

a) In fact, there's a fundamental incompatibility between development discussed last time and one discussed this time.

DRAW

b) Engine cycle from last lecture returned all heat to the high temp. reservoir and did work. Now we say that if work is done, then heat has been consumed.

c) The no-perpetual-motion argument basic to Carnot's discussion now becomes impossible.

2. This incompatibility has been recognized before and has bothered a number of people.

a) Carnot's posthumous notes.

LAST TWO CARDS GO TO

NEXT LECTURE.

CHALK.

THERMODYNAMICS III. Second Law

I. CARNOT'S THEOREM AND ~~PERFECT HEAT ENGINE~~ & ITS CONSEQUENCES

II. RECONCILIATION WITH FIRST LAW

Wm. Thomson, Lord Kelvin, 1824-1907

Rudolph Clausius, 1822-1888

III. Further Consequences

Dependent subscripts
See me afterclass.

HISTORY 336 -- Lecture 17

The Second Law

I. RECEPTION OF FIRST LAW

1. Suggested in last lecture that Joule and Helmholtz start from very different positions but converge to a common conclusion: they learn to measure a parameter, energy, which can appear in mechanical, chemical, electrical, magnetic, and many other forms, but which is conserved in all transformations.

   a) In the case of Helmholtz my discussion was somewhat truncated by the clock, but I propose to let that go by.

   b) Do, however, want to add just a word about my last topic which was reception of the idea of energy conservation.

      i) If I'm right about it, it's symptomatic of what's been a major theme in the course. One that is capped by development of Thermo.

2. Mentioned last time that no one payed much attention to Joule's theory.

   a) Essentially developed by 1843, but it's not until 1847 that it gets any atttention, and then just from one man. Wm. Thomson, who doesn't believe it.

   b) Mayer, J's predecessor, gets same treatment. Totally unrecognized until after energy conservation has been accepted.

   c) Even Helmholtz has to have his brilliant paper privately published.

      i) It does pick up some adherents from the start, but it's still a slow procedure.

Question is why?

B. ~~And, in the first instance, with somewhat the same results.~~

~~a) Inattention and resistance. Private publication.~~

b) One reason already suggested: Have to reject caloric theory.

i) But that can't be whole story. View that heat is motion was dominant in 17th century and important in 18th. Never entirely lost.

b) Both in ~~this~~ Helmholtz's case and in Joule's, I think there's another reason of a more methodological or ideological sort.

i) Conservation of energy provides mathematical interconnections between mechanics, on the one hand, and a lot of Baconian sciences. In a sense this is higher level theoretical expression of m.

ii) Seeing these a single subject matter to which ~~same~~ math is applicable is a brand new 19th-century phenomenon.

iii) And until middle of century merger has been primarily a French achievement. Little or none of it in England and only a bit more in Germany. Even where it existed they stayed separate fields.

iv) Kelvin, who is Joule's first important British supporter -- and also the man who went from math at Cambridge to Paris for expt. work,-- is first generation of the more general mathematical physics, and his models are French.

v) Helmholtz and his contemporaries are very first German generation

c) For many others this is just not a way to do science in subject matte

1847's in both cases.

of heat, electricity, and so on.

d) I said earlier that physics was a product of the nineteenth-century. Put some pressure a bit differently. Results from a merger of previously separate fields.

   i) Add now that one thing which helps promote the merger, give it important intellectual underpinnings is exactly the development of energy conservation.

   ii) And that, conversely, the incompleteness of the merger at mid-century, is one of the things that makes energy conservation quite so hard to sell.

e) Not sure how to date acceptance -- more and more widely accepted from the 1850's on.

   i) But it's accepted principally by the younger generation.

   ii) And they're a new group not only by virtue of accepting the theory but also by their adherence to the conception of physical science which goes with it.

II. THE SECOND LAW

1. Just how powerful and deep this new unification of fields is I can illustrate better by talking now of the Second Law.

   a) This grows directly out of, but is not quite equivalent to, the generalizations Sadi Carnot has arrived at from his study of the ideal heat engine. Want now to summarize essentials of Carnot's discussion

   b) Described its elements before Draw. High Temp reservoir (boiler), Low Temp reservoir (condenser), and piston and cylinder. IDEAL GAS.

   c) Now want to follow through the essentials of his analysis, much of it also given in your reading. Newto many of you, but this I think you can follow.

2. The Cycle. Draw, four stages.

   a) Two adiabatic, two isolthermal legs. Graph.

   b) Just as in Watt indicator diagram, total work done, is area.

      i) Analyse little slice, pdv = pAdl. Ditto for whole argument.

3. This is Carnot's ideal heat engine. It takes Q from T_1 to T_2 and does work W.

   a) About it Carnot enunciates the following theorem, and it's here that the heart of his originality lies.

      i) There cannot, in principle, be any better engine than this, one that would do ~~the same~~ more work for same heat transported.

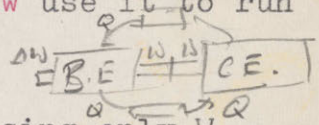
   b) Argument for this goes in two steps.

c) This engine has the special property of being reversible.

i) Can drive it backwards, doing W and raising Q from the T_2 to T_1.

Refrigerator. Heat pump.

d) Therefore, if there were a better engine, could Draw use it to run Carnot engine.



i) It would doework W + ΔW and bring heat Q down.

ii) Carnot engine would raise heat back up again, using only W.

iii) W would be left to raise weight.

iv) Thus a perpetual motion machine.

e) An exactly similar argument leads to a corrolary. Any other reversibl engine will be just as good.

4. These are extremely powerful theorems all by themselves.

a) For example, by comparing two different engines in one of which volume goes from V to V' and in other from U to U', can show that amount of heat depends only ratio, and in fact on Log(V/V').

for ideal gas

i) A number of other theorems for gases.

Implied from conserv. of energy, but also with th

Rel. between Cp & Cv.

b) Or can put other things in piston, for example, liquid in equalibrium with vapor.

i) Then can derive, as Carnot's first successor does, a law relating the variation of the boiling point with temp. to the latent heat of vaporization.

c) Or can show that melting point of ice must become lower with increasing pressure.

i) This was particularly important historically, for no one had recognized it before.

ii) Wm Thomson and his brother start by thinking an ice-water engine will violate Carnot's principle, discover that mistake is in failing to recognize lowering of freezing point.

iii) Thus permit explanation of a number of longstanding puzzles, particularly glacial flow.

iv) other things of this sort.

d) When I said that Carnot didn't help steam engines but introduced principles of vast importance to science, this is sort of thing I had in mind.

5. But the most potent consequences come only after Carnot's principle is combined with energy conservation, first Law of thermodynamics.

a) And that's not easy for the two are incompatible.

i) If heat is actually transformed to work as Joule and Helmholtz claim, then don't get the same amount into low temp reservoir that came out of high temp.

ii) At that point, as well see, the whole argument about effect of a better engine breaks down for no longer results in perpetual motion.

b) Result is that for small number of people who know of Carnot's work (it's again privately printed and largely unknown), the very notion of energy conservation makes all sorts of difficulties.

c) Among these people is Carnot himself.

i) ~~Late in life~~ After 1824 publicshn, he's convinced himself that heat must be motion and that conservation applied to it.

ii) Left notebooks declaring that he saw no way to preserve his earlier results. No influence because unknown.

d) Same difficulty applies to William Thomson in historically more important way.

i) He's found Carnot's results immensely useful and has been developing them further before his contact with Joule. Ice engine. Absolute temp scale

ii) From 1847 when he meets Joule and begins long discussions with him until 1851 he continues sceptical -- Developes Carnot but is increasingly impressed with Joule and increasingly worried what to do about conflict.

iii) Reading successive papers in which he developes Carnot principles find longer and longer footnotes worrying about the problems which Joule raises for the basic mode of analysis.

d) Not until 1851 does he see how to have the best of both worlds, and then he ~~xxx~~ is barely anticipated by the German Clausius.

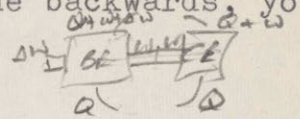
6. Their arguments are rather similar, and I'll give them in a form parallel ing treatment of Carnot. Scale engines to deliver same heat to condenser.

a) Draw. Carnot engine takes Q, does W and delivers Q-W. +W W/J

Better engine takes Q+W+ΔW does W+ΔW and delivers Q

b) If now you use better engine to drive Carnot engine backwards, you:

i) ~~Return all heat to high~~ Maintain temp of low temp reservoir.



ii) Do net work ΔW.

iii) Cool ~~low~~ high temp reservoir. Less heat reaches it from ~~exhaust of better engine~~ Carnot eng. than is ~~delivered~~ absorbed by ~~Carnot~~ better engine.

iv) In fact, just enough less so that net work done is equal to heat abstracted from low temp reservoir.

c) That's why perpetual motion argument no longer applies. It's not perpetual. World is disturbed.

d) What Clausius and Kelvin both realize in 1850-51 is that one can preserve Carnot's argument if one enunciates a new restriction, one which forbids what's often called Perpetual motion of the second kind.

i) Put in various forms of which I give you just one.

ii) Can't build a heat engine which does work and has no effect except cooling a boiler. Must always have both a boiler and a condenser. Can't convert all the heat taken from boiler into work. Engine at North Pole.

e) Then, preserve most, though not quite all, of Carnot's results.

III. FURTHER CONSEQUENCES

1. Said before that Carnot's work becomes fully consequential only in this reformed version in which it's merged with First Law.
   a) That's true in three senses.
   b) First is simply an extension of the range of the sorts of arguements I've already given.
      i) Energy conservation applies not only to heat and work, but also to chemical, electrical, optical and other phenomena.
      ii) In consequence it becomes possible to apply the revised Carnot analysis to this much enlarged range of effects.
      iii) To one of these, light or electromagnetic radiation, I'll be coming back for it's essential to Planck's work and the origins of the quantum theory.
      iv) But there are also major application to chemistry and others to electrical phenoma and others as well.
2. Another consequence is one I've already mentioned and can only repeat now, though it should now have more meaning.
   a) Whether you've fully followed the technical argument today or not, you should see sense in which arguments follow from a small number of very simple principles about way in which nature can behave.
   b) More than any other part of science, this one comes back to looking like plane geometry. Powerful deductions from postulates.
      i) Thus many people feel that that thermodynamics is the most funda-

mental sort of science, and there are important attempts during the last part of the 19th century to build all other sciences in its image, using its concepts.

ii) It's a development I'll not follow, but both in Planck and Einstein you'll get a taste of its most remarkable consequences.

3. Final effect is cosmological in a form that ultimately gets into much discussion of philosophy, history, theology.

a) Application of second law to universe as a whole.

b) Before discovery of radioactivity, all known forms of natural change derive ultimately from exchange of energy between hot bodies and colder ones.

i) Thus, sun and earth yields plant life consumed by animals or burned after transformation into coal. other energy sources.

ii) Or raises water which forms clouds, drops water, turns wheels and so on.

c) But according to the Second Law any energy transformation of this sort must not only take heat from hot body, but deliver some of it to cooler one. Can't transform it all.

d) So earth must gradually heat up, sun cool down.

e) Ultimately all at same temperature.

i) No energy has been lost, but it's not longer accessible. Degraded

ii) That's the famous heat death. Still far off. But you can imagine

KINETIC THEORY OF HEAT AND GASES

I. THERMODYNAMICS AS NEWTONIAN TRIUMPH

II. HEAT AS MOTION -- THE PROBLEM OF TIMING

Benjamin Thompson, Count Rumford, 1753-1814

III. GAS THEORY AND STATISTICAL MECHANICS

A. K. Krönig, 1822-1879
Clausius
J. C. Maxwell, 1831-1879
Ludwig Boltzmann, 1844-1906.

HISTORY 336 -- Lecture 18

Kinetic Theory of Heat & Gases

I. INTRODUCTION

1. Subject matter of thermodynamics, discussed in last three lectures, is widely viewed, though not universally, as a triumph for a generally Newtonian view of the Universe.

   a) Particularly true for the 1st Law as developed by both Helmholtz and Joule.

      i) Both see conservation of energy as an expression of the fact that the world is composed of particles which interact under the influence of forces along the line of centers and depend only on distance.

      ii) Helmholtz adopts this view from the beginning, Joule backs into it -- in fact it's perhaps only in Kelvin's reformulation that one can say Joule has it.

      iii) On this view, involving a universe of particles and central forces, simply expresses the wider applicability of what had once been a purely mechanical conservation theorem:

      iv) $\frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2 + \frac{1}{2}m_3v_3^2 + V(r_{12}, r_{13}, r_{23}, \ldots) = E$. Where chemical, electrical, gravitational, and other such forces are all in V.

   b) Only two problems;

      i) What's heat if not a special fluid, and that's solved at once.

      ii) What mechanical theorem will replace the second law, and that's

This is good, but ---

I needed two more minutes.

Not sure whether it must be cut or just said more quickly

solved before end of dentury.

c) Don't suggest this is the only interpretation. We'll run briefly into another ~~before~~ at the end of the hour, and it's important too.

i) But thermodynamics is widely seen as one more vindication of Newtonianism.

ii) And it's with the completion of that triumph that I want to deal this morning.

iii) Warning you, however, that it's the last great triumph.

iv) Already by mid-century troubles are accumulating.

v) In four lectures remaining after this one, I'm going to deal with some of them, introducing at least a few aspects of the transformation in physical world view that introduces this century.

II. KINETIC THEORY OF HEAT

1. Said the first problem on Newtonian view of thermodynamics is question what is heat.

a) But to this the answer is obvious. Joule gives, Helmholtz gives it, Kelvin gives it.

i) Heat is motion of particles of body. More precisely:

ii) Temp = average kinetic energy of particles.

iii) When hotter body is put in contact with cooler body, some of energy is transmitted by impact from hotter to slower. Faster particles spped up slower. & loose energy in process.

iv) Energy input is shared between kinetic energy and potential energy. (Point to old formula).

b) This view of heat is not everywhere accepted at once, even among those who believe in energy conservation.

i) But from the mid-1850's on, it's more and more widely believed.

ii) Also, particularly for gases, it get more and more consequentially developed.

2. Shortly want to pursue that further development, but first a puzzle.

a) Each of the energy-conservationists who announces that heat is motion points back to an important predecessor or group of predecessors who have held the same view.

i) Some earlier in 19th century, some in 18th, many in 17th. It's really been standard during much of period from 1650 to 1770.

ii) And it's been accompanied by evidence, particularly generation of heat by friction and by percussion.

iii) Won't even list names, but give you one example.

iv) When Kelvin publishes in 1851 his paper on dynamical theory of heat, the paper which reconciles Joule and Carnot, he opens is saying: Half a century ago Count Rumford proved that heat motion. I'm now going to develop consequences mechanically.

iv) This from man who's been using caloric theory for years, been sceptical of Joule, developing Carnot. odd, but not atypical.
Remember Count of Invisibility of Rds.

b) Puzzle then is, why so late in arriving? It's been widely held, often mentioned in the books, Kelvin can even persuade himself it was proved before his birth.

i) Mechanics to develop it was there.

ii) What's been holding it up?

3. Two main answers, I think, of which first is simply that caloric theory was, in fact, a vastly more powerful theory than we now remember.

a) As with phlogiston theory, we forget everything about it except places it got in trouble and assume these to be obvious.

b) Have already illustrated power in showing how Laplace and Poisson derive gas laws, including those for adiabatic heating and cooling, from it. Carnot's work is further example.

c) Reinforce the point and set up next one by dispelling a bit of the myth that surrounds Rumford, for it says something about the actual difficulties in unseating a theory as well as illustrating something about the sorts of experiments which, after the event, after the revolution, get described as crucial.

4. For reasons I won't now go into Count Rumford (1753-1814) is persuaded early in scientific career that heat is motion.

a) Performs many experiments to document his view of which most effective and one that's known as crucial is the cannon borring experiment he performs in 1798 and immediately reads to the Royal Society.

Royal Society.

i) Most of you know it. Bavarian arsenal. Horses turn cannon which is pushed against drill.

ii) He insulates both drill and cannon. Measures heat generated. Great quantities, and it goes on and on. Says he can get as much as he wants.

No way for it to get in.

iii) But there's not that much caloric. /~~xxxxxxxxxxxxxxxxxxxxxxxx~~
Heat must be motion.

3. It's an impressive experiment, and it does convert a few people. With others it leaves a lingering malaise.

a) But it is also promptly answered by the proponents of the caloric theory, a theory whose greatest days are still to come.

i) This episode could as appropriately be called the last gasp of the old mode-of-motion theories ~~and~~ as the beginning of kinetic theory.

b) What are the nature of the answers? Again a great many of which I'll here give only two.

c) First is simply elaboration of the usual explanation for generation of heat by friction.

i) Rub hands or stick together. Why do they get hot. You're rubbing skin or wood off and caloric with it. Squeezing ~~them~~ it out.

ii) Rumford says, but in this case can get infinite amount out if I keep turning.

iii) Answer -- that's absurd, you're using up the cannon. He gathers chips, and says could reform cannon. They say not without heating and putting caloric back.

d) That's a stand off on verbal grounds alone. But not everyone is willing to proceed without also checking the work.

i) One result is a particularly good experiment done by a group headed by the French chemist Berthollet. Heat by percussion.

ii) Borrow minting machine. Hit slugs of various metals. Measure heat generated in each blow. Also extent of the compression.

iii) Find most heating in softest metals. Also most heating on first stroke when compression is least.

iv) Just what one would expect on basis of caloric theory.

v) I suggest that this is often the way experiments behave in the sciences, at least when you've a good theory.

STET

III. KINETIC THEORY ~~WITHOUT STATISTICS~~.

1. So Rumford does not disprove the caloric theory or prove that heat is motion.

a) On the other hand he does help to keep the issue alive and preserve an awareness of alternatives. And this proves to be quite important.

6. All this suggests that the best you can possibly get from arguments like Rumford's is a stand-off.

   a) In practice, want to suggest that there's a reason you don't get even that. It's my second reason for delay.

   b) As those of you know who have taken any sort of elementary physics course, as soon as one turns to kinetic theory of heat one takes up gases as example.

      i) Samething is true historically. It's only in the case of gases that you get powerful quantitative results from it in early days. No P.V. energy flow.

      ii) All early development is here.

   c) But it demands a particular model. Small particles, taking up a minute fraction of total volume. Flying rapidly through each other.

   d) But almost no one has been thinking of gases in that way, even the people who believe that heat is motion.

      i) Particles of gas are space filling. 17th Century. Large a porous, like cotton balls. Gas is regarded what

      ii) Laplace and Lavoisier model. Similar ones with repulsive forces.

      iii) Those who say heat is motion talk of vibration in place or of ~~repulsion~~ ROTATION. Never of flying though each other until they collide with walls of container.

      iv) And with that view one does not get very far.

III. KINETIC THEORY OF GASES

1. Under these circumstances it should be no surprise that kinetic theory becomes consequential only with energy conservation.

   a) Now you have to give up caloric theory.

   b) What you're left with is simply the tiny massive cores about which caloric has accreted.

      i) The things which get packed together in solids and liquids but which must be way way apart in gases.

      ii) At least that's what you get after Lavoisier who has made gases into a phase of matter and indicated that same atoms must exist close together in solid and liquid that exist far apart in gases.

2. Thus, despite anticipations, it's really only in the 1850's that you get either a receptive audience or a powerful theory.

   a) Then it comes fast and from a number of people independently.

      i) Another famous case of simultaneous discovery.

      b) I propose to ignore that aspect of it entirely and pick up an outline with the first man who gets taken at all seriously.

      c) He's A.K. Krönig, 1822-1879), a Professor at the Techn. Highschool at Berlin. 1856

         i) In practice, does nothing that hasn't been done better before.

         ii) But conservation is now being accepted and he has prior rep.

3. His derivation Draw assumes particles divided into three groups each travelling parallel to one edge of box -- no collisions. Same Vel.

   a) Gets well-known result (though without correct numerical factor)

   $pV = \frac{1}{3} n m v^2 = \frac{2}{3} n (\text{av. k.e.}) = cT$. Thus Boyle's and Charles' Law.

   b) His paper his quickly followed in 1857 and 1859 by papers of Clausius' which do go further.

      i) Apparently C has been working on subject for some time but has heen holding off on publication so that his gas theory (which is bound to look speculative) won't get associated with his views on thermodynamics.

   c) Clausius from start allows for particles impinging on walls from any angle and averages.

   d) Computes specific heats, and then considers particles composed of two, three, etc., particles which can have energy of rotation as well as of translation. Shows how specific heat varies.

   e) Introduces concept of mean free path, average distance btwn collis, to explain why diffusion is slow.

   f) Generally, most elements of elementary kinetic theory of gases are in these two papers.

4. But as most of you know, there is still one important set of elements missing, and its these that give the new view its particular power and importance.

a) Call it introduction of mathematical statistics -- development of STATISTICAL MECHANICS.

i) For some time it's largely the work of J. C. Maxwell, 1831-1879, who publishes on subject from 1860, with particularly impt paper in 1866.

ii) And of also of Austrian Ludwig Boltzmann, 1844-1906, whose work on problem begins to appear in same year, 1866, after which the two interact in quite fruitful ways.

b) Unfortunately, from this point, development gets too mathematical to follow here.

i) Am giving a seminar on subject next fall, and all ~~of it~~ soumthr will be needed, as well good training in math and physics.

ii) Content myself here with a few broad generalizations and simplified illustrations.

5. First of which is perhaps the most important,

a) Statistics has a long history before 1860, but it's scarcely at all in physics.

i) Theory of games -- cards and dice -- from 16th century into 19th.

ii) From early 19th century it's also developing as theory of errors. Gauss' problem and astronomical development.

iii) And important applications to social statistics and economics. Actually it's this line of development from which Maxwell seems most likely to have taken off.

b) But nothing in physics, and the result of introducing it is again a revolution that is, in many circles, hotly resisted.

i) Among those who resist in is Planck, and we'll see what brings about his conversion in a couple of lectures.

6. Now try to illustrate simplistically the sorts of novelties introduced with it, first by Maxwell and then by Boltzmann.

a) You all know that purely abstract premises, can show that chances of a die turning up, say, 2 is 1/6. Die has six sides.

i) And similarly to show from symmetry considerations that chances of throwing a seven with two dice is 1/6.

b) Maxwell applies same sorts of considerations to moving molecules in a gas.

i) In 1860 show, though derivation is imperfect, that probability of finding molecule with vel in range $v \rightarrow v+dv$ is proportional to $\exp(- v^2)$. Draw.

c) Now properties like temp and pressure depend only on average vel and spec ht and one can treat them fully on the simplification that all particles have same vel as previous figures have done.

i) But a number of other properties depend on prop of molecules with different velocities -- among them gaseous diffusion and viscosity

ii) It's these that Maxwell develops, with accompanying expts in 1866 and theory begins to show real power.

iii) Impressive surprises. Viscosity indep of pressure. Theory & Expt

7. Boltzmann continues this line of work from 1866, and is able to generalize on an improve many of Maxwell's derivations and hypotheses.

   a) But he also manages to resolve a problem that Maxwell's worried about without much success, and in process finds answer to other missing piece of Newtonian thermo. Mech expl of Second Law.

   b) His argument is mathematical and force depends on it. I'll give qualitative version.

      i) Draw. Vertical box with horizontal diaphram. All particles in bottom half. Remove diaphram.

      ii) It's possible that particles all stay in bottom for, say one minute, but extremely unlikely. Can compute probability.

      iii) But more likely, vastly, they move up and distribute themselves approximately uniformly.

   c) Can do same computation if we have a piston, though now pressure on it, or its weight, must be taken into account.

      i) Once the piston has been pushed out, then IN ALL PROBABILITY will have uniformly distributed particles moving with smaller vel in larger volume.

      ii) It's for these that one must introduce a condenser to complete the stroke, or else, as in steam engine, get rid of them and start again.

   d) Or at least that's the overwhelmingly most likely situation.

8. But it's not in principle the only conceivable one. Could have all molecules moving at such speeds that they'd stop dead on impact. Give up all their energy of motion.

   a) Then you wouldn't need a low temp reservoir. Would have converted all the heat from boiler into work. Would have violated the second law.

      i) Only, it's not worth waiting around until this highly improbable event occurs. Chances of tossing 1000 heads in a row are vastly larger. or 1 in 1.07

   b) That, says Boltzmann, is what the 2nd Law is about. It's a mechanical one, but statistical.

   c) Gigantic achievement, but also immensely controversial one.

      i) What many physicists have most admired about thermo is it's absolute nature.

      ii) The notion that 2nd Law is merely statistical, could be violated, and thus quite unlike the first is anathema.

      iii) These people come particularly from the group that has always thought these detailed hypothetical atom models far too speculative and has viewed thermo not as microscopic Newtonianism but as a field which permits the elimination of such hypothetical entities (including forces).

   d) Result in a battle in which one participant is Planck. We'll see the edges of it a week from today.

~~The Birth of Field Faraday~~

Birth of Field Theory

I. The Problem of Electromagnetic Induction, 1831
   Michael Faraday, 1791-1867

II. The Newtonian Solution
   Wilhelm Weber, 1804-90

III. Faraday's solution
   The Electronic State
   Polarization as the Clue
   The abandonment of atoms:

IV. ~~Xxxxx~~ Consequences for Maxwell.

10:40 - 11:30

HISTORY 336 -- Lecture 19

Origins of Field Theory

I. INTRODUCTION

1. When introducing kinetic theory in my last lecture, described it as the last great triumph of a generally Newtonian approach to physics.

   a) Suggested to you that, simultaneously, troubles for that long enduring approach were showing up elsewhere.

   b) And indicated that a description of some of those troubles and of some of the resulting transformations of science would be my subject matter for the balance of the course.

   c) First of those is my subject this morning, development of field theory.

      i) Begins to be important only after middle of nineteenth century and has spread gradually through more and more of physics since.

      ii) I shall be discussing on the electromagnetic field, which is the nineteenth century triumph.

      iii) In the twentieth one speaks also of gravitational fields, meson fields, particle fields in general.

2. Past experience with this subject matter suggests that I had better start by saying something about what a field theory is.

   a) What follows is not quite a definition, nor does it entirely match current usage, but it should indicate what's novel, indeed revolutionary, about a transition to field theoretical approach.

b) Start by point out that field theories are theories of interaction between bodies at a distance.

i) And by contrasting it with two most prevalent classical modes of interaction from which it differs.

c) First of these is actual transport of matter from body to body.

i) Thus, corpuscular theory of light and caloric theory of heat in which particles actually are emitted by one body and received by the other.

d) Second is interation via action at a distance.

i) Thus gravity or the electrical interactions of Coulomb, Ampère, and Weber.

ii) These are like pushes or pulls on two ends of a rigid rod, except that the rod isn't there.

iii) That is, it's an instantaneous interaction, depending only on the instantaneous presence of both bodies.

iv) Furthermore, it's a mutual interaction. There's no sense in which one body is the source of the disturbance, the other the recipient. There's full symmetry between the two.

e) Field theoretic interactions contrast with both of these.

i) As with material interactions, one body does generate a disturbance, the field, which is propagated <u>in time</u> from neighboring area to neighboring area.

ii) On the other hand, there is no transport of matter. One speaks for a time of waves or of stresses and strains in the intervening medium. Nothing except a disturbance of what was there all along is transmitted.

iii) And finally one recognized, though not until twentieth century, that space itself is all that has to be there.

f) In this sense, then, the wave theory of sound, common since 17th cent. was always a field theory. Propagation of pressure wave, not of matter.

g) i) But not a troublesome one, for the medium was there -- air -- and known to have the necessary characteristics.

g) By same token, wave theory of light, about which you read in Prof. Gillispie's book, is a field theory.

i) And this time a more troublesome one, because the properties of medium able to support light waves but not slow down the planets seemed paradoxical from the start.

ii) But these difficulties were local, existing only for optics at the middle of the nineteenth century.

iii) It's only with the displacement of Newtonian interactions from electricity in favor of fields, and then with the recognition that light is itself a special case of electrical field interactions, that the difficulties begin to infect large parts of physics, ultimately undermining the foundations of even Newtonian mechanics.

II. THE PROBLEM OF INDUCTION

1. Leaving aside the question of its long-term roots, the beginning of this more consequential sort of field theory dates, I think, from Michael Faraday's discovery of electromagnetic induction in 1831.

   a) You all know the phenomenon, which we've in any case discussed earlier:

      i) Moving coil with current, or moving magnet, or stationary coil with varying current will all induce a current in a nearby coil.

   b) Also, I think you'll remember why this discovery creates special problems.

      i) It's a third sort of electrical interaction, different either from Coulomb's interaction between charges or Ampère's between currents.

      ii) And there's no way apparent to account for it in terms of either of the others.

      iii) From the start it is an extremely puzzling bit of behavior on the part of nature.

2. One way of dealing with the resulting problem I discussed earlier when dealing with the development of Newtonian electrical theory.

   a) Due particularly to Wilhelm Weber, it takes current to be moving charged particles, and then makes force between charges depend on speed as well as distance.

      i) Though it strains Newtonianism (for example, conservation of energy doesn't apply), it does reconcile three ranges of effects

ii) It's a very powerful approach, brilliantly developed.

2. But it's not the only approach, and it's not the only taken, in particular, by Faraday, the discoverer of the effect.

a) He's another one of the famous and creative self-educated scientists, like Dalton, Davey, and Joule, who are to be found in Briatin in early 19th century, disappearing thereafter.

i) Furthermore, his early scientific interest and work has been primarily in chemistry, much of it under Davey.

ii) This is the field from which he draws his models.

b) Had he been well-trained, at the Ecole polytechnique, for instance, developments might have been very different.

i) One of his reasons for rejecting the more usual approaches is simply that he lacks the mathematics to understand them.

ii) There is, for example, one point in his career when he claims to have refuted the Coulomb-Poisson theory of Newtonian interactions though, in fact, he's dealing with just the effects that the theory had been designed to explain.

c) Not surprisingly the appraach doesn't fit well with the learned of the day.

i) But few succeed in ignoring it entirely, for Faraday piles up one remarkable discovery after another guided by his way of thinking about electricity.

ii) Particularly after discovery, 1845, of changing polarization of

light by magnetic field, a number of people come to feel that they must try to make sense out of the way Faraday goes at this whole subject matter.

III. FARADAY'S APPROACH

1. Can give you here only a very schematic view of Faraday's route to field theory.

   a) It's in any case a tortuous route, and Faraday's writings are long, often obscure, and not entirely consistent.

   b) Nevertheless, the schematic approach is itself revealing.

2. Start by considering Faraday's analysis of current induced in one wire by the building up or falling off of current in another parallel to it

   a) From the start F insists that current in one wire must put other into a special state -- electrotonic state -- or else can't understand why current should be produced in second when size of current in first changes. (Explain)

   b) Furthermore, at least for a time, Faraday has clear idea about what this state must be like. Uses ideas that he's gotten as an apprentice of Davey's at a time when both were working on electrochemistry.

i) Davy's theory of battery and electrolyte. Draw chain of polarized molecules. One at center breaks up. Chain of combinations and recombinations.

ii) Application to wire. But no decomposition. Surge of charge when state is produced and relaxed is what produces induced current.

iii) This notion of a current from polarization is, incidentally, the one which will appear in Maxwell as "displacement current." He'll insist it be treated as real current to which Ampère's law and other apply, and result is real misunderstanding.

iv) But idea is already here.

c) Faraday, however, has obvious trouble with it. Can't explain why these charges don't break up and flow in conductor. Suggests that with a battery in circuit they do get pushed past each other. Supposes

i) But can never make this fully consistent.

ii) Does drop the details of this approach. But also preserves the fundamental direction and mode of thought. It's key.

3. This part of work was done in 1831-33 immediately after discovery of induction.

a) From it Faraday turns to electrochemistry again, apparently in a particular effort to discover difference between polarization effects and conduction effects. Solids vs liquids

i) These are leading and suggestive but I shan't try to follow them.

ii) Instead jumpto the conclusion with which F emerges in 1837-38.

b) This is an attempt at a full electrical theory based on the polarization effects we've just considered.

i) Show you just one of the arguments that's involved to show you how important it is that Faraday not be able to follow mathematics

ii) He considers the following case, long ago treated in detail by Coulomb and then Poisson on basis of action at a distance. Draw two balls, charge on one. Picks up induced charge on other side even if he touches it over the arch..



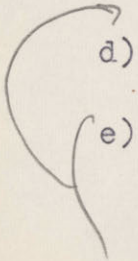
iii) Says because of intervening metal, action can't be in straight line. It's not Newtonian action at a distance. Dead wall.

c) Instead action occurs only between contiguous particles.

i) Imagine (draw) whole intervening realm filled with polarized molecules.

ii) And then take with F the following two immensely consequential steps.

d) First, assimilate the surface charge on the sphere to the medium. For Faraday from this point there's no such thing as free charge.



e) And imagine the transmission of this situation from one boundary of the medium to the other. A sort of pressure wave effect, startted by polarization at one edge and transmitted from particle to particle all along.

4. That is Faraday's view in 1837-38, and it leaves just one more essential step to go.

   a) Not explicit until 1844 but probably arrived at sooner. In describing it, I'll actually have to ~~distort~~ make Faraday clearer than he was and also somewhat distort the detail of his conclusion.

   b) There is one gross trouble with view just enunciated. Because there is space between these particles we are still left with action at a distance.

      i) Faraday tries various remedies but finds paradox after paradox.

      ii) Finally, and perhaps reluctantly, abandons the idea of atoms and molecules altogether, or at least he abandons the common view.

      iii) And replaces it with the notion that these polarization effects with which he's dealing actually take place in a continuous medium whether that medium is matter or is space filled with mere aether.

   c) It is from this point on that he begins to follow the notion that's also been used by Kelvin of treating electrical repulsions and attractions as due to something like stresses and strains in a continuous medium.

      i) Lines of force, which he's always before said are just metaphoric, now become for him quite real.

ii) He knows how they behave. Stretched rubber bands that mutually repel and other similar remarks about them.

iii) And it's this way of looking at the situation that he carries into his further investigations which include both the rotation of plane of polarization of light and the discovery of diamagnetism in which his theoretic views play an active role.

5. It is these successes which prove so persuasive to other and which finally leads Maxwell to attempt to make a coherent and mathematical theory formulation of Faraday's views.

a) This is the effort pursued in three very consequential papers published in 1856, '61, and '64, and then elaborated in Treatise on Electricity and Magnetism, 1873,

i) Clearly I have no intention of trying to follow those through here, too, except to the extent that they're discussed in the reading and may arise in precept.

ii) But I do want to make a series of assertions about the theory which results, for they have something important to do with the direction in which physics goes as the theory is accepted.

b) In the final formulation of the theory the process started by Faraday has been completed. Though it's far from clear what the nature of the medium can be, this is a continuum theory.

i) There is no action at a distance across space. All disturbances are propagated. Energy which is first in the source of the electrical disturbance can be traced into the medium, through

space and to the recipient of the effect.

ii) There is no action at a distance between discrete charges.

c) More important even than that, and harder to recapture now, there are not usually in Maxwell's theory even discrete charges.

i) Much of the time M holds to F's view which simply sees what had previously looked like discrete charge as the result of polarization.

ii) In the few cases when he's inconsistent with this view, it's hard to see what charge can be, but it is entirely clear that it's not atomic.

iii) The discovery of the electron at the end of the century is a contradiction to Maxwell's theory and a source of deep crisis.

d) But if there is not place for discrete charge there is even less place for atoms.

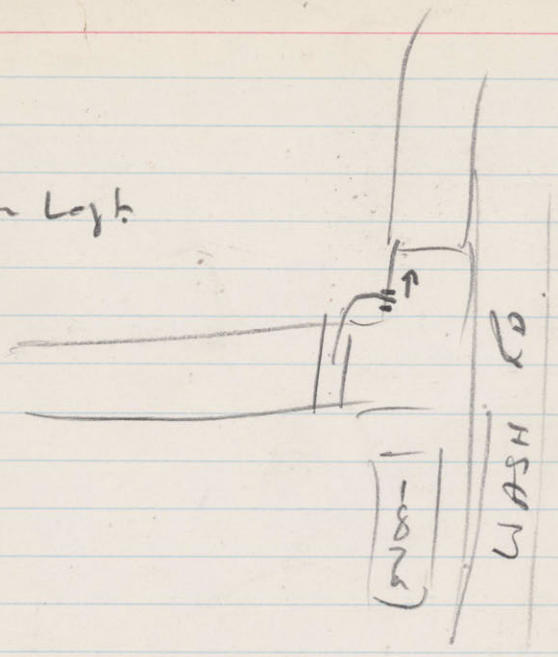
i) Though Maxwell in his work on kinetic theory is the great developer of atomism, his work on electricity is the greatest blow to atomism in the century.

ii) Here, particularly, is the source of problems that haunt the early years of the twentieth century and that in a deeper form are still with us.

iii) How to [illegible] field comes out particulate [illegible] less [illegible] clear.

61 ?

First Room on Left
Coast Floor.



Energy as Quanta

I. Black Body Radiation toPlanck

Gustav Kirchoff, 1824-87

The Black Body problem, 1860

Stefan-Boltzmann Law, 1884

Wilhelm Wien, 1864-1928

~~Wien's~~ Distribution Law, 1896

II. Planck's Contribution

Max Planck, 1858-1947

ATTITUDE TOWARDS WIEN LAW

~~New "Derivation" of the Law~~

~~The~~ Challenge of Experiment

The new radiation law

Conversion to Statistics

~~Switch to statistical derivation~~

~~The~~ A ppearance of quanta.

Sorry that emergency called me away on Tuesday. Was glad to be able to call on someone who knows more of topic than I do.

~~III. First Reactions~~

Gather from the grapevine that even those who got very little from the lecture, you did gather somewhat more than I to the whole subject. Tc. I generally include it in my own lectures.

NEED MORE CARDS

CHECK

HISTORY 336 -- Lecture ~~22~~ 20

The Quantum of Energy

I. BLACK BODY RADIATION

1. In this lecture and the ~~one~~ two that follows I want to give you just a taste of the development of modern physics, either particularly of quantum mechanics or teach much of the mathematics,

   a) Will not ~~even~~ try, to bring you up to date, but can hope to give those of you not previously familiar with the material a notion of the nature of the break involved.

   b) And for those who do know this, can hope to provide both some history of the developments and, perhaps more important, a sense of quite how squarely that break derives from problems which arose within structure of classical physics.

      i) Both groups -- humanists and scientists -- would do well to observe how many of the stands developed earlier in the course come together and into conflict here.

   c) Let me not act overambitious at this point. It's an experiment. Must walk thin line between boring the scientists and losing the humanists. Not altogether sure it's possible.

      i) In any case, not enough time for the derivations tho this is an intrinsically mathematical subject.

      ii) But can hope to show at least main concepts involved and at stake. That's my object.

2. Narrative opens in 1859 and 1860 with work of Gustav Kirchhoff, 1824-1887, on relation between ~~upon relation~~ of bodies to absorb and to radiate heat

The work quite well, I think, and should be preserved.

1. Reduce or eliminate apology at start.

2. Key to Black body argument is recognition that radiation in Black body is radiation in empty space.

3. Was short time at end for essential Black argument. Cut earlier

a). Don't need Stefan-Boltzmann except for piston & cylinder.

b) Spent more time than I should indicate going over Black body argument.

2nd Time.

There is no real formula. Also, I was again short of time, Tho I wouldn't have been. Can't do III, but not in 1½

3rd - Don't well

light or other forms of radiation. (At least that's where I'll pick it up. There are partial precedents, but they don't supply what's particularly wanted now: the conception of BLACK BODY RADIATION.

a) Kirchhoff has been working with Bunsen (of Bunsen burner fame) on earl systematic spectrascopic investigations -- identification of chem elements by the characteristic bright lines in light they emit when heated.

b) Discovers, at first inadvertently, that if white light is passed through a vapor, the vapor will absorb just the frequencies that the vapor emits when heated.

c) For heat something like this has been noted as early as late 18th century. Good absorbers (black bodies) are good radiators, also. Leads Kirchhoff now to suspect that he's confronted with a basic natural regularity, and he sets out to derive it from as nearly first principles as possible.

i) Am not going to follow derivation entirely through, tho I will show both flavor result of it.

ii) But it's just this point that the black body assumes particular role in analysis. That I do want a look at. NOTE HOW THERMODYN. BUT LESS THAN A DECADE.

Flavor of derivation

3. Start by reminding you of what you all know, even from general science, but have not thought of quite this way.

a) Any chunk of matter at any temperature above absolute zero is always radiating energy away. For low temperatures, not much of it and most of that's heat. More and including light, etc., for higher temp.

b) When this radiation falls on another body, some of it's reflected and balance is absorbed and appears in body as heat. Would raise temperature and does unless compensated by equal radiation from body that's doing the absorbing.

c) Amount of radiation (units of energy) and amount of absorbtion depend, of course, on nature of material and also on temp. and wavelnt

4. With that in mind imagine a box or cavity perfectly black on the inside and enclosing some other chunk of matter of an arbitrary sort.

DRAW.

a) Everything is at same temperature. If not there initially, wait till it settles down. Box is insulated so no heat gets in and out. Then:

i) All energy radiated by central body is absorbed. That's what black body means.

ii) Would raise temp except its reradiated. Some falls on central body. Part that's absorbed is just enough to keep temp up there.

b) Thinking about that you'll see that condition for C to stay at temp is just that black body send it a certain amount of energy in each frequency range. Any body of any shape that's perfectly black will have to give same supply.

With C solid, it depends on C's temp. & shape

i) Thus shape here doesn't matter, nor does material. As long as it's perfedtly black it must send out just the same amount of energy at each frequency as initial black box does.

ii) Phrase this by saying that it sends out enough so that for given temp T and ~~frequency~~ wavelength λ, energy/unit vol. $\rho(\lambda, T)$ indep of material. A universal function.

for us.

c) That's the part of the argument that's important. A distribution function for energy as function of wave length and temp as universal function indep of particular material.

i) Mention that it's particularly useful because for experimental purposes can turn apparatus inside out. Black central particle, metal or other cavity. Thus lamp black inside metal cavity is typical.

ii) That's not yet the concern, of course. Kirchhoff, by an argument you can work out yourselves if you like, shows that: if F is fixed by black body, then $e/a \propto$ (some function of ν and T) where e is amount of actual radiation from C, a it's coefficient of absorbtion, and e_0 amount black body would radiate at same temp., again a natural universal constant for given wave length. & freq.

5. Shan't give that technical an argument that fully again this morning, and won't ask you to repeat it on exam. But do see what's essential. Proof that, on natural assumptions, conservation of energy leads to recognition that radiant energy can only be distributed in one way within a black cavity maintained at constant temperature, T.

a) Remaining problem is to figure out what function F is, and I'll just try to name the main stages leading to Planck.

b) First involves an experimental discovery by Josef Stefan in 1879 of a regularity later (1884) derived by Boltzmann on purely thermodynamic grounds.

i) Botlzmann imagines energy confined in a reflecting cylinder with a piston. But radiation then exerts pressure on sides. Thus have

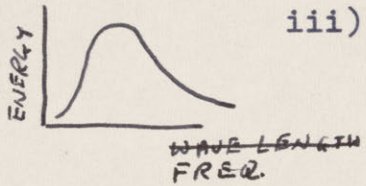
Carnot engine.

ii) Argument then leads to conclusion, $u = aT^4$, where u is total radiant energy/unit volume. (What you get by summing P over all frequencies.

c) That's a powerful and very general result, but still not all we need for it says nothing about how distribution varies with wavelength.

i) That's result first arrived at by young German physicist by the name of Wilhelm Wien, 1864-1928, in stages between 1893 & 1896.

ii) Culminating in a law that still bears his name: $P = C\nu^3 e^{-\frac{b\nu}{T}}$ thru thermodyn. argument



iii) Just the sort of curve one wants. Zero at both ends, hump whose height and position very with temperature.

iv) Generates much excitement and follow up including experimental which at first looks quite good. (Pushed hard particularly because useful for calibrating bulbs. Standard candle is tricky. Bureau of Standards stuff.)

6. This is point at which Planck enters the picture, and shall have a look at his work in a moment. First tho a word for those who know (or think they know to much).

a) The physicists will have heard of another law. Rayleigh-Jeans Law.

May have been told Planck's work is born of collision between the two. Ultra-violet catastrophe.

b) It's not really true, tho can't argue point now. It's important later to those trying to find ways out of situation Planck creates, but it's no role at start. I'll ignore it.

II. PLANCK'S WORK -- Max Planck, 1858-1947.

1. In 1896 when Planck picks up problem he's already 38 years old and a man of considerable prominence. With Boltzmann he's the greatest expert, at least in Germany, on thermodynamics.

a) What interests him about problem is that, as so regularly in thermo-, one's confronted with an absolute regularity, one indep of material.

b) And what he undertakes to do is to firm up Wien's derivation. Believe law which seems in good agreement with experiment, but is dubious of route to it.

i) On any accounting there are a number of doubtful steps in it.

ii) More important -- for here hangs one of great ironies -- Plank is unlike Boltzmann in being against the statistical approach to thermodynamics. For him 2nd Law is not just statistical, "on the average," but a regularity never violated in any domain.

iii) And Wien has used statistical reasoning, Maxwell distributions, and so on. Planck wants a phenomenological approach.

2. He's very very nearly successful, but fortunately not quite successful which helps since the law will prove to be wrong.

   a) Can't even sketch argument, but do want to show you structure of point at which it's incomplete so that you can see what next step involves.

   b) Kirchhoff has shown it doesn't matter what Black Body is made of, so we can use imaginary material we have a theory before. Planck supposes it contains many charged particles that vibrate back and forth like pendulum bobs or weights on springs.

      i) These will, by Maxwell's equations, both radiate and absorb radiation. One knows how to compute this.

      ii) One can therefore relate behavior of these so-called Planck oscillators to the distribution of radiant energy in the cavity. That's P's first step.

   c) Now concentrates on oscillators at particular frequency ν and shows that he can derive Wien Law if he can justify the following simple regularity.

      i) Entropy of these oscillators relates to their energy by $\frac{\partial^2 S}{\partial u^2} = -\frac{k}{u}$

      ii) Don't care if you know what it means or how to solve it. Do see that what is needed will follow from this if we can make this seem secure.

      iii) It's this Planck almost does. Argues that it's appropriately simple for basic regularity. One of few reasonable forms. Etc.

3. That's point Planck reaches in ~~1789~~ 1899. Almost everything is under control. One more idea may pin derivation down entirely.

   a) Only, by time last of his 1899 papers is sent off, some new experiments begin to raise question whether Wien law is really that good.

      i) It still seems to work high frequencies, but may not be good in low frequency range.

      ii) By mid-1900 it's clear that law won't work for low frequency, and in fact P behaves as 1/T at given low frequency.

   b) As soon as situation starts to go wrong, Planck has looked again at his reasoning. Discovers he can't really show necessity for $-1/u$. Any negative function of u will do on right. $-1/u$ is only simplest.

   c) Tries more complex ones, starting with $-1/u^2$. This gives the 1/T dependence he needs but not the high frequency form.

   d) So he compromises: $\frac{\partial^2 S}{\partial u^2} = -\frac{k}{u(k+u)}$

   e) Which leads to form: $P = \frac{A\nu^3}{e^{B\nu/T} - 1}$. This is Wien's law for high frequency, does give 1/T for low, and continues to fit as measurements get more and more accurate in next few yrs

4. That's Planck's distribution law.

   a) Unlike his next step it's taken extremely seriously by those concerned with problem, because it agrees so well with experiment. It's a trium

b) But for Planck not unequivocally so. It's just what he doesn't want -- a quasi-empirical regularity not one derived from thermodynamic first principles.

c) What he started out to do for the Wien Law he must now do for his own.

5. This time success is quick, but it comes at price of a complete reversal of much that he's previously stood for and then, somewhat inadvertently, of what anyone has stood for.

a) Apparently has been convinced by experience with Wien Law that a straight phenomenological approach won't take him further.

b) So he turns to Boltzmann statistical appraach which he's never used before and which he actually gives evidence of not understanding completely.

i) In the context of contemporary German scientific thought where there's a considerable battle over the legitimacy of the statistical, it's a considerable about face.

ii) And it's also immensely consequential, though not for reasons that anyone -- least of all Boltzmann could have anticipated.

6. Again, I've not the least hope of doing the derivation, but can give you a notion of where turning point comes.

a) Boltzmann's biggest contribution has been to say that we can understand entropy of state of a system as prop. to log of prob. of it's being in that state.

i) $S = k \log W$ is usual formulation with W as probability.

ii) Dice rolling will suggest what's involved. Take total on two dice as the state. Then, probability of 7 is 6/36, of 6 is 5/36, of 5 is 4/36, and so on.

iii) Planck now want to apply same technique to considering ways in which energy can be distribute among his oscillators.

b) b) But now a problem. As the dice example indicates, in order to do these probability counts one must ordinarily deal with discrete quantities, not continuous one.

i) Usual way , Boltzmann has done it continually, is to suppose the continuous quantity comes in pieces of finite size for purposes of first computation, then let size go to zero.

ii) That's what Planck does. Supposes each oscillator can have energy only in pieces ε. Counts number to find total entropy. And so.

c) That's what Planck does, and it would be find if he could carry it all the way.

i) But finds he mustn't take last step. Cannot let $\varepsilon \xrightarrow{6} 0$. Instead set it equal to $h\nu$.

ii) And that's his derivation. Oscillator of frequency ν, can have energy $h\nu$, or $2h\nu$, or $3h\nu$, ... But not anything inbetween.

iii) Not generally true that cause and effect are continuous: small force small effect, bit larger force bit larger effect, etc.

iv) But this is just the sort of continuity that has been absic to all previous dynamics.

v) If it's to be taken seriously, it's far from clear how Newton's Laws are to be preserved.

vi) Not even quite clear how one's going to preserve usual notion of cause and effect. Just the notion of measuring cause by effect that's been so important in energy conservation will here become dubious.

III. SOMETHING ON REACTIONS

1. That being so you will not be surprised that, in fact, until 1905 no one pays any attention to this aspect of Planck's work and that until 1911 almost noone does.

a) It's really only on the verge of World War I and in its aftermath that the quantum of energy becomes a matter of concern to many physicists, much less non-physicists.

i) And then it's because it's proved able to solve still other problems.

ii) It's those problems and the widening break with tradition that I'll talk about next time.

b) Meanwhile just a few remarks on the more immediate response to Planck's work.

i) This is one that differentiates sharply between the law of energy distribution in a cavity and the derivation -- the quantum

2. Law itself rapidly comes to stand alone. People don't necessarily think it's the last word, but only ones that come equally close to experiments are known, by 1901 or 1902, to be far more complex and for no reason.

3. But, as to the derivation and the notion of quanta, the politest reaction is also generally the most frequent.

   a) It comes from the men who ignore the existence of the derivation entirely.

   b) A more penetrating reaction, illustrative of effort, comes from Rayleigh, a man who does know how to do statistics, and who says he admires the law but can't think why it should work. As for P's derivation, he doesn't understand it well enough to criticize.

      i) Partly problem comes from real mistakes in derivation. W which Planck uses isn't really a probability at all.

      ii) Partly from incomprehension of what sort of argument it can be that fails to go to the limit.

   c) And these points are the ones that are elaborated by the men who do really follow Planck in detail. They point out it's wrong.

4. With the single exception of the young Einstein with whose work I'll take up tomorrow.

Reception of the Quantum, 1900-11

A case history

I. The First Reactions

Three types

II. The First Contrib. of Albert Einstein, 1879-1925

The Three 1905 papers

Light as particles

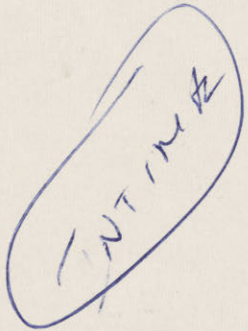
The reception of the idea

III. The Problem of Specific Heat

Einstein's 1907 paper

It's recption.

IV. First Solvay Congress, 1911



HISTORY 336 -- Lecture 22 21

The Quantum from Planck to Bohr

I

I. RECOGNITION OF THE QUANTUM, 1911-13

1. In last lecture I concluded by sketching for you the steps by which Max Planck first invented and then derived a new law for the distribution of energy in black body radiation.

   a) This was: $\rho = \frac{A\nu^3}{e^{h\nu/kT} - 1}$ with constants somewhat differently written.

   b) To look at it's only a slightly more complex expression than Wien's Law, though the differences between the two go as deep as Newton's Laws which in fact are now to be dethroned.

   c) Want to ask this morning about how this event is received. So far we've got merely a new formula for black body radiation and a rather crude derivation.

      i) Is it's significance seen, and when does that occur?

      ii) What are next steps in displaying its importance on other problems

2. Planck, at least, has no illusions that it's absolutely fundamental. His son is said to have told people that he remembers the day Planck came home saying, I've just discovered something as important as anything that happened since Newton. Not clear that it's true (Planck's personal) but

   a) Yet even Planck is uneasy with the result. Shan't follow

appropr.

It was not well. I dabbled in I. 1. (b). Biographical outline of esoteric detail.

End time. It's still good.

I did a sprint on derivation of Planck's formula. Used words like bob to show need to divide into finite bits.

them here, but he does subsequently develop two other versions of the theory, each intended to make somewhat more minimal the break with classical theory.

i) 2nd version in particular is one in which oscillators can absorb radiation continuously, thus obeying Newton's laws. They radiate energy in quantum jumps, however, thus violating Maxwell.

ii) Actually get's some results which seem to fit experiment a bit better that way, and does attract some adherents.

iii) Real importance here is showing nature of problem his theory presents.

3. As soon as one turns from Planck to others situation becomes more difficult. To describe it must distinguish sharply between Planck's law itself, and the derivations of it. Response then falls into three groups.

a) The largest group (and I mean among professional physicists, not the populace at large) has simply not heard of either the result or the derivation.

i) Black body radiation is an esoteric corner of the field. Until it's clear that implications of Planck's work are fundamental only those interested in this corner will know of it.

ii) But that awareness doesn't come publically to the profession until 1911. Until World War I can go to school at first rate European university and never hear of the quantum.

b) There are, however, people who do care about Black body radiation and do hear of the work.

i) They are greatly impressed, but only by the formula. When first announced, it has only one competitor and after a bit of further experiments it has none at all.

ii) But this happens without the derivation's making any dent at all. Typical comment is that of Lord Rayleigh, who discusses relation of formula to his own, praises result, but says, As to derivation, I can't understand it well enough to comment.

iii) Partly problem is due to genuine difficulty in a couple of statistical points that Planck hasn't quite handled properly.

iv) More basic is total lack of justification for failing to go to the limit.

v) And lying close to the surface is fear of the destruction to established physics if one does take the plunge.

c) Rayleigh's is about the best recorded reaction from someone who does know. Other, Jeans in particular, do claim to understand result and simply reject it, pointing to its mistakes. Perfectly good formula only h is zero, say's Jeans.

d) If one looks beyond Planck for someone who takes this all seriously, will not easily find more than one man. That's Einstein, 1879-1955.

3. Just why Einstein is an early convert is not at all clear, and there's a fascinating puzzle here that I'll at least name since one of you might

solve it. Sr thesis for physicist. Also, it illuminates q.m. contrib.

a) Probably you've all heard that in 1905 Einstein publishes three papers, each absolutely basic.

i) One on Brownian motion, one on special relativity, one on quanta.

b) To everyone at the time and since these have seemed to be on three quite unrelated topics. Einstein, however, ~~was quite explicit~~ implies in his brief autobiographical narrative that they do go together and were constantly interacting in his thought. Why?

c) Fundamentally, I don't know, but can sketch what I suspect is the beginning of an answer.

i) As most of you know, Einstein's concern with relativity theory grows from a sense of conflict (or more than a sense) between electromagnetic theory -- theory of light -- and Newtonian mechanics.

ii) What he sees in Planck is, in the first instance, another example of fundamental conflict, and it's natural to suppose they point to the same aspect of nature. No one since has been able to show the similarity, but that doesn't make the perception less natural, less important, or even wrong.

iii) Parallel for Einstein, probably goes even a step further and one that's more consequential. In case of relativity theory Einstein is groping towards a way out that is travelled by modifying the the substructure of both theories. Goes th naotions of space and time, revises them, and revises both theories in process.

iv) In Planck's work there's none of the same symmetry. Newton is wrecked, but Maxwell still governs radiation.

v) Effect of Einstein's contribution is to spread the responsibility between the two. Find difficulties in conception of radiation, too

d) That's part of parallel. Seeing difficulties at same juncture of theories, and trying th make them look alike. Will state the other more briefly, ~~for haven't time to develop underlying ideas~~. This is for those who already have them.

i) Einstein, by self-education, is deeply knowledgable about stat. mech. and has redeveloped a number of basic results due to Gibbs for himself. He's both expert and convinced that key to riddles is in technique.

ii) But there's one big trouble in statistical mechanics of this period. So-called equipartition theorem. Tells how to distribute energy when you've big and little particles in a box, or when a particle can both move along and also vibrate.

iii) Doesn't always work. In particular it seems to be violated by observed specific heats.

iv) Brownian motion problem, in which one actually watches the big particle with a microscope and measures energy it receives from atoms is in part an acid check on equipartition, which does hold in this case.

v) On the other hand, both Plack Law and Wien Law are clear evidence of cases in which equipartition breaks down.

vi) Einstein uses statistics and nature of breakdown to show that e.m. radiation doesn't behave as Maxwell suggests it should. Instead it sometimes behaves like particles.

4. Shan't give the argument, but will suggest how it ties to sorts of arguments we had last time.

a) Einstin imagines e.m. radiation of a single frequency in a cavity, ~~and with a piston~~. Also supposes frequency high enough so that Wien Law holds. Draw.

Remember Planck's derivation ->

i) Using Wien Law he finds what entropy must be for this radiation. More particularly, shows what change of entropy must be for change in volume.

ii) Again, won't do derivation, but form of result is what's significant even for those who don't know what entropy is:

$\Delta S = \frac{kE}{h\nu} \log(v/v_o)$ which can be rewritten $= k \log (v/v_o)^{E/h\nu}$

a lovely gestalt switch.

iii) For what Einstein then points out is that if we had n particles in box and asked for change in their entropy if they collected themselves in vol v when box was of size v_o would get:

$$\Delta S = k \log(v/v_o)^n$$

Here equipartition does hold

iv) Two formulas are the same if $E/h\nu = n$.

v) Can therefore understand thermodynamic properties of radiation of high frequency if we say it acts like particles each with energy $h\nu$

b) For Einstein this fits right back to Planck's result.

i) Each time P's oscillator jumps it emits a particle like bundle of radiation, a photon, a radiation particle.

ii) And Einstein promptly shows his wisdom by discovering in the contemporary literature three little noticed effects which are best understood by thinking of light as particle-like.

iii) These are fluorescent radiation -- Stokes Law; photo-electric effect only recently and incompletely investigated by Lenard so it's properties are not yet tied down; and ionization of a gas by light.

c) A whole new realm and new set of techniques are quite suddenly secured to quantum theory. One of the great and exciting papers of all time. All these effects will stand up.

5. Yet this drops even deader than Planck's.

a) Einstein himself has no reputation yet. Not even a university position. The ideas are, if anything, less reasonable than Planck's -- E.M. theory is still a recent triumph. Experimental effects to which Einstein refers are barely established. Not like black body law.

b) And, in fact, these ideas are going to have a different fate from Planck's.

i) Not until about 1922 -- ~~then as a result of the discovery of the so-called Compton effect~~ -- that more than a tiny handful of physicists are willing to take these ideas seriously.

ii) As late as 1914 when a group of Germany's most distinguished physicsists, including Planck and Nernst -- two strong proponents of the quantum theory -- recommend that Einstein be brought to Berlin and a special chair set up for him, they also apologize for the photon madness.

iii) Brilliance of relativity and Brownian motion; brilliance of specific heat theory to which I immediately turn; but madness in continuing to insist light is particles. Price of genius. Must forgive him it. (They do.)

6. These ideas therefore wait to become parts of physics, and I shan't this year catch up with them again. Planck's ideas fare better. Only again largely because of Einstein who in 1907 publishes another paper, this one on specific heats, in their relation to Planck's theory.

a) Have already pointed out that this is one outstanding area in which kinetic theory and statistical mechanics are known to be in trouble.

i) Using them it's possible to compute what specific heat of a solid or gas should be in terms of known molecular weights and structures.

ii) Often confirmed, but there are many many known exceptions. Also increasing evidence that number of exceptions and magnitude of deviation changes with temperature.

b) Einstein now argues, quantitatively and qualitatively, that the deviations can be understood. Look at qualitative effects.

i) Think of solid as bunch of vibrators on springs. (Like oscilla-

tors from last lecture, but now more massive. Atoms.) Freq ν.

ii) Planck's statement has been that energy (how heat energy) can be fed to them only in packets of size $h\nu$.

iii) If there's enough energy already in body so that increment is small, then feed will resemble continuous and the usual derivations apply. Thus we expect they'll apply to body that is hot enough.

iv) But how hot is going to depend ~~xxxxxxx~~ on frequency. If it's low, quanta are small and continuum behavior comes earlier. Quantitatively analysed condition is $h\nu << kT$.

v) All bodies should behave as old statistics said at ~~high~~ low enough frequencies. Experiment shows that they do. Also tell about freq

c) But that's not all, for Einstein can also predict at least approximately how specific heat will behave at lower temperature, and this too is confirmed.

i) And this is big stuff. Specific heats are at center of both physics and chemistry. The problem is old and recognized and wrestled with.

ii) This one can't be ignored as black body radiation could. It quickly does get picked up. Checked in laboratory, worked on in more elaborate theories, and results mostly keep getting better and better.

iii) Don't do so forever. Problems here that work out only with wave-mech. But that's later.

7. Only this pattern of acceptance has a bit more structure than would be indicated by these remarks alone. A very few men, and one event, are deeply implicated in making people aware for the first time of what's going on.

   a) Perhaps most deeply implicated of all is Walther Nernst. He's one of Germany's most famous scientists of this period, and the dominant figure in creation of physical chemistry as a field.

      i) Before Einstein's paper appears he's already deeply involved with his students in measureing specific heats and their change with temp.

      ii) He knows what problem is. That it can't be evaded experimentally. That it's tough theoretically.

      iii) He's the man to be impressed by Einstein's paper, and he is. (Though it's by no means clear that he's converted. Does still try to weasel on concepts.)

   b) Result, he decides he must find out more and goes to see Einstein in Zurich where he's now got junior job at University.

      i) This is about 1909, and I've been told that it's only when the great Nernst comes all the way from Berlin to visit Einstein that the physicists of Zurich begin to wonder whether they haven't got a bright man in their midst.

   c) In any case Nernst does take up the theory for his own purposes and strives, from Berlin, to get others involved. Something he's more equipped, by personality, to do than is Planck.

d) And here he is fortunate in his acquaintances -- fortunate in ways that, as my talk about dye industry may have indicated, come more often to a ~~physicist than a~~ chemist than a physicist.

i) He's acquainted with the Belgian, Ernest Solvay, who's made a fortune out of a process that replaces Leblanc's for making soda.

ii) Solvay wants to do something to improve science, and Nernst seems to have been instrumental in persuading him to try experimentally a conference of the world's leading physicists.

e) It's about the first thing of its sort for physics -- chemists have had a few precedents. Takes place -- the first one -- in 1911.

i) The roster of invited scientists is an international who's who. And the group remains small.

ii) Topic is set by Nernst and a few others (Planck somewhat resists) as Radiation and Matter.

d) Before this group the problems are quite thoroughly thrashed out. Several new and sounder proofs of Planck's results are given. Some men present proofs that you can't get these results without break with classical theory. (These are mostly men who've not dealt with problem before.)

i) Through their work and through the report which contains it and discussion, the problem of the quantum is put on the map for the profession.

CHALK
FAST

THE BOHR ATOM

I. Bohr

Niels Bohr, 1885-1962
J.J. Thomson, 1856-1940
Ernest Rutherford, 1871-1937
J. W. Nicholson, 1881-1955
C. G. Darwin, 1887-1963

I. Lessons from Electron Theory of Metals, 1911

Bohr's Ph.D. thesis, 1911
Encounters with Thomson

II. Rutherford and Manchester, Spring & Summer 1912

~~The Rutherford model~~
~~Problem of Scattering~~
The first Bohr Atom

III. Copenhagen, Winter ~~& Spring~~ 1912/13

Impact of Nicholson's model
Role of the Balmer formula

The Bohr Atom

HISTORY 336 -- Lecture 22

The Bohr Atom

I. INTRODUCTION

1. This is last lecture of the semester, and I suppose it ought to be spent in a retrospective look at the course.
   a) But reading period gives you opportunity to do that for yourselves.
   b) Given that there are few lectures in a semester, I think it more useful to continue with the development of substantive topics.
   c) Therefore use the hour to introduce you to one more essential step in the development of the old quantum theory: development of the Bohr atom.
2. Technically this is a simpler story than those which underlie my last two lectures, but historically it's more complex.
   a) Particular complexity is that what proves to be really radical and important about the Bohr atom emerges only at the very last moment in a research program that's lasted almost two years.
      i) Bohr's great success is with problems that he's not been working on until a month before his paper is submitted, but the work he's done along the way is absolutely essential to the success.
   b) That being the case I think I had better violate all my usual rules for the construction of historical narratives and remind you at the start where the story comes out, and what's important about it.
      i) What is the Bohr atom.

3. I'll stick with case of one-electron atom, case with which Bohr has particular success.

   a) Important, however, to recognize that until a year or so before Bohr's work, noone supposes that there are any atoms with so few electrons at.

      i) Even/the time only the members of Rutherford's immediate circle think the idea even remotely reasonable.

   b) Draw. Then, electron (-1) around nucleus (+1) in orbits governed by Newton's Laws.

   c) But not in all mechanically possible orbits. Only in a selected series governed by regularity of form: $E = \cancel{C/n^2}$ $\frac{2\pi^2 m e^4}{h^2} \frac{1}{n^2}$. (SAVE)

      i) This notion of stationary states is one of the important novelties in the model, but it's really not quite that new.

      ii) Close parallel to Planck oscillator which can also only exist in states with certain amounts of energy. Particularly clear parallel with Planck reformulation in 1911 at Solvay.

   d) So, though important, it's not the key point. That's the radiation process.

      i) No radiation in stationary states (again somewhat like Planck).

      ii) Occurs in transitions, e.g., $n_2 \rightarrow n_1$.

      iii) Thus, not at mechanical frequency. Seems madness. Hardest of all to accept. Man shaking rope. But key to much of analysis that follows.

II. PRE-RUTHERFORD RESEARCH

1. Now trace the path back to this point or this set of concepts, and pick it up in Copenhagen, Bohr's home, early in 1911 when he's at the last stages of his Ph.D. dissertation.

   a) At this point he shows no interest at all in model building.

      i) Copenhagen is in the Germanic educational orbit, and the Germans at this time, though they believe in atoms, are very sceptical of detailed models. Not the way they go at.

      ii) Detailed models are being worked on primarily in England, and part of Bohr's story is that he combines the two biographically. Trained in the German tradition, but then goes first to Cambridge then to Manchester.

2. But though he's not yet concerned with such models, topic he is at work on, will lead him towards them and simultaneously provide some clues that play a major role.

   a) That topic is Electron Theory of Metals, very new field, for electron was only discovered during the 1890's, but one that's been developing very quickly.

      i) General conception Draw. Atoms in some sortsofflattice.

      ii) Electrons from exterior of atoms are free to wander in between, occasionally interacting.

      iii) Then apply statistics to specific heat, heat conductivity, electrical conductivity, black body radiation, and so on.

iv) There've been some quite remarkable successes, but quantitative agreement is nowhere precise, and in a few areas it's quite bad.

b) Taking up the problem, Bohr states his objectives as follows:

i) In order to do any work with model have to make a number of simplifying assumptions, particularly about interaction of free electrons with atomic cores.

ii) Some results depend sharply on particular assumptions. Others perhaps not.

iii) He's going to try to use most general possible assumptions that can be handled mathematically, discover which difficulties are due to particular assumptions, which, if any are difficulties of principle.

c) Brilliant job of criticism and exposition. In many areas improves existing agreement so that it looks quite satisfactory.

i) But also discovers two problems which he's convinced the theory will never be able to handle without a fundamental break with classical theory.

3. First of these is simply Planck's problem. Black body radiation.

a) This is still period in which not many people take it seriously.

i) Bohr convinces himself it is absolutely fundamental and can't be reconciled classically.

ii) In fact, strengthens arguments that have previously existed by pointing out mistake in one standard argument against P's conc.

b) This part however is only moderately original. What's important is that it convinces Bohr that radical breaks are needed, and thus puts him a position to make more of them.

i) What is entirely novel and original is his second major problem, that of the magnetic properties of metals.

c) Placed in a magnetic field all metals show some magnetic response. Paramagnetic (like iron but much weaker) or diamagnetic (weakening applied field).

i) There are theories of these effects that account for them at least qualitatively.

ii) Bohr shows that they're wrong. There ought not be any such magnetic effects on classical theory.

iii) Furthermore, his argument indicates that difficulty here is much like one Planck encountered.

d) In the first place, sees that if we're to account for magnetism at all must deal with bound electrons -- the cores.

i) But it's also the bound electrons, the oscillators which are the locus of non-classical behavior for Planck. The models.

ii) Second, if we apply classical analysis to bound electrons, then we must allow them to have all possible motions. But then average magnetic effect turns out to be zero.

iii) The only visible way out is some stunt like Planck's. Allow only some of the classical motions or energies.

4. This is thoroughly original work and, even though the Coperhagen examiners don't entirely understand it, they make no trouble.

   a) Bohr finishes and immediately makes arrangements to go to Cambridge University on a Fellowship for work with J.J. Thomson.

      i) Thomson's discoverer of the electron, a principal worker on electron theory of metals, and also the creater of the leading atom model of the day.

      ii) Bohr greatly admires him, but has also discovered a number of mistakes in his work.

      iii) Wants to learn from him, but also discuss the mistakes and what's to be done.

   b) He arrives at Cambridge in the fall and shortly discovers things aren't going to work out very well.

      i) Thomson's interest has shifted from electron theory, he's busy.

      ii) There are communication problems, and besides Thomson's not very responsive to criticism.

   c) iii) Bohr works by himself plus some lab work on a problem set by Thomson. But not satisfied.

      iv) In December Rutherford gives lecture at Cambridge which greatly impresses Bohr.

      v) He arranges to transfer his fellowship and spend last term, from March 1912 on, working with Rutherford's group in Manchester.

III. MANCHESTER

1. Manchester is a terribly exciting place at this point, for it's producing a series of major discoveries in the area of natural radioactivity, perhaps the hottest area in physics and one that's scarcely over a decade old

a) But though dominantly experimental, it's not exclusively so.

i) Indeed, just at time Bohr was finishing his thesis, Rutherford has come up with a fundamental theoretical suggestion about atomic structure

ii) It's the so called nuclear atom (1911), a model that's convinced no one outside of Manchester, but is much used there. A new tool indeed scarcely discussed,

b) Can't tell that story, but need to show you sense in which it's a research tool, for that's the context in which Bohr takes itup;

i) One recently standard technique for investigating atomic structure is scattering. Shoot electrons or alpha particles at matter, and see how they're reflected or scattered.

ii) Thomson, in particular, had developed the theory.

iii) Draw. Plum pudding model. Electron transit with multiple scattering. From distribution can estimate number of electrons per atom. A major problem.

c) Rutherford's group has been doing same thing with alpha particles.

i) Find occasional back scattering. Shocking effect.

ii) Can only understand it on single scattering model for which need

massive component, the nucleus.

iii) Thus turn Thomson's model inside out.

2. It's important to realize that this idea of a nuclear atom is by no means new.

a) Find it in Weber and other 19th century Germans. Repeatedly suggested after electron's discovery.

i) But there are troubles which we'll encounter shortly, and even in their absence, there's nothing to be done with it.

b) It's the scattering application, and initially only that, that gives it a function, & that sets it out from other models.

i) But now the function is very real. Scattering depends on centtral charge.

ii) Can determine it accurately, thus also number of electrons.

iii) With model, scattering becomes even more important tool than before. Real power, which seems to be what first impresses Bohr with it.

c) Furthermore, Rutherford's use is clearly only the beginning.

i) Early in Bohr's stay, the physicist C. G. Darwin (grandson of Charles) publishes a paper taking into account the effect of the electrons on scattering, thus beginning to give still more detailed information about atomic structure.

This is when Bohr starts. He

3. ~~Bohr~~ reads this paper in much same way he's read stuff on electron theory of metals, and comes to same sorts of conclusions.

   a) Finds weaknesses in the argument and sees way to do it better.

      i) In particular, sees way to get information not only on number of electrons, but also on the frequency of their motion, and their position.

      ii) Decides to write a short paper on it. It is his very first engagement in his own research with atom models.

   b) And very quickly he runs into trouble. One that other people have known who've worked with nuclear models but that's new to him.

      ii) Draw. If you arrange electrons in a ring around nucleus and apply mechanics, find there's no stable solution.

      ii) Here again I have to unseat a myth for the physicists. Well known that there's radiative instability. Ring should give up energy and circle into core.

      iii) But it's also been shown that effect is very small if there are a few electrons in ring as there are for Bohr at first.

      `iv) His problem is that, even without radiation, the system is mechanically unstable. Displace electron perpendicular to ring, and it will continue to move away, repelled by other electrons.

      v) That's been a major reason for rejecting model in the past.

4. Bohr seems not to have expected the difficulty, but he's prepared for it as no previous man dealing with the model had been.

a) He's already convinced, from work on thesis, that non-classical behavior is to be expected from bound electrons.

i) Furthermore, from Planck has clue what to do.

ii) Planck: $E = nh\nu$ or $E/\nu = nh$.

iii) Bohr writes for his case just $E/\nu = K$, where is a universal constant related somehow to Planck's, but for the moment obtained empirically

iv) It's the application of this condition that's to be used to stabilize the atoms which, in Newtonian terms, are mechanically impossible.

b) It's terribly powerful.

i) If you apply Newton's laws, ignoring stability, get, as for planets, radius and frequency as functions of energy.

ii) Applying additional condition gives you the actual frequency and radius. Thus size and frequency are specified as soon as you know central charge and number of electrons in ring.

c) Bohr proceeds to do these computations for a number of elements and also for some simple molecules.

i) Computed size versus other estimates.

ii) Energy necessary to remove electron from ring (i.e., ionization energy).

iii) Can have H_2 but not He_2 on energetic grounds, and so on.

IV. THE BOHR ATOM

1. This is the point Bohr has reached by July 1912 when he leaves Manchester to return to Copenhagen. Notice two things about it.

   a) No stationary states. This is just the stable, permanent, configuration of the atoms.

   b) Also, no concern at all with radiation and atomic spectra, with the bright lines emitted. It's not his problem, and doesn't get to be for another seven months.

      i) Later Bohr was asked why he didn't look at them.

      ii) Knew about them, that they existed. But they were so complex. Beautiful like colors on wings of butterfly, but who'd expect to learn about butterflies from their colors.

   c) Thus the essential features are still to come.

2. First comes essentially from outside intervention.

   a) On first return to Copenhages, Bohr continues as before, trying to get paper on atom and molecular models ready for publication, and worried that someone will beat him to it.

   b) Then, late in year, discovers that perhaps someone has.

      i) Somehow runs into papers by Cambridge physicist, J. W. Nicholson that have appeared in Monthly Notices of the Royal Astronomical

      ii) Great success, though on quite different problems, using models very like his.

c) Again a ring. Again a Planck-like condition very similar to Bohr's.

i) Nicholson now supposes that radiation is dues to vibrations of electrons in planes of orbits. As with pendula, there are only certain permitted frequencies.

ii) By fiddling with parameters Nicholson gets quite remarkable results on stellar spectra. Accounts for a number of observed lines that noone has been able to give a source for.

iii) Predicts new lines, a few of which turn up.

d) It's most impressive, and Bohr is correpondingly horrified. Despite the qualitative similarity of the models, there are important quantitative differences.

i) At first thinks they can't both be right, and isn't sure that Nicholson is wrong.

e) Then, just before Christmas 1912, thinks he sees a way to reconcile them.

i) Nicholson has left a running integer, n, in his Planck-like condition. Different n's correspond to different ring sizes.

ii) Needs different values and they all prove to be quite large, from 12 or thereabouts up.

iii) Bohr concludes that difference is just that Nicholson's dealing with excited states, he with "permanent states".

iv) Changing his condition to $E/\nu = nK$ provides a route twoards reconciliation.

f) Thus by Christmas Bohr's go stationary states.

3. But he still doesn't do anything with them. As late as the seventh of February 1913, he still shows no interest in spectra and does not computation involving anything but the permanent state.

a) Where he talks about radiation at all, it's in terms of vibrations out of the normal position. A classical mechanism like Nicholson's.

b) Again some sort of outside intervention is needed, and it apparently comes early in February.

i) Someone with whom he's discussing his work, suggests that he ought to pay at least some attention to simple spectra.

ii) There are known regularities of a simple form, though no one has explained why they take that form.

iii) Bohr does go to have a look and, as he said later, Once I saw the Balmer formula, everything was clear.

c) Probably about right.

i) Balmer's formula gives frequency of lines in hydrogen spectrum.

ii) $\nu = R(\frac{1}{2} - \frac{1}{n})$. With R a universal constant.

iii) But looking at the formulas he's already got, Bohr quickly spots that $1/n^2$ dependence is just that displayed by energy of electron

iv) Furthermore, can compute just the value known for R if he says that K is one-half of Planck's constant, a value which he thinks

may be justified by the fact the frequency is a compromise between outside orbit, ~~xxxxxxxx~~ and inside one.

d) At this point he has ~~xxxxxxxx~~ begun the application to spectra, has invoked stationary states, and has detached the frequency of radiation from the frequency of motion.

i) That's what appears in paper he sends to Rutherford at beginning of March and which appears in print in July 1913.

e) Obviously it s madness and is generally so received.

i) Obviously, also, there's need for further development and application.

f) But the essentials are now here. In view of the date and the hour, that's where I shall have to leave it.

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Princeton - History 336

OK

earlier you should be looking for. What had science achieved by mid eighteenth century? What were there about how to do science? What ideas about which subjects could be approached scientifically?

b) In the process will try to point you towards some of the aspects of science that are going to change most markedly with the nineteenth century, some of the things we'll be looking for.

c) Reading due next Monday for precepts will backstop this.

3. Then in the next ~~two~~ three weeks I want to illustrate some of these points by looking at ~~several~~ eighteenth century sciences. ~~I'll be asking you to read a good deal about the development of~~ electricity and chemistry.

b) I'll talk briefly about heat and then, ~~in more detail and more analytically,~~ about chemistry.

4. At that point want to change the subject or seem to.

a) Reading and lectures on the Industrial Revolution and more particula on the question of the role of science in the technological changes that made the I.R. what it was.

b) Simultaneous discussion of the change in scientific institutions and in ~~the~~ scientific specialization and professionalization, in part as a result of the Industrial Revolution, in part for still other reasons.

5. Then back to science again until spring vacation. Two blocks of material
   a) Overall topic is the birth of a new mathematical science
   b) As illustrated particularly (and without mathematics) in the develop. of electricity and of thermodynamics.
6. After vacation we switch fields again.
   a) This time to geological and biological science. Won't have as much to say about them, but must look at the fundamentally new position they achieve.
   b) Finally back for the last two or three weeks to two closing issues.
   c) The new relation of science to technology at the close of the nineteenth century.
   d) And a taste of the events at the turn of the century that have brought about such a radical change of theory in our own day.
7. That, at least, is what I aim for. It's probably too much ground for the first year, but I promise as close an approximation as I can manage.

Institutional Contrasts around 1750

Atomism as a unifying principle

Heat as an example

HISTORY 336 -- Lecture 3

Corpuscularism - Heat

1960

I. REPRISE

1. Have never learned to squeeze material so that logical arrangements and appropriate balance fit 5o minute hour. That's one of the reasons I suggest you feel free to interupt as needed with questions or clarificatio requests.

2. Today, as some will have recognized from outline, have one item dangling from last lecture.

   a) At the point had divided sciences into two categories, initially by extent of achievement. Classical vs. Baconian.

   b) Suggested these differ also in developmental pattern. The old and the new.

   c) And a corresponding difference in method. Generally observational vs. experimental. Might now rephrase that slightly and say natural-historical. The sciences that for their start call for the collectio of lots and lots of information. The Baconian program.

3. Now add one other significant item to this list of contrast: Institution

   a) Just beaause they're old and because soc. needs men equipped to do them, classic. scie have long found inst. homes for teaching and res.

   b) For med. its med schools, a very very old sort of inst. Ancient and medieval precedents.

LECTURE'S NOT BAD THO I
DIDN'T DO IT WELL.

GOT THRU IT ALL

BETTER IF I DID JUST
BOHRISM & HEAT.

BETTER TO ADD MORE CONCRETE
MATERIAL

astronomy,

c) For/mathematics, mechanics, study of motion, it means the universities which have always had a place for at least the elements of these subjects and have sometimes, as with Newton, supported very advanced work as well.

7; By contrast, the new Baconian sciences are hard put to find an institutional home. When they do its often in new institutions, outside universities.

a) Exception is the medical schools. Watch for doctors in history of heat, electricity, chemistry through the eighteenth century.

b) Doctors do have some lab facilities and can use them for purposes that are not strictly medical. ~~Exxxxxxxxxx~~

c) But not the philosophy faculty, not the faculty of arts. The relationship we take for granted between laboratory science and the university is a product of the nineteenth century and often of the very late nineteenth century. Earlier than that it scarcely exists.

d) ~~Where else then is this science done.~~ ~~Quite a few~~ Otherwise it scattered places and without vast system.

Cavendish

i) A lot of its done by amateurs. Men of fortune or men whose jobs provides the leisure and tools necessary for experiment. Priestley

ii) Sometimes around the new institutions, the national academies like the Royal Society of London, or the Academie Royale des Sciences, or the French Jardin des plantes, an adjunct to medical fa

which rapidly becomes center for both general botany and also chemistry.

e) But pattern we know of university chairs for chemistry, botany, geology, or even experimental physics doesn't exist at all when our period opens or for some time afterwards.

i) Though we take it for gfanted and defend it when threatened, its really only been securely established for a century and was not dreamed of before 1800.

ii) Furthermore, as we shall see, it's not just the University home that comes during the nineteenth century but also the other trappings of professionalization for these new sciences.

iii) It's in this period that they'll get their own journals, own professional organizations, own recognized and names specialty.

iv) Much of which has been appreciably older for my so-called classical sciences.

8. That will, I hope, suggest some part of what we'll be looking for as we procede from here.

a) Will pick it up next time with a few remarks on elements common to the two traditions and then some remarks on heat as a Baconian scienc

b) Meanwhile, close today with a remark addressed particularly to those who were also in first part of course or who have done previous reading in the field

II. CORPUSCULARISM -- The Common Ground

1. So far have talked about differences between the older and newer sciences Now talk about one vitally important element that they almost invariably share.

   a) Metaphysical view about what universe it like. Atomism or corpusc.

   b) Much about it in your reading, so very brief here.

   c) But can't omit, because it is basic element for development of science during much of period that concerns us. Try to point up essentials for you.

2. Have said view is often called atomism. That's appropriate because view is historically derived from atomism of the Greeks and because it's on the historical road to the chemical atomism of Dalton at beginning of nineteenth century.

   a) But it's also a doubly misleading term, and it will help us isolate the nature of the view to discover why.

   b) In antiquity term "atom" means indivisible, view comes into existence partly as response to paradoxes about infinite divisibility. When it comes, it's inseparably linked to belief in the void, absolutely empty space. Thus solution to another ancient paradox. Motion, paradoxes of Zeno.

   c) In 17th and 18th century atom as a term still has all these implications, with result that most of the men history of science is concerned with deny they are atomists.

i) They're common-sensical people. These paradoxes are too metaphys for them.

ii) Some believe atoms are indivisible, others not. Some believe in No agrmnt void, others only that it exists between particles of aether whic fills all space as vehicle for magnetism and other effects.

iii) These people base their science not on indivisible atoms but on what they'll call corpuscles or particles which are relatively stable but which need not by metaphysically first principles.

d) On the other hand, if these are relatively common sense particles, they're not yet simply the smallest pieces of everyday substances like iron, gold, sulfur or water.

i) Again, there's much disagreement about what the smallest regularl occuring corpuscles are. In fact, this question plays little role in science except occasionally if people believe in only one sort of particle.

ii) But from viewpoint of modern use of term, these are all sub-atomi particles. Throughout eighteenth century a particle of gold or of some other stable laboratory substance will be thought of by almost everyone as composed of still other smaller particles in relatively stable union.

iii) If it's common sensical view as compared with Greek atomism, it's by no means so nearly related to laboratory operations as it will become during the nineteenth century.

3. This tells you largely what atoms are not which is perhaps a necessary preliminary to telling you what atomism or corpuscularism is. Can list it's main positive elements as follows:

   a) Matter exists in (relatively) stable particles.

   b) These have only Primary qualities, otherwise they're neutral.

   c) Fundamental Laws are those which govern corpuscular motion and interaction. Everything else is to be derived from these few fundamental laws.

      i) Newton's laws are fundamentally corpuscular in first instance. Applicability to gross bodies must be derived.

      ii) And not only gross bodies that must be derived but also qualities Thus heat, taste, color all other affections of bodies are to be explained ultimately in terms of the arrangment, motion, interaction, of qualitatively neutral particles.

4. As we go on we'll discover occasional pockets of resistance to this view.

   a) Particularly will find groups recurring who insist that this whole view of nature is too mechanical; that it deprives nature of life, warmth, vivacity, and all that makes it bearable.

   b) They will insist on a more organic, wholistic approach that will again make the qualities themselves real, as they had been earlier.

   c) But taking an overview and concentrating on scientists, the view just described is the background belief of all major scientists almost

from middle of 17th-century, well before Newton.

i) Thus it's a view that provides background for Newton's work.

ii) His success in applying it to motion and optics helps give it prestige in 18th century.

iii) And in that century extending it to other fields is a major part of the program for many scientists.

5. Only -- my last point about corpuscularism but one to watch for in your reading and one that at least some of next week's precepts can consider in relation to electricity -- Newton makes one change in the view.

a) One that's not by any means immediately accepted and that creates a fundamental cleavage for at least a few sciences during the eighteenth century.

b) In all pre-Newton corpuscular theories and many after his death, particles interact only by impact. There can't be built in attraction. That's not a primary quality.

c) Others are content to postulate forces between particles, and during the eighteenth century that view very gradually wins out.

d) If you watch your reading carefully in Cohen, you'll notice at least one case where it makes a big difference. Electricity.

e) So long as electrical attractions and repulsions must be handled by impact of effluvia, there's trouble. The transition to action at a distance is vitally important.

III. HEAT AS AN EXAMPLE

1. This is only one of a number of points where attention to reading about electricity should lend point to a number of the distinctions and themes I've been developing in this lecture and last.
   a) They'll also come out both in reading and lectures on chemistry with which I'll begin tomorrow.
   b) Meanwhile, in the moments remaining this morning, want to show schematically how this structure works out by making a few remarks about development of the study of heat.
2. Unlike electricity, one can find much discussion of heat in antiquity and the middle ages.
   a) It's one of the four fundamental elementary qualities, and as such shows up ad nauseum in discussions of the nature of bodies and of qualitative change.
   b) Also, it's been noted that all living things require heat and many of them maintain themselves at higher temperature than environment.
      i) Failure in this respect is sign of illness.
      ii) Thus heat figures both in medical discussion, through fever, and in discussion of nature of life and vital spirits.
   c) With this goes a good deal of lore about putative effects of extreme heat and cold, curative power of mild heat, and so on. But very little of the sort of information from which one might generalize to thermal regularities.

3. Situation doesn't begin to change until 17th century, and then two things are involved.

   a) First is an instrument, the thermometer. One of the flood of new devices that characterize the century.

      i) First sign is 1600, Galileo's thermobaroscope. Both temp & pressure, tho G doesn't know that.

      ii) Continuing development through century. Sealed alchohol in glass by 1641. Air thermometer before 1700.

   b) Other factor is clearly the new passion which emerges in 17th century for collecting a miscellany of information in practically any field.

      i) Bacon collects gigantic list of observations on heat. Boyle writes a Natural History of Heat and Cold. It's a favorite subject of experimentation for the Italian Accademia del Cimento.

      ii) And in much of this experimentation the thermometer is involved. Try it in almost every conceivable way. In mines and caves. In vacuum and under pressure. In snow and candle flame and in all sorts of mixtures.

   c) With, as again you might expect, very little in the way of useful or systematic result. The observations made in the period are a morass.

      i) Many are not reproducible. Others tell nothing not known.

      ii) This is prelude to science but not science.

      iii) True even [illegible]

4. Next stage develops only slowly and in ways that are hard to recognize between perhaps 1710 and about 1750.

   a) This is period in which all the standard temp scales develop. Fahr., Centigrade, and Reaumur. The end of the day in which everyone invents his own fixed points. (And what fixed points. Hottest day of summer and coldest of winter. Ice, snow, candle flame, body heat, butter melting, and so on.)

   b) With this comes subtler change, but one that's still more important.

      i) In literature of 17th century thermometer is as much a subject to be experimented on as with. An object of expt rather than tool

      ii) In eighteenth century it's increasingly a tool, with resulting shift in observations and some in concepts.

      iii) You know, I think, that touch and thermometer don't give same results. But you don't get concepts like specific and latent heat until you decide that it's thermometer rather than touch that measures temperature.

      iv) Thermometer must now define the subject matter. A state we take for granted, but should not.

   c) And it's only when this has happened that we find the beginning of some systematic concentration on a few types of experiments that prove particularly revealing.

      i) Method of mixtures and comparative rates of heating of different substances.

ii) Find these beging performed in a number of places independently from about 1745.

d) Though what happens next is complex in detail, from our present perspective it's also ~~just~~ the inevitable.

i) With these instruments and this ~~xxxx~~ sort of experimentation established, the doctrines of specific heat, latent heat, and a generally material theory of heat emerge in bits and pieces from a number of places in the next thirty years.

ii) It's not that part we have to understand, but why it could have been so long coming.

The Sciences in 1750

1. Cleavages in Status
2. " in Developmental Pattern
3. " in Method
4 " in Institutional Loci

Precept List are Posted
Change in Precept hours. One moved from Wedn. 9:40 to 11:40
More Reading Lists

HISTORY 336 -- LECTURE 2 SEE BACK.

Science in 1750

I. THE CONTRAST and its DEVELOPMENTAL COUNTERPART

1. Said last time that I meant today to set up at least one main theme of the course by situating myself in the mid-18th century, and asking about its overall state of achievement and well-being.

   a) What fields have flourished, what languished? Perhaps a bit about why

   b) What do scientists in general think the world is like?

   c) What do they think are the legitimate methods of science.

2. That's my program for today, and I start by suggesting that to me the most striking result of a survey of the sciences at mid-century is the contrast it produces.

   a) With all sorts of routine apologies for the oversimplifications and occasional distortions involved, I suggest that it is historically very illuminating to consider the sciences in mid-18th century divided into two groups which I shall call Classical Sciences and Baconian Sciences.

   b) No attempt to be exhaustive, but it will illustrate what I have in mind to list some individual fields under these headings.

   c) Baconian: Electricity, heat, phys. optics, chemistry, geology, (biology, excepting med. parts)

DID NOT DO INSTIT. STUFF.

THIS IS OK IN PRINCIPLE, BUT I HANDLED IT BADLY. NO GIFT OF GAB.

ALSO SOME REPETIONS NEED ELIMINATING. IT'S EASY TO SPEND TOO MUCH TIME ON ACHIEVEMENTS IN MATH, ETC. AT START. CUT THIS TO BONE AND REDISTRIB.

MUST SAY MORE OF WHAT BACONIANISM IS: BOTH EXPERIMENTALISM AND NAT. HIST. & INVSTR.

B3 IS NOW SOMEWHAT BIT ABNT CLASSIC = IMPTV OBSERV IS NEITHER CLEAR NOR PERS.

d) To be contrasted with classical: Math, astronomy, Mechanics both statics and dynamics, geom. optics, (anatomy, physiology).

3. Now ask, excluding inevitable nuances, what's the difference between these two groups, and suggest that most prominent answer is simply the extent of their achievement, amount of solid, accepted, systematic knowledge they have to show.

a) Math: Plane and solid geometry of a power and subtlety we don't dream of; Analytic geometry; algebra of real numbers; calculus.

i) No abstract mathematics -- real space, real numbers.

ii) Nor has calculus gained all of its most powerful techniques -- many functions still to be investigated.

iii) But full basis of modern "physcists math" combined with rapid progress in the investigation of special series, special functions and so on.

iv) In 1750 the great days for the development of refined analysis lie just ahead. Bernoulli's have ranked. Euler is Antiq. Lagrange & Laplace also chart to come.

b) Astonomy even more obvious. Copernican system, Kepler's Laws, Newton's explanation of them, mathematical theories for orbits of planets, comets, and so on, including perturbation theory.

i) Not much on stars except position. But enough of this backed by mech principles so that 1750, Thomas Wright, Theory of the Universe, recognizing dish shaped distrib of Milky Way; 1755, I. Kant, Nebular Hypothesis. Formation of solar system by gravcond.

c) Point is perhaps obvious for mechanics. Statics just as we know it except for most sophisticated formulations. Dynamics, reasonably nearly compete for point particles, much still to be done for rigid bodies, but well on way.

i) Work of Euler is at its peak. Lagrange & Laplace lie just ahead.

ii) Excepting a few of the most abstract formulations, Hamiltonian Kam field will be entirely frozen in another fifty years.

d) Skip over geometric optics with the remark that everything which can be done with light-ray constructions has been done both for mirrors of all shapes and lenses.

e) For medical-biological sciences situation is not quite so clear cut. Reasons we'll return to make 1750 a bit late, a less crucial period.

i) Still, can say that structure of HUMAN body, in so far as it can be discovered without systematic use of microscope, is quite well and generally known.

ii) Skeleton, muscular system, arterial and venous system, nervous system all quite well mapped out. Ditto lymphatics. Many glands are known. And so on.

iii) Physiology is not so advanced, and there is far less agreement about what has been achieved. Basically, the chemistry required is still unavailable. On the other hand, circulation and its mechanics are under quite good control; ditto mechanics of musculature; respiration and burning processes; some basic nerve routes

74. This is a record of magnificent achievement, and there's very very little to compare with it in my other group, Baconian Sciences.

a) Here I won't attempt an item by item analysis, for these are the sciences we'll be examining in the immediate future, at least in selected examples. Heat, electricity, chemistry in the near future.

b) Instead just a few overall generalizations to be illustrated later.

i) In these fields there's a great deal of activity, of experimentation, observation, publication. Perhaps more actual activity here than in other fields, exceptn critical.

ii) But it has not yet added up to a great deal of achievement. Except perhaps for Linnaeus in botany and Franklin in electricity -- men who are working at just this time -- none of these fields has yet produced a Copernicus, Kepler, Vesalius, Harvey, Newton.

iii) What they possess is a lot of assorted facts without much agreement about what's reliable and important, what's not.

iv) A number of competing interpretations, none of which goes very far as explanation and none of which is able to win universal or almost universal assent.

5c) Unlike the classical sciences, these are fields which have not yet come of age.

a) An important distinction for us because ITS symptomatic of a still more basic cleavage -- one that's still clearer if we look forward another hundred years and back about 150. Call it dist. of develop. path

5. O.K. This is my basic cleavage at or just before, mid-century. I give it particular emphasis here for three reasons.

a) First to warn you that, though a man may call himself a historian of science, he must often act as a historian of the various sciences.

i) It's not a single monolithic enterprise all parts growing together. Nor are all parts necessarily fertilized by same methods, same environment.

ii) But though can't always talk of science as one, it's equally unfortunate to take the list of modern science departments and suppose each of these is self-contained independent enterprise at all times.

iii) Instead historian must look for natural groupings, the viable professional or quasi-professional enterprises of a given time.

b) That hints my second point which is simply that these historically grounded cleavages are important because they tell things about nature of fields involved and about their development.

i) That the point -- correlates of cleavages -- to which I'm about to return.

c) Finally I emphasize this cleavage because it isolates some very impt novelties of 19th-century.

i) Look a century ahead from 1750, find cleavage largely vanished.

ii) Period in which Baconian sciences do "come of age" and also in which manyof them merge with classical sciences. Physics is form for example

iii) Furthermore, this merger proves consequential in a number of way of which I'll here mention just one . . . a very long anticipation. If one looks to the very end of the 19th century for the strains in Newtonian thought that bring the 20th century revolutions in physics, then one must I think conclude that one of their very important sources is just this new sort of more mathematical Baconian sciences which has been produced by the merger of ~~the~~ two previously distinct sets of fields.

iv) At least I shall want to argue a thesis of that sort as we go on.

Big Power

6. Turn now to developing correlates of the cleavage introduced in terms of achievement at mid-century. Find I've largely anticipated my first one, which is Difference in Developmental Pattern of Two Groups.

   a) Have already ~~xxxxxxxx~~ mentioned the difference in rate of development during century after 1750, and I might now simply underline that point before looking back in time.

   b) Suggested that in 1750 or just before, none of the Baconian sciences had found a Newton.

b) Looking forward a century the cleavage has been virtually erased. Now the Newton's have arrived.

i) Consider just two fields, electricity and chemistry, and let me throw names at you. Don't worry if you haven't heard of them;; most of them will come again.

ii) In electricity, Franklin is at work. Coulomb, Poisson, Ampère, Volta, ~~Faraday, Ohm~~ Oersted, Ohm, Faraday, Gauss, Green are all in the next century. Use Thom cause They give names to Laws & Units.

iii) In chemistry you'lllikely have heard the name only of Boyle in the period before this. Priestley, Lavoisier, Dalton, Avogadro are all within the next sixty years.

The-for Boyle's law! Let down!

iv) Period of immensely rapid transformation.

c) Look back instead -- from 1750 to 1600, a century-and-a-half before - and find a contrast of a rather different sort.

i) Classical sciences have not uniformly had their Newton, but they are all well established and long established disciplines with famous names and widely read works.

ii) Euclid, Aristotle, Archimedes, Ptolemy, Galen have between them produces standard works in all these fields, and they've been used as a basis for subsequent work. That's why I call these fields Classical.

d) Contrast the Baconian sciences in or around 1600. I suggest they don't exist at all OR they don't exist as sciences.

i) Electricity is in first category. People who write histories of electricity begin with antiquity. But they have to collect observations scattered through ancient literary texts. Amber, lode stone, (copper nails), St. Elmo's fire. No correlation, no field of work. That starts from Gilbert in just after in 17th century.

e ii) Or chemistry as another, though very different example. Here there's been vast activity, but there hasn't been a field of learned work.

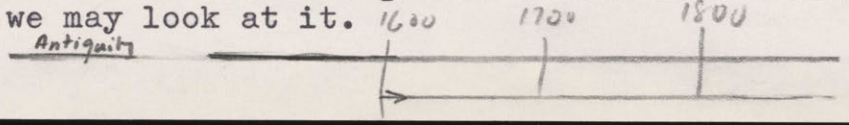
iii) Very important technological tradition. Vast and very potent recipes -- glass, ceramics, soap, gunpowder, acids, metallurgy.

iv) Also, quite important alchemical tradition. The adepts who strive for the philosopher stone which will make gold or grant enternal life. But who, like the technologists, hide their recipes and talk in parables.

iv) Look for this particularly in Boas book in 2nd reading assignment for a sense of the transformation in the status of chemistry as a learned pursuit.

6. Now let me summarize in crude diagramatic form what's so far been said in order that we may look at it.

a) Classical
Baconian



II. CLEAVAGE IN METHOD AND INSTITUTIONS

1. Now ~~return to second of these three points, and try quickly to suggest two of the major correlates of this distinction that I've so far been drawing.~~ continue this discussion of correlates and deal briefly with just two or. First I describe roughly as methodological, the second as institutional.

2. And can get at both of them together by asking baldly whether one can at all understand why classical sciences should have developed so very much sooner than others.

   a) Obviously too big a question, demands a separate answer for each, and no answer is likely to be entirely final.

   b) Nevertheless, can make a gross stab at understanding, and I'd begin by suggesting that all classical sciences share one or both of a pair of significant characteristics.

   c) Either they are socially very important (inchit), or they can develop on the basis of pretty simple everyday observation, or both.

   d) Baconian sciences -- excepting chemistry (much pr.d) -- don't seem at the start of great practical value, and they all require a good deal of fooling around and experimenting with fairly elaborate equipment before they are likely to disclose much regularity.

3. Point will become a bit clearer with even brief examples.

   a) Math, though it quickly gets away, begins in primitive record keeping and surveying.

b) Astronomy in calendar keeping, then omens, then astrology. That's what supports it for centuries.

c) Anatomy and physiology in medicine.

4. Two of these fields, anatomy and astronomy, do call for a good deal of esoteric observation, but they're also the ones society can't drop.

a) The other fields, mechanics, geom. optics, are ones that can be developed a long way with a bit of geometry and algebra and with very crude observation.

b) Stevin's incline as a ~~paradigm~~. ~~Thus~~ Shadows, reflections, do optics. An awful lot for very little. Study of motion doesn't take much more

5. What it takes to do Baconian science we'll see in more detail as we go on. But I would at this point dogmatically suggest that for most of them it takes instruments, experiments, and a concern with details about nature for their own sake.

a) These characteristics have not accompanied the sciences until early modern times.

b) Before 1590, for example, there've been almost no scientific instruments except a few for naked eye observation of the heavens, plus scalpel and forceps of surgeon.

c) Century after that date brings telescope, microscope, thermometer, barometer, electroscope, air pump, and much chem apparatus from crafts.

d) Simultaneously, for reasons I don't now even want to try to speculate about, many men begin to collect all sorts of odd and miscellaneous information about nature. freaks, and fossils, and plants; various of the new instruments and gadgets (3rd Voyage of Gulliver); and all sorts of info about what happens if you torture nature with these instruments.

e) This is the Baconian movement, about which there's just a bit more in your reading and about which far more might be said if it had not flourished largely before this course begins.

f) But even this much should make clear what I mean by methodological distinction. This is an experimental and exploratory science as compared with an observational, systematic, and often mathematical science.

g) With its dependence on new instruments and new observations, it may be no wonder that it makes so little systematic headway during its first century and a half.

6. That's what I mean by the methodological. The institutional traces to the same differences of character.

a) Just because they are old and because society needs men who can do them, the classical sciences have long since found institutional homes. Places where they are taught. Places where research, or what passes for research is often done.

b) For medicine and its correlates, this is the medical school. An institution with ancient roots and a long medieval tradition.

11 & 12 placed w.H next locker.

c) There's a famous and complex constellation of events in the 17th century known usually as the Scientific Revolution and celebrated as the origin of modern science.

i) On the one had it stands for substantive scientific work of Copernicus, Galileo, Newton, Vesalius, Harvey.

ii) Second, it points to the new methods characteristic of the period, more particularly to the Baconian movement and the concern with systematic and instrumental experimentation.

iii) And finally it points to the new institutional locus for science, the new national groups, particularly Royal Society and French Academy. ALSO JOURNALS, Modes of Communication.

e) Often suggested that this is beginning of modern science, and that everything which has happened since follows by a straightforward extension of the understanding, the methods, the institutions then achieved.

i) Now one cannot at all doubt the importance of the 17th-century to what's happened since nor question, I should think, the fact that a revolutionary upheaval did occur then.

ii) But it is nevertheless, I think, a mistake to see all of modernity emerging by a sort of inevitable logic from the achievements of that time.

iii) Instead I'd suggest one may look for a second scientific rev in

nineteenthcentury.

iv) One which is again characterized by drastic alterations in the same three areas. Many substantive breakthroughs -- decisive alterations in theory; much methodological change and introduction of old methods into new areas and new combinations with older methods; and much institutional change including both a vast professionalization of science and a considerable merger of science with engineering.

v) It's from this constellation, not the 17th century, that we acquire the pattern most familiar to us today.

HISTORY 336 -- Lecture 4

I. INTRODUCTION

1. Begin, this morning, the first of what must now be just two lectures on development of chemistry to very nearly the mid-nineteenth century.

   a) Because time is short and reading especially good want to integrate my lectures more closely with reading than is usually possible.

   b) Reading deals particularly with chemical revolution of 1870's and with work of Dalton in first decade of 19th century. I'll talk this morning particularly about background for Chemical Revolution ~~this morning~~ and next time about certain bands that connect the work of Lavoisier to that of Dalton. About latter itself I'll leave to the reading.

   c) Though notice is too short, it would be particularly helpful towards this end if you'd manage to read Gillispie, 202-241 by tomorrow. It's the material that caps the pattern I'm after for this morning and prepares the way for what's to come tomorrow.

2. Havning asked you to do that reading let me add that you apparently won't now be able to do the Boas.

   a) Thought there two copies, one on reserve shelves, but there turns out to be only the Pearson copy with no more to be had.

   b) If possible read the first of the two assigned chapters later in the semester, but don't worry about the situation. It's known.

This one went quite well.
I dragged a bit at beginning
and had to pull [illegible]
bit hard.

2. Topic itself I can perhaps best set up as follows.

a) Prevalent view of development of modern science suggests that methods and attitudes were discovered in 17th century -- THE DISCOVERY OF SCIENCE OR OF HOW TO DO IT. These methods have gradually extended scope and range since. But could all have been there.

b) Thus in Butterfield, book some of you will have met in History 102, we have "Belated Scientific Revolution in Chemistry" for discussion of work of Lavoisier, et al.

c) My remarks about classical vs Baconian sciences and their different developmental patterns are intended to set me against that view of the situation.

i) At least one other set of sciences responding to somewhat diff methods and developing through a somewhat different revolution, one that begins in late 18th but continues into 19th century.

ii) Chemistry seems to me one of these.

d) Thus, though I agree with the implication that chemistry did not until close of 18th century gain maturity or power resembling that which dynamics, say, gained in 17th century, I would deny that that was simply because chemists didn't pick up scientific methods quickly enough.

e) There were a number of things which had to occur before work of Lavoisier could be done. I want to talk about ~~four~~ three of these this morning.

HISTORY 336 -- Lecture 20

The Foundation of Organic Chemistry

I. INTRODUCTION

1. I suddenly discover that, though the fruit trees are still scarcely in bloom, there are only two weeks of regular classes left to us.
   a) Seems worth, therefore, taking a brief look at issues still left to cover.
   b) Or rather -- since there's still an almost infinite number of topics with which we might deal -- seems worth a look at what I think it still may be reasonable to try.
2. Last week's reading and lectures took a principal subject in biology into the early twentieth century.
   a) Obviously not many of you will have gotten much sense of the details of the Watson-Crick model.
   b) But I think most of you will have had at least some realization of the manner in which, at this point, chemistry ties back to biology as the manner of encoding genetic information.
   c) That's the heart of what's at the center of most of the most urgent and exciting problems of contemporary biology.
3. In the time that now remains in the course want to try to do something a bit similar with two other principal sorts of issues that have arisen in the course.

The went quite well.

I was, however, badly nobbled at end over Th. Id talked quite fast throughout. It ought to be shortened a bit. Note, Th, The I did really do the spelling out intended.

a) First of these is relation of science to technology and to industry.

   i) Repeatedly have suggested that it's radically transformed in last part of 19th century, and now want to look at example of that transformation.

   ii) Pick what's historically the oldest or one of two oldest fields: the synthetic dye industry.

   iii) This morning discuss development of organic chemistry that's prerequisite to that development. Next lecture will discuss the change in chemical industry that results and the new institutional forms that then emerge.

b) Have also suggested, however, that another characteristic modern development is the breakdown of modes of physical explanation that had been with science in one way or another since 17th century.

   i) That's topic I'll speak to next week, choosing my illustrative material particularly from the early development of quantum theory.

MATHEMATIZATION OF BACONIAN SCIENCE

I. What, ~~mathematization is~~, ~~and~~ where, ~~and~~ when ~~it occurs~~.

II. Requisites for mathematization:

~~Development of Mechanics~~

~~Institutional merger~~

~~Internal development of science to be mathematized.~~

J. Fourier 1768-1830

A. M. Ampère 1775-1836

S. D. Poisson, 1781-1840

A. Fresnel, 1788-1827

S. Carnot, 1796-1832

This week picking up and starting. I did not get to any real point which leaves too much for lecture 10.

Also, I'm a bit worried about exaggeration of individual role. Volta and Oersted are both downplayed in Progress of Physics. What does that mean.

HISTORY 336 -- Lecture 9

Electricity no. 1

I. MATHEMATIZATION OF (SOME) BACONIAN SCIENCE

1. At the very beginning of the semester I described for you two groups of sciences that follow rather different historical patterns through all of early modern times:

   a) Baconian sciences which include heat, electricity, chemistry, etc. New fields created by what I call the Baconian movement of the 17th century.

   b) Classical or traditional sciences -- particularly astronomy, math, study of motion of massy bodies.

   c) So far we've looked largely at the Baconian group, and then at some other developments at end of 19th century that help start new current in science of 19th century. Industrial revolution & idealistic phil which will here and there change characteristic approach of 18th century.

   d) Now want to begin talking about what happens, against this new background of technology and philosophy, when these two previously largely separate groups begin to intermix and cross-fertilize.

   e) To do this will clearly need to say at least a few words about what's been happening in the classical sciences.

      i) But they'll be very few for I know no way to handle high level mathematical physics in a course of this sort.

ii) But before attempting even that little let me make some general remarks about the nature of the phenomena I have in mind.

2. Describe its major feature under lecture title "Mathematization of (some) Baconian Science."

a) Had better begin by ~~underlining~~ inserting "some" to indicate that it's by no means the whole of Baconian science that we're now concerned with.

i) There is no mathematization of medical science or of biology unless one is to count the work of Mendel which is any case much later and has no impact until this century.

ii) In a less obvious sense I want soon to come back to there's not much mathematization of chemistry. Indeed, until after the advent of wave mechanics in the mid-1920's the only part of chemistry that was mathematical in sense I have in mind was "physical chemistry." And that did not come into existence until the last decade of the 19th-century, and was not quite accepted either by physicists or chemists when it did.

iii) So it's a very partial movement, and on the whole remains so even today. At beginning of 19th century and for some time afterwards embraces only three fields: Study of light, of heat, and of electricity.

iv) That restriction does not, however, make it any less consequential as you can perhaps see by noting that these three fields, with with mechanics and accoustics (both previously mathematized) are the subject matter of physics until the 20th century, when addit. E.

v) What really confronts us here is the creation of the field of physics in a recognizably modern sense, though I shall shortly want to suggest one important respect in which the change remains incomplete in several countries until after the first world war.

vi) And if this is not enough to make their emergence as mathematical fields seem important, I might also point out that it is just these three fields -- elect and light by way of Maxwell's field theory and heat by way of thermo and stat mech th that ultimately collide with the older Newtonian world-view at the beginning of this century and brigg about the transition to relativistic and quantum mechanics.

b) Probably these remarks already make clear what I mean by "mathematization."

Black a colonizing greatly extended it:

i) Not just reduction to numbers or quantification. That's existed in study of heat since adoption of standard thermometer scales in early 18th century. Increasing has existed in chemistry also during the century, climaxed by Lavoisier's consistent and immensely consequential use of the chemical balance.

ii) These are consequential developments, particularly when people learn -- as Black and Lavoisier do -- to make the numbers display a conservation principle, so that given certain numbers one can predict others.

iii) Nevertheless, it's only a first step and the second is even more striking in the extra power it gives a scientific field.

iv) What I have in mind now is the ability to formulate basic principles of a science in a fully mathematical form -- usually in 2nd order partial diff equations. Then do purely mathematical deduction of solutions of this equation. Finally check these against results of particular laboratory measurements.

$\vec{F} = m\frac{d^2\vec{r}}{dt^2}$

v) What results, of course, is in part an economy of theoretical notions. More important, however, is the new depth and precision of prediction that mathematization permits. Partly important because it points to totally unexpected effects like propagation of electromagnetic waves following from math laws for electricity. Equally important because precision of prediction allows also precision of refutation or at least of trouble making. Which again proves repeatedly consequential -- nowhere more so than in the disagreements between math theory and experiment that lead to Planck's conception of the quantum at beginning of this century.

c) Mathematization in this sense was not new in the early 19th century.

ii) Something very like it had existed in astronomy since antiquity, and it's only because it did that Copernican system came into existence without telescope.

ii) This mathematization extends into study of terrestrial motion and links it to ~~terrestrial~~ through work of Galileo and Newton in 17th century. And these techniques are considerably refined during 18th.

d) But -- excepting the use of geometry in optical constructions -- all the mathematization that has preceded concerns motion of massive bodies. Now extends rapidly to a number of fields of a different sort. Not motion of massive bodies and perhaps not motion of bodies at all

e) Concentration in both space and time with which this occurs is extraordinary.

i) All done by Frenchmen, most of it in Paris, and concentrated in years 1810-1830. Two decades which I could reduce to 15 years without leaving out essentials.

ii) Have put on board names of five of the men most centrally involved, and you'll note that less than thirty years separates their dates of birth, and that all are French.

iii) This week and next I'll be discussing work of three of these men: Poisson, Ampère, and Carnot. Other two figure in your reading, Fresnel prominently.

iv) Therefore, for the moment, I'll only distribute them among the fields to whose mathematization they contribute so greatly.

For heat the main figures are Fourier (mathematical treatment of heat flow in terms of hydrodynamic equation plus new math) and Carnot with significant assist from Poisson.

Electricity it's first Poisson for electrostatic and magnetostatic theory.

For light it's Fresnel and again Poisson whose ubiquitous. Here for one of numberous math theories of aetherial medium.

II. REQUISITES FOR MATHEMATIZATION

1. How does this happen? Meaning, several questions at once: What has happened that accounts for math at all? Why, when it comes, is it so quick and so local.

   a) Again I raise a question that hasn't been posed often enough to have a clear solution on which colleagues have agreed. Much disguised, in fact, by prevalent impression of linear march since 17th century.

   b) But whatever its final solution may be, it's clear that three things are deeply involved.

      i) Development of the classical sciences, development of the Baconian sciences, and institutional change.

      ii) Discuss them in slightly different order.

2. Classical science which is, of course, most relevant here is Newton's mechanics.

   a) The Principia leaves this subject in conceptually highly developed state, but in one that's mathematically full of imprecisions and ambiguities. It's the work of the 18th century to straighten them out.

   b) Part of the problem is that Newton has stated all his laws verbally and has used a quasi-geometric method in his published solutions.

      i) They must be translated into mathematical language, the language of the calculus.

      ii) In doing this it must be recognized that Newton's Laws as stated

apply only to mass points. These do go readily into calculus form.

iii) But the problem for an aggregate of points, rigidly connected as in a solid body or connected by springs or cords, is a major extension.

iv) It's almost the middle of the century before one finds any sort of partial differential equation for ~~xxxxxxxxxxxx~~ systems contain more than one masspoint

v) Lagrange's Mechanique analytique, perhaps the first full reformulation in totally math language doesn't appear until 1788.

vi) By no means clear what part of this work is essential to what follows, but the men involved with the mathematization generally all are adept with numerous 2nd order partial differential equations. And it's the late decades of the 18th century before even the experts are consistently proceeding in that way.

c) Part of the requisite is then this general experience with putting problems into mathematical form and solving the equations that result

i) There are also, however, certain particular fields of work in 18th century mechanics that make a particular contribution to the 19th century mathematization.



ii) One very important direction of effort is hydrodynamics. The study of the motion of fluids under pressure.

iii) This is field from which Fourier gets his equation of motion for caloric in his classic memoir. Still leaves solutions to him.

iv) Another standard field much worked on is theory of sound and vibrating strings. Propagation, pipes, vibrating

v) Some reason to think, at least in case of Thomas Young, that even the qualitative idea of wave theory of light may be suggested by such things as theory of beats which come from 18th century theory of sound. Young's been concerned with music & with ear & tone.

vi) And certainly the mathematical models which Fresnel and his immediate followers use to describe sound as small transverse vibrations of a medium come directly out of, though again with much elaboration, this prior work on strings and on the atmosphere.

vii) Finally, one rather more surprising example, an important problem for the 18th century has been that of the figure of the earth. Also problem of tides.

viii) It's problem of how fluid will distribute itself if all its particles attract each other with inverse square force and further forces due to spin and (tides) attraction of external body are imposed on it.

ix) Newton has a solution, but it's challenged first physically and then mathematically. But the math that's developed to solve this problem is almost exactly that used by Poisson in 1812, in his first great memoir on way in which electrical fluid will distribute itself over almost spherical surface or over two surfaces when both are spheres at a specified distance.

d) So particular parts of the development of mechanics in 18th century are crucial.

3. But it's not the whole story for it does very little to explain the close proximity in either space or time of the work in these separate fields.

a) Actually, it tells you why none of this happened in England, for you know from your reading that mathematics at this level was simply unknown in England at this time.

b) But the mathematics I've just discussed was developed as much in Switzerland, in Germany, and in Russia as it was France. Why the sudden concentration?

c) To which the answer clearly has to be institutional. Every one of these men was associated closely with the École polytechnique.

i) Fourier an early faculty member, Ampère somewhat later but before work of concern to us is done.

ii) Poisson, perhaps key figure in all of this, is both one of the first students and shortly after a member of faculty.

iii) Both Fresnel and Carnot are products of the school. Men who have graduated and gone on to engineering careers for which school was supposed to train them.

d) Ecole polytechnique comes up again and again in your reading, so that there's very little I need say about it here.

i) There is, however, one aspect of it that needs an emphasis it rarely gets.

ii) In their eagerness to reorganize education along rational lines and simultaneously put science at the service of the state by producing skilled engineers, the members of the Directory not only construct the first strictly scientific school, and also assemble under one roof what's probably greatest assemblage ~~(per~~ (in percentage terms) ever. They also design a curriculum quite different from any known before.

iii) Men who've reformed mechanics have typically been Professors of Math at a University or School. Occasionally also Prof. of Astronomy.

iv) Men who developed science of heat and electricity at least have generally been amateurs except for those who've been doctors attached to medical school. Except in medical faculty, none have had University positions.

v) Now the Ecole puts both parts of this scientific subject matter together in a single curriculum extending from pure mathematics, through mechanics, perspective, engineering drawing, to the experimental physical subject matters and finally to chemistry. Furthermore this is done in an institution that also possesses demonstration equipment and student laboratories.

vi) As you know its a model for much that comes later, particularly for almost all instruction in this country and formuch in Germany. In France, strangely enough, model tech sch for struct engineering and is not very basic for scientific educ. as such.

vii) That, however, is not my main point at present. Rather that's the obvious remark that it's terribly hard to see this sudden and localized mathematization of physics as anything but a product of the new curriculum.

4. But even the development of math and the common institutional base for two previously separate traditions won't altogether solve our problems. At least in most of these cases it's also clear that the science being mathematized had to first reach a certain state:

   a) Here easiest and clearest with heat. Caloric theory had to be developed in some form to permit work in this field of Fourier, Poisson, Carnot.

   b) In optics, actually, it's not clear that a similar pattern holds. Basic experimental situation and fundamental theory at end of 18th century is not obviously different from what it had been earlier, tho some new polarization effects are now being uncovered.

   c) Electricity, however, shows same effect in somewhat subtler form that I'd like finally to sketch for you. It again will illustrate recurrent situation in development of science and application of numbers and then of math to them.

5. Just sketch an overall pattern:

   a) Before Franklin and mid-18th cent people, as you know, view electrical effects as due to efluvia. Actual push.

      i) When they measure electrical forces, which they do -- belief in numbers is often strong in the period -- they design accordingly.

HISTORY 336 -- Lecture 10

19th Century Elec.

I. PRELIMINARY

1. Last time did not quite get to last point on outline and do need it. Will therefore combine with matter for this lecture which is very closely related. So closely related that I have to:

   a) Remind you that, though both are develop. of elect. first part has additional exemplary function which attaches it to last lecture.

2. Before beginning ought probably make one other remark.

   a) Have somewhat changed my original plans for schedule of remaining lecture until vacation.

   b) Result, they're somewhat out of step with reading. Look ahead:

      i) Electricity wuthin Newtonian mold this morning.

      ii) Carnot and ideal engine ~~xxxxxxxxx~~ tomorrow and conservation of energy a week after. All 19th century principles & Newt. world views.

      iii) Kinetic theory and back to Faraday Maxwell in last ~~wk~~ lecture.

   c) Reading does all of electricity first and does the thermo in last week. Will make no difference if you'll read essay in Clagett volume next week.

III. DEVELOPMENT OF BACONIAN SCIENCE

1. Where we were last time. Third leg on tripod is dev of Bac Sci. (OVER)

Note also That the Galvani-Volta story is well covered by excerpts in Magie

a) Clear for heat

b) Not so clear for optics

c) Clear again in electricity in way I want to look a bit more at.

2. To get math electrostatics need a force law. People had been after one for some time.

i) But were thinking in terms effluvia. Thus:

THIS WENT BADLY.

① CAN'T TELL TO DO SO MUCH AT ONCE. GOT ONLY THRU AMPÈRE AND WAS BADLY RUSHED AT END. WOULD BE OK. WANT LEFTOVERS FROM 9, HYSTERESIS.

② The words fail us, but the gravity idea is idea of gravity. for example, the general principle of occident - hypothesis of discussion G.V. ... Brief Tour of Forces inevitable occidental wheel wheel L'Aja.

③ Some sense is order.

④ Better, probably, volt to split it. This from Faraday-Maxwell

p.11 is in 1966 Lahr

ii) Diagram: Electrostatic machine to plate under pan balance. Get numbers but can't do anything with them.

iii) This situation is changed by outcome of Franklin's examination of the Leyden jar. Once he sees that charge on inside of glass must act on charge outside the glass without itself passing through, Franklin is able (and he's the first) to distinguish clearly between the motion of electrical fluid and the motion of its effects.

iv) Thus have action at a distance between particles of fluid. This is, if you will, the Newtonian rather than Cartesian model.

v) Immediately it becomes easy or relatively so to determine the force that acts. Mentally or experimentally use point particles acting at a distance and examine the consequences.

vi) Between 1759 when Aepinus puts Franklin's theory in perfected form and 1785 when Coulomb does his classic measurements, three other people (Priestely, Robison, Cavendish) also show that force is inverse square or very near it.

vii) A quantitative generalization that's almost impossible to get before the theory takes an appropriate form comes very easily later.

viii) Watch as you read the Coulomb selection next week how much his understanding of the way electricity acts determines his detailed design.

(2)

Modes of Biol. Explanation

I. Organism as Machine, 1650-1750

~~Prelude: The~~ Body as polity of organs - Functionalism

Occultism vs. mechanism ~~in organic expl.~~

II. ~~The~~ "Mechanistic Vitalism", 1750-1850

~~Nature of the idea~~: "Organized matter"

Albrecht von Haller, 1707-1777 - Irritability.

~~The~~ L'Homme machine, 1748

III. Some Consequences

From organs to tissue: Xavier Bichat, 1771-1802

Animals & Plants

~~Power~~ Morphology

I. INTRODUCTION

1. I'm very sorry to have aborted yesterday's lecture barely after it had gotten under way.

   a) Twenty-four hours in bed has, however, somewhat alleviated the situation and I'm ready to try again.

      i) This time, however, will take much of it sitting down.

   b) At this stage of the semester I cannot hope to get quite back on schedule, but I'd not really expected when we began to be this close.

   c) Propose therefore to pick up yesterday's lecture again this morning and to give Friday's lecture on Thursday of next week.

      i) After that I'll do what I can to squeeze the next three into two, but it will unfortunately mean that I can't do as much with 20th century genetics as I'd hoped.

2. Returning now to the main theme I introduced lasttime, I shall take the introduction as finished and pick up with the substantive beginning on which I was just launched yesterday.

   a) Said then that established fields of biology in 17th century were anatomy and physiology.

   b) i) At level where we can follow it or need to, anatomical work is very far advanced, and it's the analysis of its results that now particularly concern us.

The is quite good despite
any breakdown. However, the
angled gearing does need
reducing slightly for low
RPM.

ii) This is task of physiologist who undertakes to explain body function.

b) And in 17th century he takes view that's been current with respect to these problems since antiquity.

i) Body is collection of organs hung on skeletal frame and connected by network of tubes.

c) This much of the position is scarcely avoidable and will remain with us throughout.

i) But on next series of questions -- are organs the ultimate units of physiological analysis? Are there lower level sub-units into which organs themselves should be analysed -- here there are immensely significant changes both in 17th century and again in 18th.

ii) It's these I want chiefly to consider.

3. Before the middle of the 17th-century the organs themselves were the ultimate units of analysis.

a) Each had a characteristic function, and the physiologists first task was to identify this function and display its relationship to the working of the sound body.

i) This is what I've called in the outline the "functional" view of the organism.

ii) Whole organism is a collection of organs, each with a special function to perform.

iii) Sound working of the whole organism depends on the function of each organ in proper balance.

iv) It's here that analogy to the body politic to the state enters -- one with which I vanished last time.

b) This functional view -- which allows explanation to cease when function of each organism has been identified and explained -- is by no means constant.

i) We shall see it significantly undercut at beginning of the 19th century, though it has a significant renaissance again before the century is done.

ii) But even while the functional view is dominant, identification of function is not quite the end of the explanatory chain.

iii) Must also ask: What sorts of functions may organs have? How are these functions themselves to be understood?

iv) It's with respect to these questions that main shifts of biological opinion occur in 17th and 18th century.

HISTORY 336 -- Lecture 15

Modes of Biological Explanation

I. THE SCIENTIFIC REVOLUTION IN BIOLOGICAL EXPLANATION

1. Want this morning to start out on a new topic in development of biological science:

a) Describe it initially as changing modes of explanation in biology, and suggest that much of the change in what biology was able to achieve is associated with such changes. At least as much, of course, with new physical ideas.

b) Initially my main concern will be with these modes of explanation as such. What sort of answer to questions about living process were acceptable as disposing of the question asked? Which seemed purely verbal rephrasings? Question begging.

i) But mean by the end of the lecture to be illustrating some of the main effects of these changes in mode of explanation. Will follow this next time and next week. pointing towards

ii) In this lecture that will actually bring me back to the question of plant classification in the period after Linnaeus, a subject broken off much in mid-stream during the last lecture. to verge of merger of

iii) And in my single lecture next week want to follow this even further in showing role of this new mode of explanation in development of the cell theory -- a transformation in biological thought which makes the cell the basic unit of living process and sees the plant or animal body as an assemblage of individual living organisms, each with an independent life and integrity.

This biol. ties with Naturphil. from last time. Next will see some effects on plant work in Darwin. Next week in cell theory

This went extremely well. Ted Brown cannot see Descartes. Cords. The nerves signal to brain - fluid pressure signals out again.

— - - - -

Brown also suggests that Hellen views, etc., does derive in part from Leibnitz's monadology and thus slows up Brown and Wolf earlier.

however

c) For me, the significance of this chapter in the development of biology transcends its intrinsic historical interest.

i) During much of the period we're concerned with biology is seen by its practitioners as a relatively backwards science.

ii) Question of appropriate mode of explanation is therefore in part question of the extent to which standards of other more mature sciences should be imported. Much of the argument turns on this question.

iii) Those of you in the social sciences, at least, and some of those even in parts of biology will not need reminding that those are still vital issues today.

2. Once again, in order to discover what happens in the 19th century have to go back to the scientific revolution of the 17th century.

a) In this case, pick up in that period two fields of science that are very definitely not new but that have a long ancient and medieval history.

b) The first of these is anatomy which is already very far advanced.

i) Bone structure, arterial and venous system, nervous system, principal organs have all been located and described in terms that, at the level of gross anatomy, are relatively accurate.

ii) Main discoveries remaining to be made are those of ductless glands and lymphatic system, both of which begin to be seen in 17th century, and neither of which plays major role in physiological explanation until later date.

c) Second field is, then, physiology which attempt to explain the workings of the human and animal body (and also increasingly plant body as well).

i) Furthermore, the first step in a description of this job is both obvious and -- over much of historical time -- constant.

ii) From antiquity through the middle ages and on to the 17th and 18th century, the physiologist sees the body as an assemblage of organs hung in a skeltal frame, and connected by fibers.

iii) His job is to understand how the individual organs function so that the body as a whole may do what it is observed to do.

iv) Both in antiquity and in the modern period the analogy to a society, a body politic, is frequently explicit. Each man like each organ has a special function. Life of state, like life of body, depends on their harmonious cooperation in their individual duties.

3. This is not an entirely permanent position. Part of what I want to indicate in this lecture and the next is that at start of 19th century first tissues and then cells replace organs as basic analytic units of biological explanation.

a) Nevertheless, for the entire period from antiquity to the late 18th century we can take the view that the basic division of the living organism is into organs.

b) This is first round of any explanation -- one says what an organ is for. But it immediately raises a second question, and one for which

opinion is by no means constant.

i) This is question -- What sort of functions may we attribute to organs? Or again, how may we understand the ability of organs to perform these tasks?

ii) With answers to these questions explanation ceases but there is a considerable shift or succession of shifts as to permissible explanation during the 17th and again during the 18th century.

4. In ancient~~-~~medieval tradition and for some time into the 17th century there is a considerable willingness to answer questions of this sort by attributing to individual organs propefties that ultimately come to be called occult or vital. Ko again " enschelm.

a) Having recognized function of an organ, scientist will say it has the innate ability to perform this function. This is its nature, its essence.

i) Give you just one example and, for brevity, use one that's expanded in your reading, the function of the heart.

b) It's early noted that ~~xxxx

to prevent overheating.

i) Even Harvey, who sees heart as pump and introduces that much of mechanism into physiology, still treats heart as source of vital heat. Lung cools blood

ii) It's an intrinsically hot body -- this is its defining property or a main one -- explanation ends here.

d) Similar modes of explanation apply to at least some of the other organs.

5. This is not in principal a bad way to proceed in science. Much is learned through this approach. Before we are through with the 18th and 19th century we shall see biology coming part way back to it with results that aren't always bad.

a) But it will be no surprise to hear that in 17th century this whole mode of doing science is increasing attacked by the new philosophers.

i) It's they who call it occult, purely verbal explantion. Molza, Daw.

ii) Insist that it be replaced by explanation in purely mechanical terms.

iii) It's just because this is what the century so much values that we remember Harvey for the heart as a pump and not for the heart as source of vital heat. Most books don't even tell you he held that view.

6. Give you just a few examples of what constitutes mechanical explanation.

a) Drawing my first from Descartes who, in biology as elsewhere, is

the first great exponent of mechanical explanation.

i) Explicitly compares bodies to the automata run by water power and pressure at Versailled. clockwork.

ii) Thus welcomes heart as pump but discards innate heat.

iii) Sees the nerves as hollow tubes which signal by compression of fluid they contain. Fluid signal to brain, pressure back.

iv) Thus famous first explanation of conditioned reflex. Child gets fire imprint and burned hand imprint on pineal gland side by side via ~~pressure~~ in nerves. Next time fire alone will produce withdrawal.

Borelli: Muscular contraction

b) Others will explain taste and smell by shape of corpuscles which stimulate it. Heat often now do to friction from the grinding process (Boerhaave).

c) There are still others.

7. Throughout most of later 17th and early 18th century this is main mode of physiological explanation among up-to-date and progressive physiologis

a) It has, in fact, only one permissible alternate so far as I can tell.

b) That's chemical explanation of some physiological processes. Digestion as fermentation, for example.

c) The one thing one may not do, however, is introduce into biological explanation some process or some force which is not also characteristic of inorganic nature. Whether chemical or physical the body is a machine. With a sould true, but not one that's used for expl. body

Problem of gravity

II. MECHANISTIC VITALISM IN THE 18th CENTURY

1. This is all admirably scientific and modern in its methodological purity. Biology is returning to it now, and it may now work.

a) But in the 18th century there are two troubles with it. Does clear/

i) Detailed examination of organs rarely supports suggested phys. explanation. Two examples:

No holes in nerves. Can't transmit pressure, pushes, pulls.

No rhombic structure in muscles.

ii) Furthermore, even where particular mechanical explanations can't be refuted this way, they don't introduce fruitful novelty. Vital explanation replaced with mechanical but nothing further comes of it.

b) Result is an increasing tendency after mid-century to admit into biology special forces applicable to the analysis of living organisms that are not ever displayed by inorganic nature.

2. I'll call the view that results the acceptance in biological explanation of VITALISTIC MECHANISM, a term that's got to be used with some care.

a) By vitalistic mean that biologists will now increasingly admit special forces characteristic of living tissue.

i) Muscle tissue, for example, is made up of same atoms and molecules as inorganic stuff. Long dead muscle tissue is made up of nothing else.

ii) But long-dead muscle tissue, being held together only by chemical forces, won't function as muscle tissue.

iii) What's lacking is a characteristic life force which gives further ORGANIZATION to these molecules and enables the tissue as a whole to function in ways not explicable without this non-physical force.

b) One example may make this view very persuasive and simultaneously indicate why the term mechanistic should still be applied.

i) Chhose it from work of Albrecht Haller, 1708-1777, who is probably the most influential of all 18th-century physiologists.

ii) His most famous single piece of work is the demonstration of muscle irritability and the "proof" that it's not an inorganic phenomena.

c) He points out that when first removed from a living animal bits of muscle tissue, intestingal tissue, and other bodily tissues, will contract at the ends and expand at middle when stimulated by touch, warm water, electricity, and other ways besides.

i) Act rather like a worm.

ii) But it ceases after a while when one has just dead physico-chemical stuff.

iii) Yet it's intrinsic to the tissue. Doesn't come via nervous impulse or anything of the sort. No nerves there. Tie them off if there are.

d) Thus have intrinsic property, quite strictly defined, of much organized or living tissue.

i) Hope is that by noting just a few other such vital forces seated in organic matter, one can succeed in explanation where physics and chemistry have failed.

e) Now perhaps you see why term Mechanistic still applies though these are special living forces.

i) First, because they're on a par with physical and chemical forces

ii) Innate to matter. Not disembodied spirits, NOT IDEAS towards which life process tends, ~~and not characteristic of whole organism, nor breath.~~

iii) Furthermore, their seat is in matter less organized, more primiti than the organs of the body. Clsoe to atomic level. It's the small chunk, even sometimes microscopic chunk of living tissue that displays them.

f) If the justice of the adjective mechanical still seems dubious, let ~~must~~ add the following bit of evidence to what's been said.

i) In the mid-18th century a famous book is produced by a Frenchman of the enlightenment. He's LaMetterie, and the book is Man a Machine.

ii) It's not much read, but it's become a symbol of the rationalism ~~materialist~~ and scientism of the enlightenment. Indeed it's ~~just~~ author has to flee France and his book is widely condemned for atheism.

iii) One supposes, or I always have, that is mechanical man is like Descartes' but without a soul.

iv(iv) I was therefore quite shocked to discover ~~recently~~ that it's not a bit like that -- LaMetterie's machine is made up of vital fibres just like Haller's. In fact, he's accused at the time of stealing the idea from Haller.

v) Yes, it's a machine made of parts functioning interms of known laws of force. But not just gravity, impact, and affinity. The man built like a watch, the clock metaphor in biology is now gone.

3. ~~Xxxxxxxx~~ Mechanical Vitalism therefore describes a genuinely novel mode of explanation that becomes increasingly important in biology during the later 18th century.

a) Let me, in what little time is left, begin to talk about some of its effects.

III. EFFECTS OF THE NEW MODE

1. Of which the first to be clearly manifest and one of the most important is an increasing switch of attention in physiology from organs as unit of analysis to tissue.

a) This appears most clearly in work of Xavier Bichat, 1771-1802, brilliant young French physiologist, who publishes a treatise on tissues in 1799 and a General ~~Physiology~~ Anatomy and Physiology in 1801, the year before his death.

b) In the first book he describes the twenty-one distinct types of tissue from which he thinks all animal bodies are composed.

c) In the second he applies the doctrines of the first to the description and explanation of body function.

i) Tissues are employed to build up organs and organ function is explained from more basic properties of tissue.

ii) Then body is built up from organs as before.

2. For physiology itself this mode of analysis proves particularly fruitful -- far more so than the earlier mechanical and chemical approaches had been -- though it's of course also true that as it's pursued during 19th century the vital forces which preside at its birth are increasingly replaced again by physical and chemical agency.

a) Some taste of this physiological line you will, however, get in Goodfield's book, and I don't propose now to pursue it further

b) Effects of new approach are not, however, all in physiology and do want from this point to examine two more that lie elsewhere in biology.

c) Job itself is for next week's lecture, but can already usefully begin to see how the new emphasis on tissue as unit leads us there.

3. One further consequence of the new analytic unit is that it makes people able once again to talk usefully about the similarity between animals and plants.

a) Tried in 17th century with organs. Rising sap was circulating blood. Plant respiration also studied. Some help, but didn't get far.

b) At level of tissue, however, parallels are far closer, and one of the major routes to the cell theory is exactly through comparison of animal and plant tissue that this new view permits.

i) Starts in France immediately after Bichat and comes to culmination in Germany in late 1830's.

c) But there's another equally important effect that's also via the plant world.

i) Turning from organs to tissue leads to deemphasis on organs and thus on function.

ii) What emerges with this shift in emphasis is an increasing attention to form, to what's called morphology, overall structural shape and design of organism.

iii) But this subject, which I also want briefly to talk about next time takes us right back to last subject. (Plant) classification.

iv) For what I did not get to say last time is that, though Linnaeus is thoroughly successful with his classification at the level of species and of genus, he does not manage in his published work to discover viable natural categories at higher level of family and order.

v) Here he counts pistils and stamens, uses essentially arbitary sorting system, and announces that the job of discoverying God's plan at higher level is still to be done.

d) It's 19th century that does that job, but in doing it relies essentially on a new emphasis on plant form.

i) As this is used, however, the relationships that turn up are just ones that prove terribly important to evolutionary theory and are simultaneous hard to fit with notion of divine plan there from the very beginning of things.

Botanical Taxonomy to Darwin

I. Establishment of a mature botany
   Carolus Linnaeus, 1707-1778
   Aspects of maturity, c. 1750
II. Problem of Classification
   The filing system
   species and their fixity
III. Natural Classification & Darwinism
   A. P. de Candolle, 1778-1841
   Form for Function in botany
   [Sources of morphology.]

START Fair

HISTORY 336 -- Lecture 16

Taxonomy and Morphology before Darwin

I. LINNAEUS & MATURE BOTANY, c. 1750

1. Want this morning to tie together in a concrete example several strands that have run through recent lectures and reading.

   a) Concrete example is development of botany -- particularly descriptive and classificatory botany.

      i) Could do the same with zoology, but botany actually starts sooner, develops further by beginning of 19th century, and I'll stick with it.

   b) That's my subject matter, then, but my object in dealing with it is somewhat larger.

      i) Before close mean to illustrate the manner in which philosophical current from last two lectures play into actual biological work.

      ii) And the way both of these together help supply the background for evolutionary theory, Darwinism.

2. Turning to botany make my usual remark that it was a Baconian science.

   a) Meaning that, except very briefly in antiquity (Theophrastus), knowledge of plants before the 16th century has been principally medical and agricultural.

   b) Only in 16th century that this begins to broaden to concern with plants at large and with systematizing them.

K" went very well. But
ever talking quick fast and
effectively, didn't get to start last
term or outlaw. Went overhead & I
anyway.

c) Do not, however, propose to follow this developmental process which we've seen before.

i) Instead, pick field up in mid-18th century where I'll consider it in form into which it's put by Carolus Linnaeus, 1707-1778, the man who really completes the professionalization of the subject.

ii) Won't really talk often about his work, but do take his sort of botany and attitudes towards it as symbolic.

iii) Movement has now come of age, and is set in ways in which it proceeds for some time.

3. What, then, does coming of age mean with respect to botany. Some of the same things as with physics or chemistry, but some others too.

a) Clearly, institutions. Medical schools plus botanical gardens.

i) Plentiful in 18th century and often with professorships. Not same sort of problem that chemistry and experimental physics face.

ii) These forms, and with them herbaria, another standard tool, can be traced through standard evolutionary pattern sicnce 16th century though not earlier.

b) What's more recent, however, and much of it Linnaeus' doing is world-wide system of communication between these centers.

i) His own collectors range the entire world and send back specimens to him.

ii) He'll describe them for others, exchange dried specimens, etc.

iii) Others do the same for him. By last half of 18th century, botany is international cooperative enterprise, at least for Europe, United States, and gradually parts of Asia.

c) But success in an undertaking of this kind presupposes a standardized terminology for describing plants, and since plants are complex and have many varied parts this is a genuine technical language.

i) Worth illustrating, since its unfamiliar and is perhaps best index of where we've come since Bacon.

ii) Take my example from 19th century so you won't think problem is just that I'm reading Latin.

Gray's Genera of the Plants of the United States, p. 29. Genus Ranunculus whose most familiar examples are buttercups. READ

iii) There were at this time about 200 described species under this genus ranging over most of the world.

iv) Gray will stick with genera and to the United States. Nevertheless expects to take ten volume like this one to complete the job. Here he does a hundred genera.

d) That indicates what I mean by mature science, and also introduces last requisite that need emphasis.

i) Classificatory system. Also largely standardized by Linnaeus, though it's some of the post-Linnaean changes I want to come back to ~~xxxxxxxxxx~~ later in the lecture.

4. Partly thru Linnaeus' own effort, but even more by two centuries of development, this is stage botany's reached by mid-18th century.

   a) Linnaeus' own role is perhaps principally that of organizer and standardizer.

   b) Trust it's clear, however, that if one's object is to explore and discover the kinds of plants there are, to describe them so future specimens can be identified, and to arrange the descriptions so that one can find the one needed again, then organization and standardization of both vocabulabulary and filing system are essential.

   c) Those are jobs mid-18th century and later botanists are trying to do.

      i) Way past medical and agricultural roots.

      ii) Now driven partly by love of nature, partly by love of classification (Linnaeus does it with everything: clouds, stones, physiognomies, etc.), partly by desire for fame (naming species after discoverer) and partly by desire to see God's plan.

II. PROBLEM OF CLASSIFICATION

1. So much for sketch of mature botany. Now what are its problems.

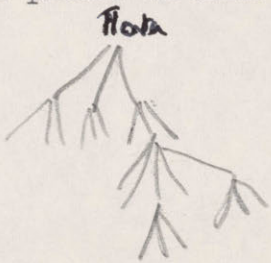
   a) Restrict myself here to intellectual problems, and pick the one that proves most vexing and important at end of 18th and beginning of 19th century. Problem of Classification, or of designing an adequate syst.

   b) Here I'll treat this very generally, in form alost equally applicable to problem of designing subject index or numbering system for large library, or problem now confronted by linguists, ethnologists, anthrop. etc.

i) Design a filing system for plants or plant-descriptions so that I can quickly find it again for comparison with new plant or new plant description.

ii) If possible, do this in such a way that similar plants will be near each other in the filing system. Partly for convenience. Partly because seeing the way different kinds of plants group together into bundles of similar kinds may display God's plan and will surely increase out ability to deal with plant world inconcept and in memory.

2. In Linnaeus' case technique is to place a plant within four successively finer divisions. Draw.



Point on all like branch.

a) Order, family, genus, species. Two others since added and sometimes more. 'Division' and 'class'.

b) Basic notion very close to common sense, WHICH IS ITS SOURCE.

i) Species is "kind," genus is group of "related kinds," and so on.

ii) If you don't try to duplicate botanists results you can do this yourself in any gardent There is no continuum. Some plants are like each other, others not.

c) And this whole way of doing the job can and sometimes does be given philosophical basis via notion of essences -- the informative principles which give each species its characteristic traits, and whose interrelation give h'r re

i) With or without notion of essence or plan it's a natural way of doing this job.

3. Yet even before Linnaeus it's begun to run into difficulties at the lower levels, species and genus.

   a) Thse get taken care of, but only in ways that constitute a profound intellectual barrier to Darwinism right within the working equipment of botanists.

   b) After Linnaeus they also get solved for higher levels, but as they do, they provide all sorts of hints, which Darwin exploits quite fully, for the theory of evolution.

   c) Take these two points in order.

4. Low level problem is, what do you do with a new plant that looks quite a lot like a plant you've already classified.

   a) Progeny don't look quite like each other or like their parents. Yet they surely are the same kind of plant. Where set the limits.

   b) Linnaeus's answer, which is older than he, is from experimental plant breeding. Draw.

      i) Plant both specimens, watch variation spread, look for natural bonndaries.

      ii) If they overlap, then it's single species, otherwise two varieties of the same species.

   c) Good technique, but look what it does. Builds fixity of species right into the working definition of the practicing botan.

i) If one species can breed another species, then the two species are the same.

ii) By the same token all species are tracable back through time to others of the same sort, perhaps to the original pair created by God.

b) Notice how very closely the biblical and the necessities of botany cohere. For many botanists it was the tools of their trade that were the important force.

i) If you doubt that it was essential, let me only say that the decline in popularity of taxonomy dates from theory of evolution.

ii) And that those who do still do it, have gigantic problems of a thoroughly philosophical sort deciding what on earth a species is.

c) No wonder then that Darwinism was hard to take for working botanists. It destroyed an essential tool of their trade.

d) And note also, here, that what's true at the level of species is also true for the ~~xxxx~~ higher levels.

i) Put briefly, the very notion of classification is static. Like geometric shapes. Once a triangle, always a triangle. Think of Linn system.

ii) Though in retrospect evolution does supply ways around this problem, the most obvious (indeed, only obvious) assumption is that if you can find natural groupings of similar plants at all, that must because they conform to a general plan, built in at time when individual species were created. And cool solution does make system not permanent somehow ad hoc.

III. POST-LINNAEAN TAXONOMY

1. Nevertheless, it is at the higher levels that many of the most important clues to Darwinism accumulate, and it's this I new want to examine.

   a) Beginning with Linnaeus' own defeat by them.

   b) For the higher plants at least (not mosses, for example, or ferns) he's thoroughly successful. Almost all his species and genera have stood up in modern classification.

   c) But above this, at level of family and order, he does not himself find a satisfactory set of natural divisions. It's very tough.

      i) Wants to, works on it all his life, leaves a very perceptive solution of part of the problem at his death.

      ii) But for purposes of getting on with the job at hand adopts an essentially artificial solution. Counts pistils and stamens, sexual parts. Gives up on natural resemblances.

      iii) And it's this system, natural at the bottom but artificial at the top, which gets used everywhere but in France for most the next seventy five years.

2. But people do look for natural systems, including some of those who are actually using Linnaeus' for day to day work.

   a) Among these one of the greatest and most influential is A.P. de Candolle, 1778-1841, a Swiss botanist who mostly works in France.

      i) Draw my examples from him, though again he stands for a number of people.

ii) Through whose work emerges the very important lesson that one can do far more successful natural groupings at high level if one will play down emphasis on function, play up aspects of form.

(iii) Let us illustrate.

where

a) Some plants have tendrils/ others have leaves. Functions are quite different. This has previously been used as criterion of separateness in classification.

i) de Candolle notices that the manner of tendril attachment is same as mode of leaf attachment.

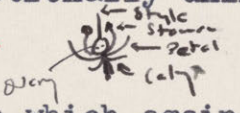
ii) Treating tendrils as leaves, and using arrangement ~~xxxx~~ (opposite vs. alternate, for example) as classificatory device, produces order and system where there had been none before. THUS TENDRILS ARE ABORTED LEAVES.

b)

b) Or again, earlier botanists, emphasising function, have put great weight on number of ~~xxxxxxxxx~~ OVULES

i) Candolle notes that can have them closely packed. Thus spectrum from o o to ꝏ to o. Again abortion so not useful for classification.

ii) So this gets played down. In its place get great emphasis on functionally unimportant features. For example, points of attach

iii) E.G. 

vs. 

iv) From which again, order emerges.

c) And also something that may in the long run have been more important. Pressures and arguments for Darwinism.

i) Abortion is Candolle's word. Others used for this sort of thing are degeneration, adhesion, transformation, and so on. Doesn't fit well.

w.r divine plan.

fit well. Looks more like change through descent. Darwin will see it this way tho de Candolle does not. He's very close to Lamarck's view of the process of evolution

ii) Or again, the aspects of plants most useful for classification are functionally the least important. That's an odd sort of divine plan.

iii) But it makes perfect sense in evolutionary theory and supplies Darwin with a terribly important argument. The functionally important parts are the ones most likely to be modified in struggle for survival. They have survival value. Others don't and are therefore left alone for the classifier to find later.

9. All of which should help you see both what I had in mind when I spoke of the role of technical scientific considerations and their development to coming of evolution. ~~Also role of larger explanatory schemes like that of living tissue in the evolution of the hardest parts of the science~~

III. REMARKS ON CELL THEORY

1. Now let me turn and try very briefly to show you how a number of these same lines of development play into the development of cell theory. Absurd to do it so fast.

a) But you will continue with cells as one of the strands in the development of genetics, next week.

b) And the points that tie cell theory into the themes we've examined so far can be seen without a full survey of the story of the cell.

Development of Cell Theory

I. Basic Conceptions

II. The "Speculative" Route

Lawrence Oken, 1779-1851

R.J.H. Dutrochet, 1776-1847

III. "Observational" Route

Robert Brown, 1773-1858

Matthias Schleiden, 1804-1881

Theodor Schwann, 1810-1882

HISTORY 336 -- Lecture 17

Development of Cell Theory

I. WHY MORPHOLOGY

1. Last lecture discussed manner in which, once it takes a morphological approach, botany piles up a great deal of evidence for Darwinism.

   a) This morning want to begin by asking why the emphasis on morphology came when it did.

   b) Issue is one I had intended to discuss at end of last lecture, but, though some discontinuity will result, it can go almost as well at beginning of this one.

      i) The last issues I mean to raise are ones that will recurr in my main topic this morning, development of the cell theory.

2. If I'm to address this question, why morphology, had better begin by admitting that it's a thoroughly controversial subject, and that I think the state of study in the field permits no very final solution.

   a) At the very least, this is a development that's overdetermined. More different sources than are needed.

   b) Can evaluate relative effectiveness. In any case, that probably varies from man to man and certainly nation to nation.

   c) But almost certainly all of the following factors contribute.

This was not good, partly because my grab was off and partly because of excessive condensation after extended rounds of morphology. Need some readjustment.

3. That picture of clues to Darwinism emerging from botany during first half of 19th century could be elaborated. Also it could be extended to zoology. In particular Cuvier's zoological procedures put much the same emphasis on form at expense of functions that's found in de Candolle.

   a) But think this taste is sufficient and go instead to ask here, why this change occurred. How did these clues happen to pile up when they did.

   b) And say at once, this is one of those cases in which many causes collaborate. Outcome is overdetermined.

      i) Not clear relative order of importance, but probably not the same for all men and all countries.

      ii) Nor need they all be quite independent.

4. First cause is one I've just been over. Internal development of botany itself. Linnaeus was going at least partly in this direction.

   a) And this trend is surely hastened by something else that occurs after his death.

   b) Last third of 18th century is period of first Pacific voyages. Captain Cook's first voyage is 1768-71.

      i) Always carry a naturalist (remember Darwin), and these bring back specimens.

      ii) But tropical species are a shock. Strange, exotic, don't fit well. It's partly fitting them in that gives de Candolle and others their clues.

5. But that can't be whole story, for this emphasis on form at expense of function is showing up in a lot of other places too.

   a) At end of last lecture I suggested that it's clearly seen in Bichat and his successors who look to see how tissue is layed out in arrangement of organs.

      i) Here it seems to follow in part from direct development of physiology, but even more from new willingness in last half of 18th century to allow non-mechanical aspects of living matter to play a role as fundamental categories in bio explanation.

      ii) We'll see that again as factor in cell theory development.

   b) But what we'll also see there, and are almost certainly seeing here also, though the historical connections are not clear, is a by-product of Naturphilosophie.

      i) The term morphology (for study of form) was, in fact, invented by Goethe who at very end of 18th and first two decades of 19th century does a good deal of both botany and zoology.

      ii) The basic polar forces, having first created matter and then the chemical elements by differentiation of matter, next create the basic plant form, the basic animal form, and further create indiv. plants and animals by differentiation of these forms.

      iii) Thus, basic plant form (or type when used by de Candolle and Cuvier) has stem, root, and leaf. Flowers of various kinds formed from these by further differentiation.

      iv) Next step differentiates this further into subtypes. Thus flora differ

iv) Thus, pistil is stem extension.

v) Stamens are leaf forms.

vi) So are petals

v) And corrola.

} ALL TRACEABLE AS VARIANTS ON BASIC PLAN, BUT SOME CLOSER TO EACH OTHER

c) ~~And so on~~. It's pretty monstrous in its detail. But it's an accute approach and one that can be done far better. And it does emph form.

i) From a non-evolutionary point of view de Candolle is one who does it better.

ii) Since then its been done still better by evolutionary techniques.

d) Furthermore, though it takes me away both from morphology and botany, should also point out that this general Naturphil approach, when applied in the animal realm makes one further contribution to evolution and to a special branch of biology, embryology.

i) Stages in development from ~~plant~~ form to special ~~plants~~ are not seen as evolutionary, except perhaps at very beginning of life.

ii) Rather they're stages in evolution of the plan to which life conforms.

iii) ~~But they can easily flip to evolutionary view~~. That's made particularly easy because it's early observed that embryo's display the progression or some aspects of it.

iv) Again seen as formation of unformed matter under influence of forces, not as evolutionary, but makes embryology basic way to expl. and on track also to evol.

II. INTRODUCTION TO CELL THEORY

1. ~~Many of t~~hese same factors play a role in the development of the cell theory, and they there present similar problems in evaluation. Will shortly come to that, but for this audience had probably better say just a word about what the cell theory, in its most basic components, is.

   a) Not a definition, not quite applicable to every single cell, and not fully up to date. But main lines of view as it's developed by late 19th century.

2. First element then is that cell is a basic unit from which organisms, all of them are built.

   a) Sometimes the entire organism, as in protozoa.

   b) Otherwise the building blocks of which organism is built.

3. Second element is what's sometimes spoken of as the double life of the cell.

   a) It is itself alive in that it can carry through processes necessary to maintain itself, repair itself under some circumstances, and reproduce.

   b) Also, though a participant in the life of the organism of which it is a part. Individ. life process of each cell contributes to life of whole.

   c) It's here, far more than with organs and bodies, that analogy to state or to body politic holds.

4. Next important feature is that though cells vary considerably from one to another, almost all share some basic structural features.

   a) Overall form: Outer membrane; interior fluid mostly called protoplasm, basic life stuff in 19th century, now cytoplasm; and finally nucleus, opague object visible in cells at most times.

   b) Furthermore, there's also a good deal in common in the material, first recognized and emphasized in 19th century for the protoplasm which, at least until subjected to quite refined analysis is transparent, viscous, albuminous fluid with much common in its chemical composition.

5. Finally, having spoken of cell reproduction, emphasize as final feature that all cells are generated from other cells by process of division.

   a) Though cells themselves can grow by taking materials into their interior, basic process of growth for organisms involves multiplication of numer of cells, not an increase in their individual size.

6. Now want to ask how these ideas come into being and when.

   a) Clear that two sorts of factors are intimately involved, observational and speculative.

      i) Here as with morphology it's extremely difficult to disentangle them from each other and evaluate their relative weight.

      ii) And that's true not only with respect to overall development but with respect to many individuals as well.

b) I'm going to simplify my task by discussing the two separately even though ~~a number of~~ some individuals ~~will recurr~~ may in both parts.

c) And I'm also simply going to leave open the question of relative weight.

i) Except to say, that until people can and do learn to see and describe cells and cell processes in great detail, you've not really got the cell theory as we know it and use it. 1665 is it late 1830's.

ii) On the other hand, it's clear that cells are seen first and most often by people who are looking for them on speculative philosophical grounds.

iii) And that much of what they see, both right and wrong, is for some time determined by their philosophical position.

iv) In the historical evolution of cell theory, the bias is also essential. Some descriptions from this group are excellent. Even for later work

III. THE SPECULATIVE BACKGROUND

1. Let me here start with the speculative background, since it relates most closely to ground already covered.

a) Origin, or what I take for present purposes to be origin, we've really already been over.

b) If we take a cell to be only a living building block of which organisms are compounded, then idea is very close to Buffon's Living atoms (reading) or the fibrils and other living parts from which LaMettrie builds his man machine.

i) Haller's bits of irritable tissue are larger, but as living structural units with their own properties and life, they're also close, and considerably better defined and observed. Thus macroscopic models for cells.

c) With Bichat, who is generally next figure I've treated in this line of development, there's no tendency to see tissue as composed of smaller parts.

i) Though, to break my emphasis on speculation for the moment, Bichat does contribute terribly important techniques originally for tissue but with great importance to cell examination also.

ii) Staining, acid treatments, maceration techniques for preparing tissues. Transferred to and developed further for cells.

d) These plus the internal logic of his argument, do place some of his followers in the middle of early history of cell theory proper.

i) Particularly R.J.H. Dutrochet, 1776-1847, who in 1824 brings out a book called Anatomical and Physiological Researches on the Internal Structure of Animals and Plants.

ii) In many parts of both he finds structure of living globules.

iii) Doesn't get general preseription that all parts of all organisms are cellular.

iv) Also, clearly, has only occasionally, and them mostly in plants seen actual cells. His animal observations, at least, are often now thought to hve been due to spherical aberattion of microscopes But, it's the sort of writing that clearly helps to set up what's to come.

2. This line of development, however, lacks both the generality and the developmental emphasis that's closely associated with cell theory.

   a) That appears first in Germany, and it is there closely associated in clear cut ways with Naturphilosophie.

   b) Here central figure is Lawrence Oken, 1779-1851, an often mad but extremely influential and sometimes perceptive Naturphilosophical biologist.

      i) He elaborates the type theory for animals that Goethe has started

      ii) But also carries it back to stages after inorganic but before basic forms of plants and animals.

      iii) And in doing so gets both developmental and generality. 1805

   c) "All organic beings originate from and consist of vesicles or cells. These, when detached and regarded in their original process of production, are the infusorial mass or Urschleim [infusoria are single celled animals, Uhrschleim is basic or original slime] whence all large organisms fashion themselves or are evolved. Their production therefore is nothing else than a regular agglomeration of Infusoria." (Singer 328)

3. It's this viewpoint, rather too precisely (for it's not altogether right) that's going to be elaborated by observation in the late 1830's. Not clear that this passage is source. But general viewpoint is.

IV. OBSERVATIONAL

1. To get at that side, however, must take observational route, which will have to be extremely condensed. Though structure is what's important and

can preserve most of that.

2. Of which first stage goes back to first microscopes.

   a) There are in the 17th century recorded observations, descriptions, and drawings of what are undoubtedly cells. First of them by Robert Hooke, cells in cork, actually uses the names

   b) Nor is he alone. Most of the microscopists see at least some cells. well described.

   c) But it's far from being what we're after.

      i) Again, none of the generality, nor the notion of basic unit of life.

      ii) On the contrary, this is generally seen as fibrous structure. Draw cross-hatch. It's the walls, not interiors, Individual blocks are not units. This is a floor plan, if you will. ~~Only xim~~ A structure of fibres, not of blocks.

3. By and large that's the situation that obtains through the 18th century and into early 19th.

   a) With a few people like Dutrochet, you begin to get some combination of bits of good observation with drive towards generality, and with cell seen as living unit.

      i) But he's not seeing enough to take people with him. Or even to develop idea very fully himself.

4. And then, in 19th century, two things happen which set the fully scientific and techniqal developments off.

a) First of these is increasing deployment of achromatic microscope. Corrects aberations that have greatly limited microscope resolving power and thus permits observations that are basic to further development.

i) Actually developed in late 18th, but not much used until close to 1820's and 1830's.

b) Second, which is actually done with single lense, is what's often called discovery of the nucleus by Robert Brown, English Botanist, 1773-1858.

i) Like cells, they've been occasionally seen before, tho not neces. in cells

ii) Brown, however, working on plants, where cells are far more easily visible because of strong walls, notices that he can always find nucleus. Suggests that it's an invariable concomitant of cell structure, where this is exists. 1831

5. This is the lead that's very quickly picked up by the German Matthias Schleiden, 1804-81, and transmitted by him to Theodor Schwann, 1810-82, who are generally called discoverers of cell theory, though clearly it's hard to say at just what point theory is actually discovered.

1838 & 1839 a) Schleiden certainly and perhpas Schwann as well have been much influenced by Oken, though not necessarily by particular passage I quoted earlier.

i) They have the better microscopes and, if you will, the right mental set.

ii) What the nucleus then provides is a double clue.

b) Even in plants, which are what Schleiden works with, the nucleus is sometimes easier to see than the cell.

i) Using it to find cells, Schleiden is able to see them as making up whole structure.

ii) Furthermore, in animals where the walls are often extremely difficult to find, the nucleus is the basic tool for unravelling cell structure.

iii) This is work of Schwann, who uses nucleus plus easier plant observations as clues and proceeds to delineate many many real cell structures in animals.

iv) This is where the generality and in close conjuntion with observ comes in.

c) Other importance of the nucleus to development of theory is that it comes to be the vital element of the cell, the source of its formation and the cause of its properties.

i) All wrong in details, and another generation that I'm not going to follow through is needed to get it straight, substitute idea of cell division,

ii) But the main lines are given here, both transfer of attention from walls to interior, and also emphasis on role of development of cells in development of organism.

d) What both Schleiden and Schwann to say, though with some differences of detail, is that in cell development you start with common gummy substance, which is ~~xxx~~ generalized protoplasm.

i) Then nucleus crystallizes out either within existing cell or in spade between existing cells.

ii) Membrane forms by further deposition on this nucleus and then swell out around it until cell is shaped by pressure on neighbors and stops growing.

6. This, of course, still leaves all the work to be done, both cofrection of errorw and filling in of detail. Last a process that's still continuing.

a) But thousands of men involved -- hundreds in next generation. Not sure it makes sense to try to follow.

b) Except for idea of cell division, basic notion is here. And latter comes from hard observation within next twenty years.

Heredity and Genetics, 1858-1903

I. Cytology, 1858-1883

R. Virchow; ~~1821-1902~~
Omnis cellula e cellula
~~The~~ containing a Structured Nucleus

II. ~~Fertilization~~, to 1883.

Mechanical theories

Cytological evidence

~~III.~~ O. Hertwig, ~~1849-1922~~ 1876
~~H.~~ Fol, ~~1845-1892~~ 1879
E. van Beneden, ~~1846-1912~~ 1883

III. Heredity from 1883

~~C.~~ Naegeli, ~~1817-1891~~ 1884
O. Weismann, ~~1834-1914~~ 1883

IV. Problems of Darwinism from 1883

~~Francis~~ Galton, 1822-1911 1889
H. de Vries, ~~1848-1935~~ 1901

FOR STUDY

Note for future. Ch. really starts with this.

HISTORY 336 -- Lecture 18

Heredity and Genetics, 1858-1903

I. INTRODUCTION

1. I want this morning to trace background for emergence of modern genetic theory from about mid-century (actually from Origin of Species) to the rediscovery of Mendel's work in 1900 and its integration with detailed cytology by Sutton in 1903.

   a) Main concern is with the narrative itself, but also want to say something about problem which will have arisen in all precepts.

   b) Problem was: Why are people so late in recognizing Mendel's work?

      i) Shall scarcely speak to it directly, at least not often.

      ii) But want to relate it to story I'll be telling--in following way:

      iii) If a paper thirty-four years old is suddenly rediscover by three men independently in the same year -- a paper that's only been cited four times in the interval -- then something's happened in the interim to make the paper more interesting.

      iv) Somehow, because one's now sure the paper makes sense to readers for the first time, I'm left with feeling that even without Mendel's aid, the same view would shortly have emerged from several sources without him.

   c) Part of what that means is that Mendel was "ahead of his times."

      i) Finding out what happened to the times between M's publication and rediscovery is inevitably finding out respects in which he was ahead

Even talking fast, this is too long by almost 5'. But good!

2. Turning back to narrative proper, want to try to sketch four partly separate lines of development: cytology, fertilization, heredity, and development of Darwinism.

a) Need secretly sig
Inevitably complex developments whose fine structure will be missing.

i) Often something arbitrary about choice of names to whom I attribute individual contributions.

ii) By the same token, much that's arbitrary about dating. Each idea has been partially enunciated before. Even when cleanly and fully enunciated, there are years of criticism, rejection, modification before acceptance. None of that can show.

But do want to say: have lost it sense it not been true before
b) All of that's said partly for preliminary warning, but mostly for a a more positive reason that has recently struck me very strongly,
and it really about scientific development itself.

i) If I turn from fields with which I'm more familiar -- mostly physics and chemistry -- to development of cell theory or the various topics for attention this morning, literature has a very different feel from other sciences in same period.

ii) Getting a narrative out of it is a different sort of problem. Reason is that there are many many more people who make essential contributions. Dropping them from the story changes it in ways that would not be true for physics or chemistry in same period.

c) Think there are two reasons for this, both worth noting.

Inst. just.

i) First has to do with nature of the field. In physics and, to some extent in chemistry, new theories like Lavoisier's or Ampère's are often responses to a small set of strategically chosen expts.

ii) Theory itself explains far more than those experiments, but in finding <u>where theory came from</u> need mostly ask, what made those experiments seem worth performing and why were they so suggestive. Think of ground we've been over.

iii) In much of biology, at least until this decade, theories are not to nearly the same extent born whole -- Darwinism, cell theory, theory of heredity.

iv) Do have suggestive observations -- like Brownss on the nucleus. But they usually depend upon knowing a great deal of the earlier observational literature and recognizing that a number of other people have seen something like what you're seeing, so your phen. may be general.

v) And the first suggestion also always needs working out against other observations on other specimens, in the course of which it's invariably modified and changed so that it will fit them all.

vi) As a result, in doing history of developments of this sort, really need to pay far more attention to far more observers and to many more partial formulations of a view than would be necessary in physical sciences. That's what I mean by different texture of narrative. Fine structure is essential part;

d) Other difference is of a quite different sort. Institutional. There simply are more people even though histology, cytology, and so forth are newer fields.

Move further up i) They relate to medicine. Socially important. Major institutions.

ii) Thus, people available and support for them to follow breakthroughs

II. CYTOLOGY

1. Turn now to first strand of story, cytology or cell theory, and pick it up in 1858, almost simultaneous with Darwin's Origins.

   a) This is year towards which I was pointing at end of last lecture. Year in which Rudolph Virchow, 1821-1902, a towering figure in German medicine, biology, and ultimately politics announces famous generalization, OMNIS CELULA E CELLULA, all cells from cells.

      i) He's not quite the first or the one who does very best work. But he does enough, and it's his talent and authority which sells the view.

      ii) Meaning that, from this point or shortly after, cytologists drop the view that cells can be spontaneously generated by quasi-crystallization from protoplasm. There must be a prior cell.

   b) That, in turn, is important because, though there's still not talk about implications of this work for heredity, it's nevertheless at just this point that root for continuity of ideoplasm or germ plasm enters into detailed biological research. Beyer could have, did have, spont. gen. of cells.

      i) You've seen this in particular clarity in Weisman. Remember how he builds the view from the generation of unicellular organisms by division.

      ii) Notion that that's the universal process by which cells are gained is established only at end of 1850's.

2. Weissman's remarks on this subject don't come, however, until over thirty years later, and there's much more to happen on this cytological line frst

a) Of which next element is recognition of role of nucleus. It's been instrumental in teaching Schleiden and Schwann to see cells. But once people have learned to see them, nucleus has declined in import.

i) During most of the 1860's a cell is taken to be a membrane filled with protoplasm. The latter, is the essential part of the cell. ← essentially unstructured,

ii) Nucleus is recognized, but not as having strucure. Nor is it thought to be permanent.

iii) Thought widely to disappear before subdivision and reappear or reform after division.

iv) A few people, including Haekel and Huxley describe cells without nuclei.

b) That situation ~~begins to~~ changes only in decade 1873-1883 when two important doctrines are gradually established, partly as result of gradual improvements in microscopic technique: staining and immersion particularly. ← Another dyel.

i) First of these is continuity of the nucleus. Doesn't disappear, just gets harder to see. Separates into two halves first, then cell divides.

ii) But when first seen, it is mostly supposed that it can divide anywhere so long as parts are about equal. There's no structure either to nucleus or to process of division.

iii) But first in a few favored cases and then gradually in more and more, people begin to see at least some chromosomes in the nucleus

and are able to watch them form as distinct bodies before cell division, move to equatorial plane, divide along their length, and then move homologous units towards the cell's poles in forming new nuclei.

iv) That's already too clear and general a statement. The next quarter century will be required to fill in detail and to show generality. For this the development of the Zeiss microscope in mid-1888's is also essential.

v) But that there is nuclear structure and that it too is retained in division is relatively clear by the mid-80's.

c) And what makes this important is that it leads to general recognition that it's structured nucleus that must contain key to both individual development and to evolution.

i) Already some people look particularly to the chromosomes for it.

ii) Protoplasm is core food or collect nuclear waste.

III. FERTILIZATION

1. It's during this same decade that work I've just been describing makes firm contact for first time with work on fertilization and beginning of embryological development.

a) The mammalian egg was discovered in late 30's, and by end of the '40's a number of people -- though not all -- regard it as a single cell and see embryological development proceeding by subdivision.

b) But egg doesn't begin to divide until fertilized, and about fertilization, however, there are a good many different theories.

i) In Germany, however, these theories have a good deal in common. This is period of revolt against Naturphilosophie, and everyone insists fertilization is a mechanical or chemical process.

ii) In one way or another it's by contact between the egg cell and the fertilizing material. Sometimes the action is seen as catylitic, other times as a stimulation by molecular vibration.

iii) But nothing material passes from the fertilizing agent to the egg. Sometimes it's even thought that the sperm is non-essential. The active agent is the seminal fluid.

c) This situation continues until the mid-1870's at which point it comes into contact with work on the nucleus, which has previously been unimportant as compared with unstructured protoplasm.

i) Again, many people involved, but key paper is probably that by Oscar Hertwig in 1876. (1849-1922)

ii) Can't follow sperm actually into egg. But see's it touch. And then sees a second nucleus appear inside and merge with nucleus already there.

iii) Fertilization requires completion of egg nucleus by sperm nucleus.

d) This view is hotly combatted, in part just because it has vitalistic overtones, but it's rapidly developed and most people are convinced within decade. I'll just look briefly at two major events in this process.

i) First is work of Hermann Fol, 1845-1892, who in 1877 does follow sperm into egg and in 1879 does something even more important:

ii) Artificially induces fertilization involving more than one sperm and shows that results are generally monstrous. Need proper structural units. Equal shares.

iii) This is followed up in 1883 by Eduoard van Beneden, 1846-1912, who was initially one of the great opponents of Hertwig's view.

iv) Now he follows nuclear strucure in developing egg cells. Sees that in last division only half of chromosomes go into egg cell and that sperm supplies missing half to make up full complement.

v) Again there's more to go in generality and detail extending to beginning of century, but basic elements are here emerging.

IV. HEREDITY

1. All of this takes us only to 1883, and it's important to notice that as late as this none of the cytologists are talking about possible relationship between these discoveries and the problems of evolution and heredity.

a) That comes only with this much detail established, but then it comes very quickly. In 1883 and 1884 in work of Carl von Nägeli, 1817-1891, and August Weismann, 1834-1914.

i) They're both discussed in reading, so I'll be brief.

ii) Also, they're quite a lot alike from viewpoint that's important here, and I'll therefore mostly talk about Weismann.

b) Except that I first want, partly to amplify & change emphasis in the reading, to say a word about similarities and one great difference.

i) Both are deeply concerned with individual development and also with evolution, ontogeny and phylogeny.

ii) Both are concerned to give mechanical or chemical explanations. No mystic forces.

iii) And both build quite firmly on this previous cytological work. Neither Naegli's ideoplasm nor Weismann's germ cell are mystic, life preserving elements. They're chemical substances contained in (or, for Naegeli, largely in) the nucleus.

c) On the other hand, Weismann is a Darwinian -- meaning he believes in natural selection -- and Naegeli, though an evolutionnist, does not.

i) His ideoplasm evolves over time in rather the same way we now suppose the elements of inorganic nature may have been built up. By gradual chemical combinations towards more and more complex organic molecular types.

ii) This is what gives his work that teleological and Naturphilosophic cast that Gillispie emphasizes. Likely there's an influence. But Nägeli would probably have been much offended to have it pointed out.

2. Now come back to Weismann.

a) Germ plasm theory is in the reading. It's this that contains the key that shapes individual development. Also it's germ plasm that's

transmitted from generation to generation to account for hereditary variation.

i) Here I want to emphasize just one thing about it, and then pass on to two of its consequences.

b) Point to emphasize is simply that germ plasm is the structured nucleus of the germ cell or reproductive cell. Past research built in.

c) First consequence is that: partly because of its location and partly from earlier experimental work of his own, Weismann denies that environment can have ANY INFLUENCE on it at all. in 1880's.

i) Naegeli's been almost as strong. Though he allows a bit of effect from long-lasting environmental influences.

ii) Even, then, in less extreme forms than Weismann's whole thrust of this line of development from cytology is to make inheritance of acquired characteristics an impossibility or virtually so.

iii) But this is the theory that Darwin himself has increasingly employed to explain evolution.

iv) Effedt of this work is to throw the problem back more and more on variation. It had been a puzzle to Darwin. Now it increasingl becomes one that's got to be solved.

v) Even that much would probably have made Mendel seem more important for evolution than he had at the time the paper was published.

d) But, in fact, in 1892 Weismann himself takes another step that brings him very much closer.

i) Using van Beneden's results and others he provides a mechanism for variation.

ii) van Beneden's specimens have showed four chromosomes that in the formation of the germ cell divide leaving only two.

iii) Weismann takes all four to be distinct, rather than two pairs. Calls them a, b, c, d, and suggests that after division may have either ab, ac, ad, bc, bd, cd, six combinations.

iv) These won't, of course, give Mendelian ratios. But one can, I think, be reasonably clear that if Weismann had seen Mendel's paper in the '90's he'd have thought it very important indeed.

v) Here we come very close. It's Sutton in 1803 who uses the more detailed cytological evidence to get it right, but by then Mendel's been rediscovered. This is a decade earlier.

V. DARWINISM

1. What one sees in Weismann is first a new importance for the problem of variation and then a mechanism for discrete variation drawn from cytological evidence.

a) What I want in brief conclusion to suggest is that second of these ideas has also emerged quite clearly by a quite different route, criticism of Darwinism.

i) And, of course, I emphasize idea simply because this is what Mendel's studied and, in part, what's made him seem irrelevant before.

ii) Evolution, whether seen as result of natural selection or a teleological force, has appeared to be a gradual process to which sudden changes in color of flower or form of bean has little relev

b) But what your reading in Bateson should have indicated is that by the 90's it's increasingly recognized that this one won't work.

i) Critics have insisted that any tiny variation will be bred out in stages and have produced powerful arguments.

ii) Even before Bateson's work on this, Francis Galton, 1822-1911, the man who introduces detailed statistical analysis into study of heredity, points out that need something else.

iii) Draw. Polygon model. Return to base and oscillate, vs. tipping onto new face.

c) And after Bateson the trend continues.

i) Hugo de Vries, 1848-1935, one of the men who independently rediscovers Mendel has been doing experimental corn breeding trying to see how much he can increase number of kernels by artificial selection.

ii) Finds he gets all improvement in first few generations. Then is stopped. Needs a discontinuous jump.

2. Since you all know Mendel's paper andhhave had at least a taste of Sutton' I shan't try to carry this further.

a) But would like to think I don't have to, for this is the point at which many lines converge towards same conclusion. No wonder it's sim

KINETIC THEORY OF HEAT

I. Dynamical Theories before Caloric

1. GENERAL
2. Daniel Bernoulli, 1700-82.
Hydrodynamica, 1738 (Magie 247-51)

II. The Rumford Episode

Benjamin Thompson (Count Rumford), 1753-1814

III. Kinetic Theory

1. Pre-statistical: Herapath (1816); Waterston (1845); Joule (1848); Kronig (1856); Clausius (1857)

2. Post-Statistical: J. C. Maxwell, 1831-79
Ludwig Boltzmann, 1844-1906.

LECTURES 18 and 19 -- Two lectures by Lorch on genetics intervene at this point. In the first he dealt with overall views of heridity from Aristotle to Darwin. In the second he dealt with Mendel and since. First was far too loose and general; also it left out both developmental lines and also some essential topics (Did pangenesis but not epigenesis, for example). Second was better, but could also have covered more ground.

HISTORY 336 -- Lecture 13

Birth of Kinetic Theory

I. DYNAMICAL THEORIES BEFORE CALORIC

1. Having talked last time about development of the doctrine of energy conservation, want this morning to take up closely related development.

   a) It's the emergence of the kinetic theory of heat which finally displaces the caloric theory during the decade or two following 1850.

   b) This is view which, more than any other, stands as crowning triumph of Newtonian science. In two senses:

      i) It's one of the greatest achievements of Newtonianism.

      ii) Also, though, it is the last of them. When it occurs the Newtonian world-view is already in some difficulty. During remaining decades of the 19th century, those difficulties become clearer, more precise, and more severe.

2. I say that kinetic theory of heat ~~is closely related to~~ emergence of energy conservation; ~~and it turns out to be, in the event.~~

   a) But that fact, in itself, poses a problem. Kinetic theory of heat is view that heat is motion of the atoms and molecules of bodies.

      i) Or at least it's a powerful mathematical version of that view.

   b) And the qualitative view of heat as motion has been available for more than two centuries before it's nineteenth century triumph occurs.

This won't work.

1. I think it does work built-in right views.

2. CCG thinks it does work shy of an organizer set for over an audience of physicists should take more time.

3. I doubt that it that ought but...

But want to add that basic part which emerges for me from lecture about role of new views of genes is probably important and work pressing. Notice, for example, that diffusion problem, probl. of mixed genes just doesn't exist beyond info. or the river bed ought to have a role of the rotation models, particularly R's (The organizer wishes some changes me.)

i) From time of Galileo, Descartes, Boyle, and Newton in the 17th century until perhaps the work of Black in the 18th century, it's even been the dominant view. In one or another formulation almost every significant scientist has held it.

ii) Question, then, is: Why does caloric theory intervene? Why is theory a nineteenth-century triumph rather than an 18th?

3. ~~One answer is obvious, but also, I think, mostly wrong.~~

a) ~~In this case, it is not because the mathematics wasn't yet developed.~~

i) ~~That's clearly the reason why one does not get a statistic theory like that developed by Maxwell and Boltzman.~~

ii) ~~But the versions of the theory developed in the 19th-century by men like Herapath, Waterston, Joule, and Clausius -- all of whom ignore collisions and treat gas as having a single average vel. for its particles -- would be easy for the 18th-century or even the better 17th-century mathematicians to perform.~~

4. So it's not the lack of mathematics, which suggests it may be lack of adequate knowledge of heat. This surely does bring us closer:

a) Until Black and the development of calorimetry it isn't clear what one wants to apply math and principles of mechanics to. ~~xxxxxxxxxx~~

i) Or at least it's not categorically clear, though there's one famous and relatively successful attempt by Daniel Bernoulli to which I want to return in a moment.

b) But with the work of Black, Lavoisier, and Laplace, with the establishment of a measure of heat which leads to conservation of heat, it's rapidly recognized that if heat is motion, then quantity of heat is quantity of vis viva -- total mv^2 -- of constituent particles.

i) This is known to be conserved as a mechanical quantity.

ii) Thus in Lavoisier-Laplace famous memoir in 1880's, they say heat can be either matter or vis viva. Makes no difference.

c) Nevertheless, both Lavoisier and Laplace proceed to treat it as a substance. No one really takes advantage of this widely announced correlation.

d) Almost everywhere the caloric theory now triumphs, which leaves our question as before.

e) Thus allowing me to suggest that most fundamental answer is of a different sort.

5. With the kinetic theory as with the caloric theory, the easiest applications and the ones which test the theory are to gases. It's here where individual properties of different elements have least effect, and where uniformity is expected and experienced.

a) If now one asks how people who think about gases in the 17th and 18th centuries conceive of them, it's clear that they think of them in a way very different from that associated with kinetic theory in 19th century.

i) That theory says atoms and molecules occupy very little space. Fly long distances, sometimes even wall to wall.

b) But before this time atoms of a gas have usually been seen as space-filling or the equivalent.

i) Clearest in the caloric version of Lavoisier and Dalton. Draw

ii) Earlier than that some people have suggested the atoms were like little springs that expanded to fill interstices.

iii) And most people have taken some version of Newton's view which has been what I'll modernize as a lattice theory. Repulsive forces hold them apart and approximately in place.

iv) When people holding this view talk about heat as motion of the particles, they think of a vibratory motion about the average position or else of a rotatory motion or of both.

v) Can't quite get a kinetic theory -- or a powerful one -- that way.

6. Place where I think this shows most clearly is in the derivation that's always taken as first derivation of the gas laws from kinetic theory. Daniel Bernoulli, 1700-1782. Hydrodynamica, 1738. (Mage 247-51)

a) No influence at the time. Discovered only after kinetic theory is established. Viewed as brilliant precurser.

i) But it's a view based on plane misreading of text.

b) ii) Unfortunately of a sort that's terribly typical. Look back and see familiar diagram. Read text and say he had our view.

b) Instead, Draw, only outer layer of particles ("contiguous") make contact with container. They rebound against next innerlayer. Etc.

c) Those of you who have ever followed through an elementary derivation like Joule's will see that you can get from this $pv \propto mv^2$, as Bernoulli does.

i) But the model's absurd, for it depends upon their being small volume occupied by the atoms and on no forces between them. In that case there's nothing to keep them in place and lined up, and bounding off each other. Derivation depends on that. Can't lettnext innerr layer hit. This is non-developable.

d) And raises another problem that runs through much 18th-century literature on this subject.

i) Only works if atoms are perfectly elastic. But that means they deform and regain shape.

ii) But can't deform unless they have parts, in which case they're not atoms.

iii) Widely held that atoms, as perfectly hard, can meet only at a point and for an instant. Will fall dead if they do.

iv) Billiard ball atom is a nineteenth-century fiction, not an eighteenth-century one.

e) In eighteenth century people who treat heat as atomic motion generally introduce an aether as intermediary. Vibrations transmitted not by collision but by shaking aether which shakes nearby particle.

i) And that view makes it particularly hard to see, what no one does see, that pushing on piston must cause faster motion thus more he

6. It's work of J.C. Maxwell (1831-79) beginning in 1860 and of Ludwig Boltzman (1844-1906) from 1866.

   a) There's a taste of it in reading, and I hope to discuss something about novelty of the approach in precepts.

   b) But in its essentials its too mathematical and abstract to be done briefly in course like this, and I propose only to emphasize two things about it. (in advance of a exhe lecture

   c) First, that it is terribly important. Introduces a whole new method into physics, and one that's grown steadily in significance since.

   d) The other is that, though it tacks neatly on to the end of an almost continuous story about concepts of a gas, it really is far more than part of that story.

      i) Unlike what has preceded, this work of Maxwell's and Boltzmann's couldn't have been done with 17th or 18th century mathematics.

      ii) It depends upon a very different line of development involving the study of ~~error~~ games of chance, of error theory, and of sample populations.

      iii) As yet the nature of that dependence is very far from clear. But it would be a bad mistake, and it is a frequent one, to see this last chapter of the story as though it grew from either theory of heat or dynamical theory alone.

1966-67

~~The~~ Problems of Science & Industry

I. Science in Industrial Revolution

II. Chemistry and Industry to 1860

~~The break at 1860~~

III. The dyestuff Industry

Royal College of Chemistry, 1845
A.W. Hoffman, 1818-88
Mauve (1856) and Alizarin (1869)
New Industrial Pattern

Talk year-

HISTORY 336 -- Lecture 10

Chemical Science & Chmical Industry

I. SCIENCE & INDUSTRIAL REVOLUTION

1. I want this morning to introduce a set of issues and problems rather different than any I've dealt with so far in the course, and I'm somewhat perplexed how to do it.

   a) In past years, both in this course and elsewhere, have generally managed to find several lectures for range of problems I mean to raise this morning.

   b) This year exigencies of scheduling squeeze me to a single lecture, and I'm not altogether happy about it.

      i) What I shall try do therefore is raise issues here, some of them quite big ones.

      ii) In doing so I shall largely -- though not exclusively -- restrict my attention to chemistry, the field we've just been over.

      iii) Issues are, however, larger than chemistry, and in next week's precepts and, to some extent in the precepts following, I want to pursue them further.

      iv) Now from past experience that area which now concerns me is one on which many of you will have strong feelings, and I think we may get furthest most quickly by exploiting them.

2. The issue I want to raise can best be introduced as follows:

a) In the past two weeks we've traced chemistry from ~~crafts~~ roots to ~~a~~ highly developed and highly specialized science.

i) In doing so we've taken the background technology, the ability to produce chemical products for granted.

ii) Now I want to ask, what effect did these developments within the science have on them? In what ways, at what points in time, did the sciences ~~of chemistry~~ begin to pay its debt to the crafts?

iii) In the year 196? you can scarcely doubt that it has done so. Too many of you are wearing synthetics; some of you will have had your lives saved by one or another of the "miracle" drugs; ~~chemical technology~~ penetrates your lives in ~~other~~ ways ~~too~~.

iv) Many of them, and all the most recent ones, would simply not exist without the chemical theories whose development we've recently been examing.

3. Phrased that way the question is, of course, only a specialization of a more general range of issues:

a) Chemistry is, of course, only one of the sciences of the 17th, 18th, and 19th centuries. And its only one of the sciences that is today vital to national life and to public policy.

i) Many of these fields also have roots in older technologies, and can ask of them too when they began and how to repay old debts.

ii) Furthermore, when its put in this ~~more general~~ form it has a longstanding answer which, though now generally discredited in a few scholarly circles still exerts great influence.

i) There is no evidence that transition from phlogiston theory to oxygen theory and the transformation of understanding of what went on in ~~xxydxxx~~ retrieving metals from ores did anything whatsoever to improve metallurgical technique.

ii) ~~Black~~ James Watt may have learned something from talks with Joseph Black, but otherwise the story of the steam engine belongs to blacksmiths, metalurgists, and instrument makers.

e) From an overall view, innovations of Industrial Revolution come from where technology had come ~~frx~~ before -- imaginative and skilled craftsmen. Technology need not depend on scientific discovery.

As late as Ind Rev.

i) There is no debt to science -- OR AT LEAST NOT TO SCIENTIFIC DISCOVERY

ii) Fourth student of the subject used to say -- Until 1870 Sci. owed more to TE than T. to Sci. Applies to all technology.

II. SCIENCE AND CHEMICAL INDUSTRY

1. Yet let me now admit that this is a one-sided answer to an evaluation of science's role in Industrial Revolution -- one which I emphasize largely because on this subject there's so much that's misunderstood.

And because its consequences affect public policy

a) What's the matter with is clearly indicated if we turn from main components of Industrial Revolution to Chmical Industry in particular and ask what progress of chemistry did for it.

i) Worthwhile for two reasons. Chemistry is science that throughout retained closest ties to its craft base.

ii) It's in chemistry that transition from the pattern I've just been describing first occurs.

i) Here the answer comes in two parts divided both in time and with respect to sort of chemistry involved.

ii) In time the division is around 1860. In sort of chemistry it is, as you might expect, between inorganic products, which dominate before 1860 and organic products, almost entirely dyes, which come to the fore from that time on.

b) The pre-1860 story, belongs essentially to 3 products Bleaching powder, Soda (Na_2CO_3), Sulphuric acid I shall here leave entirely for your reading, suggesting only the essential qualification you will disoover there.

i) Chemical theory and ~~even the~~ new laboratory ~~work of~~ discoveries by men known as chemists play very little more role in the development of chemical industry than in other aspects of the industrial revolution.

ii) The most prominent exception is probably bleaching powder which depends essentially on the discovery of Chlorine by the Swedish chemist Scheele, but which is really only made practical for commercial purposes (previously its made holes in cloth) by the Scottish bleacher Chrles Tennant, a man with no known training in interest in chemistry.

c) On the other hand, if instead of asking about discoveries made by chemists you ask about the ~~involvement~~ applications of the men themselves, you get a very different picture.

i) In France there's a repeated involvement of men like Lavoisier and Berthollet called in to inspect plants and suggest improvements

ii) In Britain, lawyer ~~chemists~~ Thomas Lea & Hen Watt many of the men who go into chemical industry are

people who started as doctors, learned medical chemistry, and decide to put it to use when they get discouraged with medical practice as a career.

d) Here at least training in chemical technique and experimental method does often prove decisive.

i) And it leads me to suggest that -- though the argument has scarcely been developed and the information on which it would depend has not been studied -- ~~that~~ a somewhat similar tie between science and industry can probably be found elsewhere in the Industrial Revolution as well.

ii) Not that the men are scientists, either by training or by objectives. But that they do do the sort of careful and deliberate experimentation which has become a standard tool for the Baconian scientists in the 17th century.

iii) Even that would be hard to show for textile machinery. But for metallurgy, agriculture, and steam engine technology the role of deliberate pilot operations, of controlled experimentation could, I think, be shown.

iv) At least at this level -- perhaps ideological level -- there are almost certainly ties to be shown. Maybe here the inventors are the heirs of the 17th Century Baconians.

5. But that, of course, is not the only level at which interaction can occur, and it is not any longer the most important one.

a) Today when we think of impact of science on industry, we think of impact of new discoveries of fact or theory. E=mc², Uranium fission, transistor

i) You don't need to be told that it exists, but you're likely to be unaware how very new it is.

ii) Scarcely visible at all until about 1860. Then it appears first in the organic dye industry, shortly after in electric lighting and power.

iii) From which, though only since the last war, it's spread to many other fields.

b) Let me simply here start the story for you, suggesting that it's subsequent development is all around you.

6. Begins in the early 1840's when the German chemist Liebig makes a trip to England and speaks with considerable disfavor about what he sees.

a) British realise ~~s~~harply that, though they still lead the world in ~~xxxx~~ inorganic industry, they know very little about the developing techniques of organic chemistry and that there's no one to teach them.

i) Group of ~~industrialists~~ band together and set up a new school -- shortly becomes Royal College of Chemistry.

ii) In 1845 persuade one of Liebig's most promising pupils and assistants, the German A.W. Hofmann, to come over and direct it.

iii) By summer of 1846 he has the school going and a group of over 60 students doing advanced work under his direction.

7. For England, at least, this is a new sort of institution, and it's within this context that first synthesis or an organic dye emerges. Happens

2. Instead just a few words, directed mainly to those of you who've not studied modern version of Carnot cycle elsewhere, about what makes this line of development so important.

   a) It's not that it improves engines. Only when one gets to steam turbines it it any real use. Steam engines already as good as they could be.

   b) Instead it's a key to all sorts of unexpected regularities in nature that on the surface have nothing to do with engines at all.

3. Let me just try to indicate how this occurs -- adding that it occurs very fast, but only after people start to pay attention to Carnot's work. That actually doesn't occur until about twenty years after its publicat'n.

   a) Carnot imagines his engine filled with perfect gas and proves two theorems about it.

      i) No engine can be better.

      ii) Any fully reversible engine will be just as good.

   b) But one knows about behavior of perfect gases. Can now learn about actual gases and about other substances and cyclic processes by direct comparison.

   c) Process begins with Carnot himself:

      i) Proves that for any gas whatsoever: $q = F(p_1, v_1; p_2, v_2)$
      a result that Kelvin puts to use soon
      in definition of absolute temperature scale. One indep
      of working substance.

ii) Then further specification of form of function for case that gas obeys Boyle's law.

b) Or Clapeyron who imagines cylinder filled with liquid and vapor in equalibrium. Temp changes due to phase transition.

i) Analysis of cycle gives relation between heat of vaporization and shape of curve determining change of boiling point with pressure.

c) Or Kelvin and brother who first imagine they can refute Carnot with freezing of ice since this expands on freezing.

i) Wind up realizing that pressure raises freezing temp. and thus giving first explanation to long recognized puzzle.

ii) How do glaciers flow.

d) From here, tho more slowly into chemistry, Heat-vapor equalibrium is model for others.

e) Encluding finally, of course, radiation in box. It too exherts pressure. Thus Kirchoff's law and basis for Planck's work.

b) Kelvin's work on Carnot and holding off on Joule as late as 1849. But he's also one of Joule's greatest defenders.

c) Probably fair to say that among the few people really best equipped to handle Joule's results, i.e., the experts on thermal phenomena, its incompatibility with Carnot's highly successful theory is main barrier.

d) Only by mid-century it's clear that they're both immensely plausible and attractive. Need way to preserve both.

3. In fact, it's quickly forthcoming from two sources independently:

a) Rudolph Clausius in Germany in 1850/ William Thomson, later Lord Kelvin, in England in 1851.

b) Knowing that it will leave many of you behind until we return to it in precept want nevertheless to suggest essential nature of step taken.

c) Problem in preserving Carnot now is that once heat is used up, one can no longer appeal in going through Carnot's argument to the impossibility of perpetual motion. No longer can say a better engine than Carnot's would drive C's backward, do work, but leave everything else the same.

d) Need some other impossibility to justify the analysis and it's this Clausius and Kelvin find in 1850 and 51.

e) ~~Therefore~~ Their formulations are slightly different, but it's Kelvin's that's the more familiar.

f) It forbids what come to be called "perpetual motion of second kind."

4.

i) Says in effect that every engine must have a low temp reservoir.

ii) There's no way to run an engine that takes heat from a boiler and converts it all to work.

iii) Must dump some of out into a lower temperature reservoir than the one at which it went itn.

g) And this, of course, is just the conclusion that leads in short order to notions like the heat death from which I began last time.

i) If doing work, using energy effectively, always demands a passage of energy from hot to cold, then we ultimately cool down all hot and heat up all cold.

ii) Still have same energy, but it's no longer accessible to you.

HISTORY 336 -- Lecture 14

Emergence of Field Theory

I. INTRODUCTION

1. Want this morning to discuss briefly the emergence of field theory as the first great non-Newtonian approach to enter physics since Descartes.

   a) This is topic to which Professor Gillispie's pp. 435-476 are directed, and parts of what I shall be saying this morning is really by way of explication of those pages.

   b) For one who has wrestled with some of the original literature of the subject, these seem to me to be among the most rewarding pages in the book. Delineate the main developmental lines from among a mass of verbiage with the greatest precision and insight.

   c) On the other hand, it's far from clear to me how one who does not know the subject matter in its original form can see this in them.

   d) I'll try to provide a road map, and then send you back. You'd do well to wrestle with that section of the reading again.

2. As most of you already know, the emergence of field theory is closely associated with development of electrical theory, and I should further emphasize that it is particularly associated with one particular electrical effect.

   a) This is electromagnetic induction, discovered by Michael Faraday in 1831, as a counterpart to Oersted's ten year old discovery of the effect of a current on a magnet.

b) You all, I think, know what the effect is: Draw

i) Two loops. Current induced in one when current changes in other.

ii) Or when magnet moves in vicinity. Equivalence of two effects following from Ampère's discovery that current loop acts like a magnet.

c) Fact that Faraday is man who discovers these effects already tells us something about him.

i) Like Oersted and like many of the German Naturphilosophen, he's a man with a deep conviction of the interrelationship between apparently divergent natural phenomena. He knows that one should be able to get a current from magnetism.

Possible tie Oersted reference

ii) Furthermore, as your reading indicates, this conviction does not cease to guide his research after his discovery of induction. Throughout his life he searches also for a relation between gravit and the other forces ofnnature.

iii) In that search he's not successful, but in another he is. He also seeks a relationship between light and these other forces. In 1845 discovers that if you send a magnetic field through a crystal and also send light through it, can rotate plane of polarization of light.

iv) Probably it is this discovery, totally unexpected, as much as anything else Faraday does that convinces men like Kelvin and Maxwell that, though they cannot understand his view, he is seeing deeply into the heart of nature and should be taken extremely ser.

d) Also, I think it is the deep conviction about an underlying unity that leads Faraday to place such emphasis upon the role of the medium that intervenes between interacting bodies.

i) For him interaction is seated in the medium. It's through the medium that interrelationships occur.

ii) This, again, is something that shows particularly clearly in the discovery about polarized light and magnetism.

II. THE NEWTONIAN APPROACH TO INDUCTION -- WILHELM WEBER, 1804-1890.

1. It is e.m. induction that sets Faraday and through him Maxwell on the route to what will become field theories -- theories in which there is no action at a distance but in which all effects are transmitted in time through the space that intervenes.

a) That being so it is sometimes felt that this was the only route that science could have taken at this point.

b) That there could be no action-at-a-distance explanation.

c) This is doubly so because it's clear that the great theory developed by Ampère to deal with Oersted's discovery and with its successors will not handle this effect. Draw.

i) Select current elements in each loop. Interaction on line between them.

ii) This tells you force at each distance or each value of current, but gives no special effects for motion or change of current. And there's no suggestion how to go about including these.

2. Nevertheless, there is a very good way to handle all of these effects (including now static interactions which Ampère has insisted are quite unlike current effects) within a still Newtonian model.

   a) This is an approach first suggested in 1845 by Gustav Fechner, a man more famous in history of psychology that in physics, and followed up during a long and distinguished research career by Wilhelm Weber.

      i) Weber began his career as a friend and close colleague of Gauss' at Göttingen, and he lives to be recognized as a dean of German science.-- the new Newtonian science.

      ii) That, as well as the intrinsic success of his theory, accounts for the fact that Maxwell is only very gradually accepted in Germany. Perhaps only post. 1890 and the last revision. Probably ever in England

3. Here I can only suggest what the approach is, but even the suggestion will remind you what Newtonianism here looks like and will serve for the contrast with Faraday.

   a) Draw parallel wires. If charged the usual static attractions and repulsions govern, and inverse square law holds.

      i) Furthermore, it holds even if charges are in motion, but is rapidly swamped by a stronger interaction between moving charges.

   b) That's governed by following regularity. Like charges attract if moving towards a common intersection. Repel if moving apart. Unlike repel under same circumstances.

      i) Thus Ampère's attraction of parallel currents.

c) To understand inductive effects make further supposition that current actually consists of charged particles moving in opposite directions, + one way, * the other.

i) Thus no effect on loop at rest.

ii) But move the ~~loop~~ towards wire with current and get induced flow.

4. This is the qualitative version of the theory produced in 1845 by Fechner. It's gigantically ingenious and really does quite well.

a) But that's only the start. In 1846 and from then on Weber produces a quantitative mathematical version and applies it to all sorts of problems.

b) His equation, which I write only for those who may wish to fool with it, takes the form:

$$F = \frac{e e'}{r^2} \left[1 + \frac{1}{c^2} \left(r \frac{d^2 r}{dt^2} - \frac{1}{2} \left[\frac{dr}{dt} \right]^2 \right) \right]$$

r is relative dist.

c is const (= vel lt)

c) And I simply assert that so far as any electrical or magnetic or electromagnetic effects known at mid-century are concerned, this equation is as good as Maxwell's equation and gives same results.

5. If this approach had been uniformly pursued (as it might well have been), Maxwell's equations and electromagnetic theory of light and radio waves might have been a long time coming.

a) That there is an alternate approach is reall F's responsibility single handed. I know of no other case in h of s where the existence

of an abherrant individual has made so decisive a difference.

b) Usually one develops a sense that the individual determines timing but not much more. But that's indefensible here, or so I now think.

III. FARADAY'S APPROACH

1. Now look at the very different approach taken by Michael Faraday. Only first two provisos.

a) In the description of his guiding ideas and beliefs Faraday is neither very clear nor consistent in any one place. And his ideas develop. What follows necessarily includes important elements of conjecture.

b) Also, I should say to you that though I'll take responsibility for these particular conjectures, several of them originate with one of the graduate students here, Mr. Arthur Quinn, who did a particularly perceptive piece of work on Faraday in my seminar last fall.

2. Start following Faraday by going back to earlier diagram with two parallel wires.

a) From the start F's view is that current in one wire must put other into a special state -- electrotonic state -- or else we can't understand current that's produced while current in first wire builds up or stops.

b) Furthermore, at least for a time he has an idea about what this state must be like. Uses ideas that he's gotten as a student of Davy's and at an earlier date when both were working on electricity.

(1)

Taxonomy & Evolution

I. Plant Classification to Linnaeus (1707-1778)
   The Emergence of Problems, Institutions, Techniques
II. The Problem and Rationale of Plant Classification
   Nature of the Problem
   Taxonomy as a bar to Evolution
III. From Linnaeus towards Darwin
   Artificial vs. Natural Systems

Charles: I got only half-way through p. 10

HISTORY 336 -- Lecture 15

Problem of Plant Taxonomy

I. INTRODUCTION

1. This morning begins a rapid switch of subject which will carry on for the next three weeks.

   a) Subject switch is from physical to biological or natural historical science. That will be the most noticable transition.

   b) But for reasons that may not be altogether apparent, there will also be something of a switch in method. From this point on in the course, there will also be a greater divergence than previously between reading and lectures.

      i) Partly, there is somewhat more good reading on 19th century biology than on physical science in same period. It's less technical and it includes theory of evolution whose general impact on thought about man I need not here and now elucidate.

      ii) Also, true, however, (had best make it explicit at start) that my own background is in physical rather than biological science. Where there's a good book, I can't add that much to it.

2. Therefore propose now to proceed as follows:

   a) Excepting this morning's lecture, which will overlap some of the reading, will cover separate topics in lecture and reading.

   b) Two reading topics are Theory of Evolution and Ideas of Animal Heat. Latter is ideas about functions of respiration and nutrition. Energy

See back of 2.

c) In lectures after this morning will deal first with development of cell theory, under general heading of search for natural unit of biological analysis, then with development of modern genetic theory.

i) Latter, to be done in week after next, will be handled by Professor Jacob Lorch, a visitor this semester from Israel.

ii) Has the advantage for this topic of being both a biologist and a historian of biology. We are fortunate to have him at Princeton this semester, and I'm looking forward to hearing these lectures myself.

3. That's where we're going, and we'll begin almost right away.

a) Only, as I've indicated already, this morning's lecture doesn't quite fit the pattern. Here I do want to talk about a subject that's part of the story of the theory of evolution.

b) And ask you to realize as I do so that there are a number of other parts of the story that might be treated in the same way.

c) If I have a criticism of Eiseley's book, it is that it tells the story of evolution too much as a story of overarching ideas about nature and too little as a story about the hard scientific research and the established scientific traditions from which evolution is evoked.

i) Read carefully and you'll find information about both, but you'll have to read carefully.

ii) This morning I want to take one of those strands and show you what

The Made bad trouble.
Partly I was very ~~ill~~ tired. Said too much about I (and too apologetically)
Then washing time and reading among those. Don't actually need as much as is written.
Can also cut down 17 & 18 reading chiefly to Lilloetus.
Don't need ~~Herbst~~ all that data & elsewhere.
Probably must point up, make more effective, idea of taxonomy.
Poorly handled Got silly thru
III. 3.
Must consider whether the is to be done at all unless I can get thru P. de Candolle

can be found by following it.

iii) Have chosen plant classification -- plant taxanomy -- partly because it's so terribly important, partly because it's highly representative, and partly because it's much misunderstood.

iv) But could do the same with geology, with animal classification and comparative anatomy, with embryology and studies of plant sexuality, and with several others.

v) Watch for hints of these in your reading as you go along.

II. PLANT CLASSIFICATION TO LINNAEUS

1. Botany, as a field of professional specialization, belongs among the Baconian sciences in rather the same way that chemistry does.

a) There is much concern with plant life in ~~the early~~ antiquity and the early middle ages.

b) But except in Aristotle and his immediate successor Theophrastus it's associated almost exclusively with the study of medicinal drugs.

ii) Until the 16th century or thereabouts the concern with practical therapy dominates the concern with plant life at large.

ii) The herbal, a list of medically useful plants with directions for recognizing them, gathering them, and (sometimes) preparing them, is the product of the group from whom botany will emerge.

iii) As late as mid-16th cent, by which time transition to botany proper is underway, find one of the greatest of the plant descri-

bers appologising to his readers for sneaking in one illustration and discussion of a plant with no known medicinal use.

2. Well, we're supposed to be working on mid-19th century science at the moment, and I'll therefore not pause to try to explain the reasons for the change in botany that begins in late 16th.

   a) Many of the reasons are those already discussed early in this course and in 335. I might add that this is one of the fields in which the availability of a printed text makes vast differences.

   b) But, though I'll pass over the causes, I do need in a general way to sketch the effects.

3. Of which first is already implicit: a change in the problems to which ~~plant~~ men concerned with plants direct themselves and, as an obvious corrollary, a change in the scale of the operation.

   a) Still roots in medicine, but increasingly a concern with whole plant world for its own sake. By end of 16th century there's no need to appologize for including a medically irrelevant plant.

   b) But that means there are very many more plants to be studied.

      i) Typical herbal discusses some 500 plants.

      ii) By late 16th century Cesalpino, one of first great systematists, describes 1500 in his printed book.

      iii) Century later, John Ray's General History of Plants, 3 volumes, describes 18,600 distinct species, which is still a long way short of the achievement of Linnaeus in first half of 18th cent.

4. But any activity on this scale needs multiplicity of people, and also institutional home. This is just what it gets beginning in 16th century.

   a) Thus first botanic gardens grow up rapildy. Padua, 1545; Leiden, 1577; Montpelier, 1592; Paris, 1626; Oxford, 1632; and many others. Mostly associated in origins with medical schools, but their scope is rapidly increased.

   b) Simultaneously get, what for taxonomist is even more important tool, the herbarium. Collection of dried and pressed plants from variety of locations (won't all grown in garden and isn't room anyway) that can be used for comparison with new samples as they are sent in or found in one's travels.

      i) Oldest known is from Italy, 1540. Still one dating from late 16th century in Bologna. Has 4,000 specimens, many more than covered in any books of period.

      ii) Ever since it's been one of systematic botanist's most fundamental tools.

5. Well, what goes with this is by now perhaps obvious. I'll label it specialization and simply indicate it's of a variety of kinds;

   a) Geographical specialization: flora of particular regions.

   b) Or types of plants: flowers, shrubs, trees, ferns, and so on.

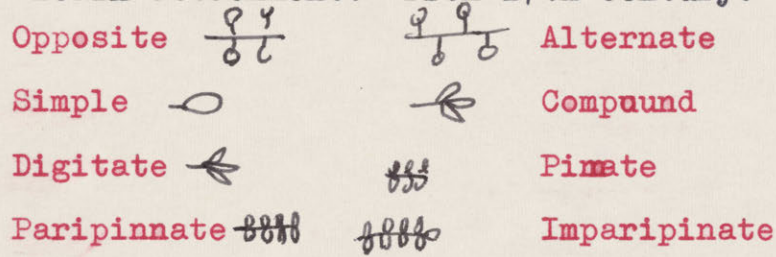
   c) And at least equally a quite different sort of specialization, that of language.

      i) Whole enterprise depends on communication and description. Ordi-

mary language is quite inadequate. Need special terms for descriptively most relevant features in which plants differ or are similar.

ii) Begin to accumulate fast in mid-17th century and are virtually completed by mid-18th. Linnaeus himself is one of main men involved.

iii) Give you just a sample, since it's unlikely to be familiar to many. Leaf attachment. From 17th century.



iv) Similar special terms needed for leaf shape, for type of edge, for kind of stem. Ditto for root structure. For flower, seed, and so on.

6. It is this whole line of development begun in mid-16th century that culminates in Carolus Linnaeus, 1707-1778.

a) For present purpose he must remain a symbol rather than a person, but be clear what he's a symbol of.

i) Botany, partly through his own effort, is by mid-18th century a fully professional activity, standardized, on an international sc

b) By later parts of his career, plants from all over world are sent to him: Europe, Russia, United States.

i) His vocabulary is used in describing them.

ii) Except in France his classificatory scheme is almost always used in sorting them.

iii) BE CLEAR THAT his is by no means the first classificatory scheme. They're as old as 16th century in their rudiments. But it is the first to become standard, and therefore to cry for elaboratio and perfection.

c) That's gigantically important because both in its successes and its failures some system of this sort was clearly among the requisites to the theory of evolution.

i) Ability to compare and contrast plants and animals over whole area of globe demands international system of this sort.

ii) That's success. It's also true, however, that difficulties encountered by this system when used in that way supply one of the pressures that Darwinism responds to.

III. THE PROBLEM OF CLASSIFICATION

1. That, however, gets ahead of mystory. Let me first try to indicate what the problem of classification is, though in a way that's necessarily going to be pretty abstract.

a) But it is a problem which in many respects shows up again and again elsewhere. Basically, for example, it's like problem of designing a

subject catalogue or a number indexing system for a large library.

b) Here the problem, working from the top down, or from most general category to more specific is: Given a specimen, decide:

á) Order, family, genus, species.



RESEMBLANCE

ïb) I'm choosing central four because Linnaeus chooses four, but there are more in both directions today.

c) I say problem is to do the classification, but clearly it's even more fundamentally to design a system which will permit you to do it.

d) And the great taxanomists are in all cases the designers of systems or the people with greatest skill in employing them.

2. Only, why should one suppose that this systematization can be worked out, that there will be a classfication system able to give unambiguous answers about where to put a given specimen?

a) That question can be answered historically by tracing the notion of species and genus back to Aristotle, relating it to Aristotle's notion of essence, and then coming forward.

b) But it's got an equally relevant common-sense answer that simultaneou helps account for the appeal of Aristotelian explanation.

i) Look around: there are only a restricted number of plants; they do group themselves quite naturally into boxes that show great resemblance; we don't find all intervening kinds. Ought to be able to do this systematically for all plants, and animals.

ii) Or, same point a slightly different way, the initial plausibility of the classificatory enterprise is really derived from success with which in the every day world, we divide up multiplicity of objects and give them names.

iii) Have no trouble distinguishing -- in local surroundings -- trees, shrubs, flowers, ferns, mosses, CAN'T GET ON WITHOUT SUPPOSING THAT NATURE PERMITS THIS SORT OF DIVISION.

iv) Only it gets tough when one collects over wide area and begins to find that intermediate objects do exist.

c) When that happens, classification gets deeply entangled with notions about structure of the natural world.

d) In short, classification -- taxonomy -- turns out to be a thoroughly theoretical enterprise. And theory is one, even when implicit, that makes theory of evolution very hard to hold.

3. See this first with notion of species.

a) Basically it's notion of "kind". Primrose is one kind of flower, nasturtium another. It's what gets named.

b) But it's not true that all nasturtiums are alike, nor are nasturtium's and primroses totally different. Not tough while this degree of divergence persists, but when closely resembling plants are brought in, need some way to make decision. New species or new example of old one.

c) Linnaeus's answer, which is older than he, is that all plants are same species if they are or could be descended from same parents.

observation plus

i) Experimental plant breeding tells you what the natural limits of a species are.

ii) Anything outside those limits belongs to another species.

d) At which point two things happen.

i) Fixity of species -- invariability -- gets built into definition of term or at least into main criterion for its employment in case of difficulty. ADD PARENTHETICALLY that since Darwin, whole notion has been in trouble. Great current debate on what a species is. Notion no longer makes sense.

ii) Other is that notion fits a larger theory of nature. Each species traces back to original pair created by God at the beginning (or perhaps in some later special creation).

4. Extension of this way of looking at things provides basis for faith in workability of higher classificatory categories -- genus, family, order.

a) If species are the originally created kinds from which all life is now descended, then genera and other classificatory categories indicate the plan of the architect at the creation. God did not create at random. It would be

b) Original form of idea is that of the Great Chain of Being -- discussed in your reading so I'll be brief. in projects Wiggett mid-

i) God creates so as to fill all possible levels of being from primal inorganic mud, to algae, plants, animals, man, angels.

ii) By 18th century most biologists convinced that a single linear arrangement won't do. But nevertheless, think one can map the

relationships built into the divine plan. That phrase, "map," is actually Linnaeus's and runs through much subsequent discussio

c) So that here again one sees just how deeply the notion of fixity of interrelationships between beings of the created world is built into the enterprise of the taxonomist.

   i) In a perfectly real sense, one want to say that the job will lose its rationale when these beliefs are upset, as they are by evolution.

   ii) And in fact taxanomy has not been a very popular enterpriese since acceptance of Darwin.

d) Underline this relation between implicit theoretical underpinnings of classification and notion that species are fixed and permanent because of widespread belief that delay in getting evolutionary theory and resistance to it when it was announced are generally biblical in origin. Incompatibility with revealed religion.

   i) There were, in fact, problems of this sort.

   ii) But at least among professional students of plant and animal life they are relatively minor.

   iii) Rather idea of fixed species, of the plan, are built in as underpinnings of their professional enterprise.

   iv) Darwinism will call into question much that's already been achieved.

IVI. TAXANOMIC ROUTES TO DARWINISM

1. Yet that's only part of the story. Though taxanomy in its natural and original form is based on notions of fixity of plant and animal forms, the development of the field in late 18th and early 19th century creates a number of the pressures, ~~and certain of the ideas that~~ much of the data, and some of the ideas that lead to evolutionary theory.

2. To tell whole of that story need ideas from another source that I'll take up in next lecture, but ban begin in this lectures concluding moments by telling you something about where Linnaeus is forced to leave this problem. What it is that successors concentrate upon.

   a) In dealing with at least the higher plants (those other than mosses, lichen, etc.) Linnaeus is thoroughly successful with species problem.

      i) Most specimens that he put in single species are still there, and conversely.

   b) And to almost the same extent he was successful with genera. For the higher plants his genera are still largely in use and contain same members as well as more recently discovered specimens.

   c) But at level of family the problem proves tough. L works on it all his life. His literary remains include a fragmentary manuscript outlining some 67 natural families -- categories based on mutural resemblance -- and they're close to those used today.

      i) But this scheme was never completed, nor did it get this far soon enough to be used in L's own practice.

ii) Instead, for purposes of practical taxonomy, resorts to an explicitly artifical solution.. Counts pistils to determine family and stamens to determine order.

iii) Perhaps not totally artificial. Probably chosen because these are sexual organs, and most concerned with parentage. But L has no doubt that it won't do.

iv) Urges botanists to keep on. His whole practice at lower level provides the mddel.

3. Botanists of late 18th and of 19th century do keep on. Do work out higher classificatory techniques that seem to divide plant world into natufal boxes, ones which reflect basic plan.

a) Yet the plan they derive has a number of puzzling features.

b) Harder and harder to look at it and still maintain fixity of species. It looks more and more like a geneology. A family tree with variation over generations.

c) And it offers a number of detailed puzzles besides -- for example -- the characteristics most useful for high level groupings turn out to be not the functionally important ones like sexual organs, but unimportant ones like shape.

d) Will give more detail on this next time, but the movement in question comes out of more than taxanomy as such and I need some other themes from next lecture before building back to classificatory problem.

(3)

Some Effects of Morphology ~~Plus~~ and...

I. Morphology and Naturphilosophie

Lorenz Oken, 1779-1851

II. Morphologie and Plant Taxonomy

A. P. de Candolle, 1778-1841

III. Birth of Cell Theory

Henri Dutrochet, 1776-1847

Robert Brown, 1773-1858

Mathias Schleiden, ~~1810-82~~ 1804-81

Theodor Schwann, 1810-82

HISTORY 336 -- Lecture 17

Some Effects of Morphology plus

I. INTRODUCTION

1. In my last lecture I talked at some length about changing modes of biol. explanation from early 17th to early 19th century, and ended by pointing up two effects of the shift towards emphasis on "living pafticles."

   a) First of these was an increasing deemphasis on organs as basic unit of physiological analysis. By early 19th century tissues have to a large extent replaced them. Bichat as central figure in this trans.

   b) Second was corrollary of the first. Deemphasis of organs is also deemphasis of function. Emphasis on living tissue and its principles or organization carries with it emphasis on shape and form irregarless of function.

2. My intention this morning is to examine two widely different effects of this way of looking at organisms.

   a) One of these is on the study of plants, and particularly on their classification, taking me back to topic which I talked of first in dealing with bio.

   b) Second is ~~new mode of explanation as background for~~ elaboration of the cell theory. View that the basic unit of all organisms is the cell, a unit which has simultaneously two lives one of its own (so it has integrity as an organ) and one in the community of cells which constitute the organism.

   b) This is view with which much bio. advance in 2nd half of cent is assoc

3. The first of these subjects could easily be given a lecture to itself, and the second ought to have two. My presentation will inevitably be extremely schematic.

   a) Partly this means that, though I introduce these subjects as effects of new emphasis on tissue and on morphology, they derive from more in eighteenth and nineteenth century than that: My "morphology plus"

      i) ~~Yet these extras I shall simply introduce by name with no attempt to trace their development.~~

   b) Partly, also, it means that in introducing morphology, I've derived it too simplistically from new emphasis on living tissue as organized matter, organized by life forces.

      i) For at least some of the people -- particularly the Germans -- who pursue it at beginning of the nineteenth century, there is another THOUGH OVERLAPPING route to many of the same emphases.

      ii) This is Naturphilosophie, the romantic, idealistic view of the world which dominated German philosophy in late 18th and early 19th century.

      iii) Need scarcely now tell you that it was a generally anti-scientific and particularly an anti-mathematical, anti-materialistic, ~~anti~~ anti-Newtonian movement.

      iv) Even in biology, where its organismic approach and insistence on vital forces came closest to being appropriate, its results were often entirely mad.

v) Yet it's residual impact on some of the people who were raised under its influence and then rebelled against was occasionally fruitful.

vi) In particular cases, it's hard to tell whether Naturphilosophie or a more mechanistic approach is at the basis of a given contribution. Shan't attempt to ~~display~~ its influence that way.

vii) But do want to say just a few ways about how it appears in biol. of early 19th century. Find it hard to understand everything that occurred without recognizing that it too is part of the environment for scientific practice.

4. Like the mechanistic vitalists I discussed last time, the Naturphilosophen believe there's something special about living organisms.

a) But they are idealists, notmaterialists. They don't locate the special characteristic of life in living atoms, living particles, of matter, and they draw no analogy between Newton's gravity and living forces.

b) Rather they see an IDEA, a disembodied spiritual force like a Platonic Idea, underlying life processes.

i) In a way reminiscent of Aristotelian theory, all organisms grow to realize this plan. It's the force which directs and organises their matter.

ii) But in ways that are not at all Aristotelian, they seek to see all life as manifesting but a single plan, or a minimum number of related plans.

5. One result of this view is an emphasis on the study of embriology -- development of the organism from egg newborn infant.

   a) Guided by life force, realization of plan, so it's clue to force.

   b) Also, since embryo's do look more like each other than mature form (do have tails, gill slits, etc.) there are clues here to unities of plan hidden in more mature forms.

   c) Will see the emphasis in all these.

6. Second result is search for far-reaching resemblances among superficially different organisms. Search that starts in the influential writings, particularly on botany, of German poet Goethe at end of 18th century.

   a) He manages, for example, to see many parts of flowers as modified leaves.

   b) This program continued, particularly for animal world, by biologist and philosopher Lorenz Oken, 1779-1851, whose basic schema is the following:

      i) Basic animal form is reiterated segments as in worm, centipede.

      ii) Residue of this is vertebral column.

      iii) For man, to jump to top of line, last vertebra becomes skull; next is jaw bone; arms grow out, and so on.

   c) This will indicate how absurd the view could be unless controlled by disciplined observation of established science. Done this way, it's not reputable biology at all. Contrast Cuvier.

   d) But it can become that, or at least the same sorts of ideas can eventuate in reputable biology.

II. MORPHOLOGY IN PLANT TAXONOMY

1. Place I shall try to illustrate this is in work of Swiss botanist, August Pyramus de Candolle, 1778-1841. In turning to it, say at once that in his case as in a number of others, there's no direct evidence of influence from Naturphilosophie. Far more like Bichat, than like Oken.

   a) Hard to see the coincidence of views as purely fortuitous, however, and one supposes that there are at least overlapping roots, not yet very clearly delineated.

2. de Candolle is one of a number of men, predecessors and contemporaries, who are trying to extend the work of Linnaeus, and we can start with de Candolle by remembering what Linnaeus leaves to be done.

   a) His program is classification into species, genus, family, and order.

   b) For the first two categgrizations he studies whole plants from root to fruit with great care, including microscopic examination, and does some experimental growing as well.

      i) His conclusions, at least for the higher plants, have stood up very well. Most of his species determinations and of his genera have lasted into modern botanical classification.

   c) But at the higher levels he runs into difficulty. Wants to do it the same way. Find natural resemblances, divide the plant world up according to God 's plan.

      I) Actually continues with this effort throughout life and leaves fragmentary list of some sixty-odd natural families, which are very like ones in use today.

ii) But day-to-day field work can't wait for this, so in his manuals of classification adopts an arbitrary or almost arbitrary solution

iii) Counts pistils for family, stamens for order. Thus emerges with what -- at these higher orders tho not at lower -- is an artificial system.

iv) Urges others to carry on.

7. Perhaps the greatest of those who does is Pyrame de Candolle, who is very signficantly affected by two post-Linnaean developments.

a) One of these challenge presented to classifiers of exotic species brought in by voyagers to the tropics, particularly to the South Pac.

i) Beginning with voyage of famous Captain Cooke in 1768-71, late 18th century is age of voyages of distant exploration.

ii) Many of them carry botanists. (Remember Darwin is a naturalist on a voyage, and he's only one of many. It's a training school for 19th century naturalists.)

iii) The plants brought back often resemble European types only in most general way. Attempt to fit them in produces emphasis on features previously left in background.

b) This is one of the two differences, the other, of course, being morphological approach.

8. Subject of result as a whole is too complex for discussion here, but two examples will be leading.

2. That story actually originates in the 17th century with the invention and deployment of the microscope.

   a) Almost from the start people see cells. What is more important, some of what they see they even describe as cells, using that term.

      i) In particular, this is true of Robert Hooke, looking at cork. He's apparently first to use word. Others use it in connection with examination of plant tissues.

      ii) Situation continues with word popping up from time to time during 18th century.

      iii) Also, in this later period get a few people reporting that they see matter made up of globules. In this case, we now suppose they were often seeing diffraction patterns caused by their microscopes

   b) Anyone concerned to write the history of cell theory goes back and collects scattered references of this sort, but it's clear that if one is looking for organizing principles of the period, there's no cell theory here. At least two vitally important things missing

      i) No notion of generality of cell structure. Just some tissues.

      ii) Much more important. Word cell still means the wrong thing. Cell is honeycomb, it's the walls. They're not independent units. Furthermore, the interior is really just space, or storage Not part of functional organic unit at all.

      iii) Only exception would be a few of the globulists who think perhaps they're seeing living atoms of which all living matter is made. But they can't do much with their observations.

3. This pretty well describes the situation as it continues through the 18th century. In the early 19th, however, a numberof things begin to happen all at once, and it is they that transform these previously scattered observations into a coherent system that develops during the first half of the century.

4. Of these things the first and perhaps also most important is the new emphasis on tissue which follows on the work of Bichat.

   a) Bichat has developed a number of criteria for tissue and a number of techniques for examining them. Grinding, some staining, chemical tests with acids, and so on.

   b) His successors refine these, making more use at the same time of the microscope.

      i) Furthermore, apply them to plants as well as animals for tissue study bridges gap. Fortunate for cell theory, since plant cells are more easily seen than animal.

      ii) What can come of this appears most clearly of all in work of Henri Dutrochet, 1776-1847.

      iii) He develops, for example, a technique which separates plant cells one from another. Shows two walls, not one. Separate independent units.

      iv) Immediately also draws parallel between these and the globules seen in animal tissue.

      v) Without seeing full generality, he is seeing some cells in plants and animals as basic structural unit.

5. Second line of development that underlies some of Dutrochet's work as well as that of my second figure, Robert Brown, 1773-1858, is development of improved microscopes.

   a) Achromatic lenses are actually developed in last third of 18th century though its only in first third of 19th that they come into relatively general use.

   b) Some, though by no means all, of the observations basic to cell theory could scarcely have been made with the older instruments.

   c) One of these is the discovery of the cell nucleus by the Englishman Robert Brown, a botanist.

   d) He notices that almost always when he can see a cell in plant tissue, it somewhere cotnains a special structure, ~~usually darker~~ than the rest. Suggests that it constantly accompanies cells. 1831.

6. That's the discovery that's picked up by Mathias Schleiden, 1804-81, and, through him by Theodor Schwann, 1810-82, two German biologists in whom at least some influence of Oken is relatively clear.

   a) In their hands, Schleiden working first and working on plants, Schwann following and applying the theory to animals, the nucleus has a double importance.

   b) The first is technical. Under many circumstances the nucleus or some part of it is easier to see than the cell wall. When the nucleus is taken as the sign of the cell, it is possible to learn to build the cell walls around it where no divisions had been seen before. Thus, these two now really do manage to see cells everywhere.

i) For what's probably the first time the cell is seen as recurring in all living tissue, and this time people can trace it in most tissue.

c) And, what's probably still more important, though also quite wrong, is that for these men, trained to look for developmental patterns, the nucleus also becomes a key to organic growth.

i) Quasi crystallization process. In the organic fluid known as cytoblast, nucleus condenses out, then surface crytallization gives cell wall which expands out from the ~~exit~~ nuclear surface to form the mature cell.

ii) And this, I think, though it quite wrong gives two more of its characteristic features to the cell theory.

iii) At this point the emphasis swings full away from cell as wall. Cell is the nucleus plus attached liquid and membrane. It is no longer simply a hollow strcutrue or ~~bag~~. walled

iv) Equally, important, because ~~it~~ The cell provides the key to the growth process and thus to development, its life and growth become for many the central biological problem. It, now, even before tissue becomes the unit from which the biologist must build.

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Princeton - History 336

OK

HISTORY 336 -- Lecture 6

The Electric Current, 1791-1845

I. THE BATTERY AND ITS AFTERMATH

1. Treatment of electrostatics in last lecture carries us very close to a modern treatment of charge at rest.

   a) Particularly will seem to have done so if I add that along with development discussed last time come concepts very close to those of potential -- then called "tension" -- and of capacity.

   b) Yet that apparent modernity needs to be qualified by reminding you that only known electrical effects are static, charges at rest.

      i) All thinking about ~~field~~ electrical science is exclusively from this viewpoint. Other possibilities just not open.

   c) And in addition, of course, even within electrostatic phenomena the whole set of notions about what electricity is is subject to many further transformations continuing into present day.

2. So the last lecture provides only the first chapter, or series of chapters, in a continuing story.

   a) Today carry story a bit further, setting my limit for the moment as the furthest point to which Newtonian electrical theories advance in the 19th century.

      i) Having done that will drop electricity for the time being, returning to it late in the course with the concept of field.

b) Break is very far from being arbitrary, for electricity is one of number of fields -- a key one, however -- in which Newtonianism and mathematization of Baconian science has its greatest advances.

i) And also, just as it does so, runs into severe difficulties which are ultimately responsible for its breakdown at the beginning of this century.

ii) Am now doing advance, reserving breakdown for close of the course.

3. Line of development sketched last time might have continued unbroken through the 19th century, and indeed that's part of what occurs.

a) Gave you only first taste of mathematization and no examples of it power.

i) Long way to go still in work of Gauss, Green, Kelvin and others through the 19th century to give you full mathematical structure for electrostatics.

b) But, in practice, though that line does continue, there's another far more important ones that starts totally unexpectedly even before this one is well underway.

i) This is discovery of the electric battery -- of current electricity -- inaugurated just about 1790, immediately after Coulomb, by Luigi Galvani's famous discovery.

c) The story of the frog's legs is terribly well known and is also fully described by Galvani himself in your reading.

i) I propose to say nothing whatsoever about it here.

ii) But I would like to pose one question about it for discussion in precepts.

iii) It's always billed as one of the famous accidents that carry science forward, and it clearly is in a sense that you will see.

iv) But in another sense the whole application of the term accident seems wrong in this and in other similar cases of which scientific development is full.

v) I leave you with question: To the extent that accidental discovey in the sciences is like this example, to what extent does scientific advance depend on accidents?

4. So let us the experiment done and Galvani's conclusion reached:

a) There is a special electrical fluid, brand new, labelled animal electricity.

i) It can be discharged under various circumstances, and in particular if a bimetallic strip draw is connected from the crural nerve of the leg of a frog to the muscle.

b) But this is still not the battery. That step depends upon intervent'n of man briefly mentioned last time.

i) Alessandro Volta, one the great European experts on electrostatics inventor of both electrophorus and condensing electroscope.

ii) Nor surprisingly he's extremely reluctant to believe that a brand new form of electricity has been discovered.

c) With his very sensitive instruments, he manages to detect electrical effects from bimetallic junction and without intervention of frog.

i) That, he thinks, is just a very sensitive detector.

ii) Result is big fight with Galvani who thinks there is essential role for frog.

iii) And, of course, both are right. Volta's success, tho vital for electricity, is not good for physiology.

iv) Electrical effects generated physiologically now get much harder to discover.

5. Volta, then, has gotten electrical effect from contact of two different metals in the late 1790's, then, in 1800, announces that he's found how to multiply it, make it unmistakeable.

v) Supported by standard experimental technique.

iv) Realize also that it's just this switch that makes the work of Ohm possible. It's in your reading, and I won't discuss it.

v) But realize that it separates out the battery effect, potential, from the external circuit effect, resistance, and sees the current as resulting from these two.

vi) Done just four years after Oersted and then much resisted. This whole mode of analysis is not even there to be done earlier while people assimilate the circuit to the battery.

2. That's one piece of what makes the work of Oersted so important. Another is what happens to the discovery almost immediately when analysed by Ampère. Author great case of mathematician

a) He sees that must now either view electric effects as magnetic in origin or magnetic effects as electric.

i) Rapidly (a matter of weeks) opts for second alternative.

ii) First, magnet as current sheet. Then, with an assist from Fresnel , he suggests that all molecules are surrounded by circulating currents which make them little magnets.

b) Problem of interaction is now reduced to that of interaction between two currents, and Ampère proceeds to a series of classic papers on this topic which virtually close if off within four years after Oersted's first paper.

8 i) Oersted himself has spoken of a helical motion of electrical particles around the wire. It's effluvial. Cartesian.

iv) Ampère and his contemporaries laugh. That's oldfashioned, and provincial. They know how it should be done. Newtonian. Action at a distance.

v) Same as transition made in electrostatics but now made immediately

c) Imagine two circuits Draw. Concentrate on one element in each circuit. Draw. What is force between them.

i) With a few very simple assumptions that he provides demonstration for, answer almost falls out in his lap.

ii) Reversing direction of current, reverses force.

Current behaves as vector quantity.

Couple of others almost as obvious, and he's almost ready to proceed deductively.

iii) But inspection reveals that of course he needs one more thing, one he takes for granted without even attempting a demonstration. FORCE IS ALONG LINE OF CENTERS.

iv) This is the basic Newtonian assumption and also the ultimate weakspot.

d) Given that much Ampère can go immediately to: $F = i\,i'/r^2\ (f(\theta, \theta'))$
Where Ampere does make angular dependence explicit.
Simple solid trigonometry, but not needed here.

i) Almost ultimate triumph for Newtonian approach in this field.

ii) And simultaneously points to where break with Newton will come.

V. WILHELM WEBER

1. Say this is almost last step in Newtonian development of electricity, and indeed it's about the last one people now remember.

   a) But there is another series of steps taken particularly by Wilhelm Weber, a friend and colleague of Gauss' at Göttingen.

      i) He's really in first generation of German mathematical physics. A man of first-rate talents and vast influence.

      ii) It's he who creates the theory that rivals Maxwell's in much of Europe until the very late 1880's and the 1890's.

   b) Like Maxwell's own work, Weber's seems to be a response to Faraday's and particularly in this case to Faraday's discovery of induced current. In reading. Won't discuss. What it is.

      i) Direct action of current elements gives you no way to explain the induction of one current by another. Must be still another effect at work here. Faraday takes one approach. Ewald and Helmholtz another.

      ii) Weber, led by a colleague Fechner, insists that two effects should be aspects of more general law which should also include electrostatics.

      iii) Finds it by going from the current element, or the element of wire with current in it, to the actual charges that are moving within the wire.

iv) One very important virtue of this approach should be very quickly apparent to most of you. Can now treat a moving charge as a current. Thus to move a wire with current in it is to change direction of current. Thus can distinguish effects of loops in motion from those of loops at rest. Basic for electrodynamics.

2. What Weber needs and produces is then a law of force between charges that will depend not only on their position but on their velocieties and it's this he proceeds to develop. Looks like this:

a) $F = ee'/r^2 \left(1 + \frac{1}{c^2}\left[r\frac{d^2r}{dt^2} - \frac{1}{2}\left(\frac{dr}{dt}\right)^2\right]\right)$

b) Some people will think it absurd because velocity dependent forces seem so un-Newtonian. Maxwell is bothered by this as by some problems of energy conservation presented by this formulation.

c) But for most people it's just the necessary broadening of the older Newtonian conception.

d) And it has the great virtue of giving with great precision the right forces between static charges, between currents, and for induction.

e) There are no hard arguments against it until the discovery by Hertz of electromagnetic radiation in 1888.

~~Rakkoxxkoxkavoisier~~

The Route from Lavoisier to Dalton

I. What was the Chemical Revolution?

1. The text book tradition before Lav.
2. The genesis of the Traité élémentaire, 1789
3. The Physical nature of the ~~new~~ chemistry

II. ~~The Vital Step~~ remaining for Dalton's New Chem-

CHARLES:

THIS NEEDS MUCH POLISHING, POINTING, BALANCING.

I RETHOUGHT MUCH OF THE SUBJECT AN ENTIRE ROUTE. BUT IT SEEMS VERY WELL IN AND INCLINED TO FORK IT.

HISTORY 336 -- Lecture 38

I. WHAT IS REVOLUTIONARY ABOUT CHEM REV?

1. I want this morning to locate myself midway between the work of Lavoisier and Dalton, say somewhere in the 1790's, and look in both directions.

   a) In the process I hope to point up certain characteristics of both their work, simultaneously show the sense in which Dalton depends on Lavoisier, and finally indicate why, despite the dependence, the steps taken by Dalton are ones which Lavoisier could not have taken.

   b) Indeed, one of the most important points to be made about Dalton is that he breaks with a tradition in a way that's almost imperceptible, but radically important to subsequent history.

   c) Usually Dalton is called the first of the physical chemists or something of the sort since he firmly attaches chemistry to distinct physical bodies, or atoms, for the first time. This is generally the viewpoint taken in your reading, and there's obviously an import. truth to it.

   d) But the point has a converse which in part reverses it. I'll want to argue before we're through this morning, that Dalton drives an intellectual wedge between chemistry and physics. Atoms yes, but for the first time they're not the physicists atoms, not the atoms of the Newtonians.

   e) Nor do the two come together again until the 20th century.

THIS WENT VERY WELL.
BUT THAT PARTLY BECAUSE
I ACHIEVED BETTER
BALANCE AND POINT OF
I GAVE IT.

CCG FEELS THAT
I DO TO LITTLE WITH
WEIGHT RELATIONS. ER.
IN PRE-TKAITÉ WORK.
MUST DO FAR MORE
IF READING CHANGES.
OTHERWISE, I'M NOT
SURE THAT NAMING
LOCK MAY NOT
BE ENOUGH.

This needs rewriting for clarity. But the material is good.

f) In sense I'm after want to suggest that chemistry gains with Dalton an intellectual integrity and separateness that it's previously possessed only in experimental technique and in institutionalization.

2. That, however, takes me too far ahead. Treat it as look at where we're going.

a) For the moment drop back to where we've already been, to Lavoisier and the Oxygen theory of combusion.

b) And ask why do people call this episode the Chemical Revolution. What's so staggering about it, even to the professional chemist?

c) Clear from the reactions that it is staggering.

i) Much resistance in a number of places. Priestley never never comes round, and the issue remains live for a full generation.

d) Not altogether easy to see why? Combustion is only one type of reaction among many; oxygen is not so very far from being negative phlogiston, something that's given off when phlogiston was said to be taken on. Nor are there any overwhelmingly novel techniques in Lavoisier -- he's more consistent in handling gases and in using balance, but it's all been done before.

e) Then what's the fuss about?

3. Let me say at once that I'm not sure I know the answer. In a sense its triumph enough to have discovered the questions which obviously ought to be asked but very seldom is.

3. That's a tougher question than it sounds, partly because it's scarcely been asked. ~~Though it clearly must be.~~

   a) In fact, Mr. Gillispie's description of Lavoisier as banishing the occult and romantic from chemistry in favor of the objective is one of the very few honest attempts at an answer I know. I admire it a good deal.

   b) Unfortunately it's not to me in that form an entirely convincing answer. Phlogiston was not that mystical or occult. In the sense that it was, there are similar features to be found for a while in later chemistry.

   c) I want to attack the same problem a little differently, though I think you will all see a considerable convergence of the views reached from Mr. Gillispie's and my rather different starting points.

4. I'd suggest, then, crux of the transition is ~~not so much to a more objective chemistry as~~ to a more theoretical chemistry,

   a) There's even a sense in which chemistry before Lavoisier is the more objective if by objective we mean largely descriptive, operational. ~~Simultaneously, though~~

   b) All of this shows quite clearly if one contrasts a typical chemistry text of the early 18th century with the text book tradition that's inaugurated by Lavoisier's Treatise on Elementary Chemistry of 1789.

   c) The pre-Lavoisier elementary chem text has a relatively standard form.

      i) Introduction that opens with a definition of chemistry. Usually as art which teaches how to separate bodies into elementary

7. In one sense this should sound entirely familiar to you. It's just what I said in talking about general corpuscular worldview two lectures ago.

   a) But in another sense its terribly different. These are no longer kernels of the chemical principles, vital oil, or whatever.

   b) Instead they're particles of laboratory substances or will be as soon as they've got suitable caloric sheaths.

   c) At this point atomism has become chemical as it had not been before.

   d) And in a way which leaves one with perplexing alternatives as to description.

      i) Clearly one can say that the chemical principles have vanished. Chemistry henceforth deals with real substances.

      ii) That's true enough, provided you recognize that, except in prefaces, the principles hadn't had much to do with chemistry for years and that some of Lavoisier's laboratory elements do act as principles -- oxygen in particular.

      iii) On the other hand, if you'll go that far with qualification, you can make an equally good case for the opposite view -- Say instead that the principles have multiplied in number and become the stable laboratory substances.

   e) My own view at the moment is that you don't quite catch what happened in the chemical revolution unless you see the validity of both these rather different approaches.

II. DALTON AND THE REDEFINITION OF CHEMISTRY

1. This seems to have brought me a long way from my announced topic. Said I wanted to explore route from Dalton to Lavoisier, but have never gotten passed L's Traité élèmentaire.

   a) Yet in another sense I may seem to have passed Dalton by. These cores of lab substances with caloric atmospheres are just Dalton's atoms.

   b) Real question is: What is there left for him to do? Or, better, why is the remaining step so hard to take?

   c) That step is itself clear enough: Must conceive the notion that when these atoms combine, they do so in simple and regular ways -- one-to-one or one-to-two or something of the sort.

   d) Realize also that if two elements can combine in different ways to give different products, as with nitrogen and oxygen, then these different products contain different but charadteristic ratios of the two ingredients.

   e) In short, one needs to see how nearly this picture implies the laws of fixed, definite, and multiple proportion, and then find these laws in the data.

   f) WHY WASN'T IT DONE AT ONCE? Why hard to take when it was done?

2. One part of the answer is clear, and I take it to be the one in your reading. Atoms had been around for years. It's not immediately apparent that they've now got implications for chemistry that they didn't have before.

a) But there's another piece of the story, and I think it may account for the fact that when these remaining steps are taken they're taken by a man who doesn't know chemistry -- a meteorologist with problems of his own.

b) Furthermore, may help understand why until very very late in the development of the theory Dalton seems unaware that you can even do chemistry with it.

c) Look at the Case Book carefully may find reason to believe that Dalton really didn't know he had a chemical theory until Thomas Thomson told him so.

3. Well that's all too cryptic. Let me try to make it plainer, which it will become if you'll remember what was saad in last lecture about chemical affinities which remain in Lavoisier and others of his time the mechanism of chemical reaction.

a) Chem reactions are just the ones that are brought about by forces acting between these cores.

b) But those "reactions" include solution, alloying, and for Lavoisier the combination of oxygen and nitrogen in the atmosphere.

c) In short, affinity theory draws the line between chemical combination and mixture in a very different place from where its drawn during the nineteenth century.

d) And the place its drawn makes fixed proportion and the others just impossible.

4. Problem appears with particular clarity in famous controversy between two French chemists Proust-Berthollet controversy.
   a) Begins in 1790's and is still not really settled when Dalton's work appears.
   b) Proust's argument.
   c) Berthollet's response. Special conditions.
   d) Shortly turns out neither is going to convince the other for they're speaking of somewhat different things when they speak of chemical reaction.

5. In fact, there's a choice to be made here.
   a) Can save Proust's thesis by making it a tautology. Reactions are chemical if they take place only in definite proportions.
   b) That's the decision that's made as a result of Dalton's work. Brings much more powerful analytic chemistry with it because of a whole set of new interconnections between reactions.
   c) But there are also clearcut arguments against the choice. There's no way to understand the forces that will result in the sorts of combinations that Dalton's theory restricts one to.
   d) Bad enough at the beginning and even worse when must admit molecules like H_2.
   e) There simply aren't such forces in physics, and there don't get to be until after the development of wave mechanics. It's really only in 1928 or thereabouts that Daltonian bonding becomes physically plausin

f) Until that time all rational theoretical considerations speak in favor of affinity theory and of Berthollet's position.

6. In short, what I am trying to suggest to you here is a pattern that I've only recently come to see myself.

a) From Boyle to Lavoisier, I suggest, the success of chemistry is more and more associated with taking seriously physical models of chemical processes.

b) ~~Physics~~ Natural Phil and chemistry cohere, more and more closely together. Never more so than in the work of Lavoisier himself.

c) Yet almost immediately they begin an important drift apart.

~~i) With Dalton chemists must~~

i) From Dalton until Heitler-London chemists must either posit their own special forces of a type not recognized in physics or get along without them entirely.

ii) In a sense which becomes increasingly important as the century goes on, one wants to say that Dalton gives chemistry an ~~intellectual integrity distinct~~ from that of physics .

Dept. of Intell. Indep. →

1964-65

Science and Technology I

I. Importance of the Industrial Revolution

II. Agriculture as an Example

Enclosure

Jethro Tull, 1674-1741

Robert Bakewell, 1725-1795

Arthur Young, 1741-1820

III. Science and Industrial Revolution.

Put up charts on pp. 8 and 10 but without enough labelling to permit interpretation.

Quiz on Dishowly

Must cut Iad

HISTORY 336 --- Lecture 6

Industrial Rev. no. 1

I. SIGNIFICANCE OF INDUSTRIAL REVOLUTION

1. Want in this lecture and the next to change the subject rapidly and markedly.

   a) Have been talking about science, want now to turn to technology.

   b) Most recently have been talking about Chem Rev, now talk about an even better known upheaval, the Industrial Revolution.

   c) As most of you already know, this is series of quite drastic changes in modes of production and distribution that takes place first in England, and centers in period 1760-1820. (Dating is, of course, as usual somewhat arbitrary.

   d) Effects are most marked in Agriculture, Textile mfg., Metallurgy, and Power Sources.

   e) My plan is to talk this morning in a fairly general way about the problem of science in the Industrial Revolution, hoping to point towards some more general problems about relation of science and technology. THAT, at least, IS STILL VERY MUCH WITH US.

      i) Where I need specific examples will draw them from first field, Agriculture.

      ii) Your reading this week is largely concerned with the two next innovations, Textiles and Metallurgy.

WENT QUITE WELL, THO
IT'S DULL (?) FOR STAGE.
CHARLES POINTS OUT MY
LACK OF DEEP INVOLVEMENT
SCENE.
FIRST PART MIGHT BE
CUT. DOWN? OR OUT?

To Col Charles

Townsend.

iii) Then in next lecture I'll return and consider one special example in some historical detail. The steam engine. A particularly interesting example and one with a special impact on subsequent science.

2. If this were a course in general European history, we could scarcely find a more important topic to discuss. Surely nothing we've touched on yet begins to approach it in significance.

a) Unlike the new chemistry or Franklin's theory of electricity, these developments change both the landscape and the way of life of a large part of the population of England, Germany, the United States and bits of France by middle of 19th century.

b) In areas affected I.R. brings end of significant role for small indep farmer, and corresponding change in distribution and distrib. of agricultural land.

c) Closely correlated with this shift and even more marked is immense urbanization particularly, at the start, in England.

i) Have been centers for trade and commerce. Now extend their monopoly and activity and range of influence.

ii) Far more important, take on a new role, that of centers for manufacture. They're the sites for the new factories which are the characteristic new production units and thus also for the sizable new labor force, the growing proletariat, that the factories require.

d) But if concentration in cities is one sign of what goes on, so is vastly improved communication between cities.

i) First come better roads. J. L. MacAdam, man who finally manages a hard smooth road surface still in use, is important figure in I.R.

ii) Only slightly behind improved roads in 18th century is a major spurt of canal building, connecting inland cities to each other and more particularly to ports.

iii) And then just as this system is becoming adquate comes the locomotive engine to displace it as the main carrier of raw materials to factories and finished products to consumers and ports.

e) Of course what goes with all this is in many areas a drastic transformation of a previously pastoral landscape, both geographical and spiritual.

i) Slag heaps and smoke palls and beginnings of smogs that are external scars due to industrialization.

ii) Equally its long hours for women and children in factories. Low pay. Crowded, unsanitary, living conditions.

f) Not clear that people were really much worse off than they'd been on the farms, but their plight is far more obvious and draws attention.

i) Thus the push towards corrective legislation and agitation for social reform that characterizes much of 19th century.

ii) And also the beginning of a literary movement that in prose and verse proclaims the pastoral life and declares man's a slave to

the machine. In a variety of ways the theme sounds through English literature from Blake and then Wordsworth to Dickens and Butler's Erewhon.

3. Probably that's more than enough to identify the movement for you. One or another of these concrete symptoms of a larger change must have rung bells for everyone in this heterogenous audience.

   a) Industrial Revolution is episode that gives us the first "developed countries." Before 1760 or thereabouts all countries are "underdev."

   b) Quite clear that for social history, economic history, or even political history (push to Empire) no more central movement of the period could be found.

   c) Only . . . WHAT IS IT DOING IN COURSE ON HISTORY OF SCIENCE?

II. AGRICULTURAL INNOVATION AS EXAMPLES.

1. To even begin an answer to that question -- and we'll have no full one today or even this week -- need some concrete details about the innovations around which Industrial Revolution centered.

   a) We'll have several, but for this morning restrict my attention entirely to agriculture, the area in which change is first felt.

   b) Asking what are -- in brief summary -- the central changes that take place.

2. First innovation is really simply the intensification of a movement that has recurred in England since end of Middle Ages. Enclosure.

   a) What it means is consolidation of small independent farms and their

combination with land previously open to common grazing thus forming large fenced tracts owned by single individual and farmed by tenants or hired laborers.

i) Previous tracts generally run fifty to sixty acres and are all intertwined one with another as residue of older system when land was distributed in one acre plots scattered here and there.

ii) Between 1740 and 1780 some 40,000 to 50,000 of these are bought up for consolidation. Perhaps 30,000 farms disappear entirely -- that's almost one for every 200 in population.

b) Objective of all this is to increase the efficiency with which food can be grown and cattle raised.

i) Partly drive for efficiency comes from increasing population, though also agricultural prosperity supports population growth. Cause and effect become impossible to disentangle but mutual support is clear.

ii) In this situation movement seems at least occasionally to be accelerated by desire of landed nobility to recoup fortunes and influence that once went automatically with land holding but that's been increasingly lost to leaders of commerce during the preceding century.

iii) Famous example, ~~cited in all the books~~ is Lord Townsend, ~~ridiculed by foxhunting neighbors as Turnip Townsend~~.

iv) He's famous Royal ambassador at start of his career, but retires to his estates and starts farming them after quarrel with Rob't W

v) Knocks down walls between small fields, fences large ones, plows previously fallow land, tries new crops, and so on.

vi) Yes, daughter, but by time of death late in 18th century price of land in his county is up by a factor of ten. Others trying to

v) And the multiplier, if not typical, does recurr repeatedly. Both in land value and in land produce, increases by a factor of ten in response to new methods are not uncommon.

3. Why the increased productivity? Partly, as indicated, the larger plots can be plowed and harvested more efficiently. Distribution of crops can be more rational.

a) But as happens in almost every area of production through these years, reorganization in one sphere brings innovation in another.

i) You will see in the reading as much reason to believe invention the mother of necessity as vice versa.

ii) Cause and effect are rarely unequivocal in this affairs, but a rythm of accelerated growth is quickly established.

b) A few typical examples of what goes on here can be treated in terms of names on board. Each stands for many.

4. Begin with Jethro Tull, 1674-1741. One of earliest leaders.

a) Attends Oxford, admitted to bar, but instead of practicing returns home to farm family estate. c. 1709

b) First experiments with new techniques and crops there, then on a farm of his own, Mount Prospero.

c) From 1711-14 he travels through various parts of Europe carefully observing techniques in use for different crops and at different localities.

d) Finally, in 1731, publishes first edition of vastly influential book that goes through many other editions in both English and French.

i) The New Horse Hoeing Husbandry or an Essay on Tillage and Vegetation.

e) Among vast variety of new techniques recommended in it I pick just a ~~two~~ few for illustration.

i) Tull is inventor of first practical seed drill. Drawn by one horse it plants six rows of seeds in parallel rows at a distance great enough so that cultivation can be done between rows with a plow or other horse drawn implement. HORSE HOEING

ii) There are other things of same sort including instructions for deep plowing, pulverizing soil, and so on.

iii) Also much experimentation with crops and rotation. Previously main system, dating from late middle ages when there has been a previous agricultural revolution, left one-third land fallow at all times.

iv) Now deeppr plowing and use of winterfeed crops keeps all of land in production ~~at all times~~. Cool year and for use of year

5. But, of course, winter feed crops makes it possible to raise more meat, also needed by population, and that's where my second figure comes in.

a) Robert Bakewell, 1725-1795 represents for stock breeding what Tull represents for cultivation.

b) Father is well to do farmer whose estate Bakewell takes over in 1860.

i) Turns it particularly to stock breeding and raising.

ii) Having previously travelled through England collecting information about desirable characteristics of different breeds and about breeding practices.

iii) Becomes in short order the first of the great systematic animal breeders and his work has permanently changed the look of the domestic sheep and beef cattle as well as of farm horses.

c) How effective he and contemporaries are is indicated by following figures for cattle brought to market at Smithfield Market

d)

	1710	1795
Oxen	370 lb	800 lb
Calves	50	150
Sheep	38	80

6. All of this, of course, has started with scattered individual innovators, most of whose names have been forgotten.

a) But by end of century it's become a national movement, and is beginning to acquire its own institutions.

b) That's what my third name stands for: Arthur Young, 1741-1820.

c) He's son of a minister, apprenticed to a merchant, a career he dislik and drops in favor of freelance journalism is London.

d) Then after his father's death he tries to manage small family estate and becomes experimental farmer.

e) In none of these pursuits is he notably successful, but he gains unique experience which begins to pay off when he combines farming with journalism.

f) From 1768 begins travels in England, Wales, and ultimately Ireland and France, observing agricultural techniques and reporting them in a long series of books that are sometimes travel books and sometimes specifically letters on agriculture.

g) In 1784 he begins publication of the Annals of Agriculture, probably the first of all the technological journals, a breed that begins to multiply from this time on.

h) In short, even as individual he's playing many functions of modern Dept of Agriculture or of Agricultural college.

i) And after 1793 he ~~know~~ no longer does this alone. Is first secretary of annew organization, Board of Agriculture, private association support by government and aiming to raise agricultural productivity of whole nation.

j) This is read grandfather of all Departments of Agriculture and their like. Inhibitions which have been mostly guards for in perfect bird. science and practical journey

7. By now it should need no telling that, in general, these reforms are highly successful.

   a) Give you just one further indication before asking again how these developments relate to course.

   b) Size of population that's supported by use of these new techniques. Rough estimate are, of course, all we've got, but it looks aboutlike:

      1700 5 1/2 mill (just a bit more than it's been for past 100)

      1750 6 1/2 " (it may be this that pushes early enclosures)

      1800 9 " (note it's just about now that Malthus writes Essay on Princ. of Pop.) Essay on limitation of prosperity and population growth by limitation on means of subsistence.)

      1831 14 million.

III. SCIENCE AND INDUSTRIAL REVOLUTION

1. All this should leave you with no doubt about the importance of the Industrial Revolution, but it's likely to have done nothing directly for the question: Why Consider I.R. in course on History of Science.

   a) In closing moments this morning have no real hope or even wish to answer that question.

   b) But do want to set it up with more precision so that you can watch for detail in reading and contemplate significance for precepts.

2. Probably best to start by pointing out there's been a standard answer to the question, and it's still remarkably prevalent in many circles.

   a) I.R. seen as fulfilment of Scientific Revolution of 17th century. Newton, Descartes, Huyghens, Boyle and their contemporaries are people to whom this transformation of society is traced.

      i) It's they who broke with traditional authorities and made the first great modern scientific discoveries.

      ii) I.R. is their somewhat belated application.

   b) That view was often popular both in and out of England during the Industrial Revolution. It can still be heard, though with declining frequency, from both general and economic historians.

      i) But for agricultural revolution, at least, it's nonsense, and I'd be surprised if you felt differently about other aspects of I.R. in your reading.

      ii) In late 19th and 20th century science does begin to have useful applications to agriculture. Partly through genetics, partly through organic chemistry and the ability to recognize trace elements required in fertilizers, and so on.

      iii) But there's nothing in chem of 17th or 18th century or in bio that can be seen as usefully applied here.

   c) Urge only necessity of recognizing that there can be all sorts of technological progress without any boost from science at all. Or at least that was the case during most of history.

3. But that should not be taken to suggest that two enterprises have nothing to do with each other.

   a) Notice, in particular, the use of methods that are also proving very effective in science.

      i) Careful collection of data on farming practices in various region These are Bacon's histories of crafts.

      ii) Or experimental planting and breeding. Trial and error yes. But method is putting nature into new situations and carefully recording results. Deliberate attempt at improvement. All of these are parts of same program that have helped to transform the sciences.

   b iii) The transformation of science and of technology in 18th century may have common roots in 17th century society and ideology.

   b) But it's far from clear, and this is something I ask you to look for hard as you do your reading and contemplate next week's precepts.

      i) To what extent are the innovators you examine, the same people or even the same sorts of people as the scientists you've been reading about? Eatter we've already observed are close knit and recurrent. Do they recurr?

      7ii) If not, why do you suppose that is? What's the difference in the nature of the work? What difference in climate necessary to support it. Needn't emphasize quite how important those question are today.

4. So one reason for a look at the I.R. is desirability of investigation methodological and ideological interaction with science, but that's not the whole story. Two other parts are still ahead.

   a) Even though scientific discovery has little impact on I.R., the new craft techniques have occasionally notable impact on scientific development.

      i) Animal breeding experiments just discussed are part of background for Darwin's Origin of Species and so is Malthus' concern with population pressure.

      ii) The steam engine, whose development I'll discuss next time, provides a subject for scientific study which, in hands of Sadi Carnot, is instrumental in the forging of the fundamental concepts of thermodynamics.

      iii) Probably these are main examples, but they're not unique.

   b) Nor is that the whole story and the last part is probably most important of all.

      i) People do think that science has had a good deal to do with I.R.

      ii) With the result that, both in and out of England, the IR changes attitudes towards science and its importance.

   c) Note in your reading how many of the new scientific societies that begin to arise from late 18th century spring up in manufacturing centers of Scotland and the midlands.

d) Notice how many of the new educational institutions which finish by bringing science back to the universities are, in their origins, schools to give engineers or manufacturing foremen the rudiments of a scientific education.

e) Or notice, if you can find full citations, how many of the new scientific journals which begin to appear after 1780 in both England and France are, at the start, jointly journals of the practical arts and of the sciences. Youngs Annals of Agriculture is initially a source for organic chemists and plant physiologists as well as for farmers.

f) It is these journals and these new institutions, partly professional partly educational, that make 19th centiry science so much more specialized, technical, and erudite than its been before.

g) The Industrial Revolution must, I think, be seen as an important source of the push that drives science in that direction.

Lecture 7 -- The Steam Engine

This was done from mildly revised old notes. They're in 105B -- II folder. It went well.

Lecture 8 -- CCG Lectured on Science andPhilosophy, particularly Kantian philosophy. I've got notes. Not easy to fit into course as it now stands.

New Philosophical Currents, 1650-1850

I. Separation of Science and Philosophy

The (new) Problem of Knowledge
David Hume, 1711-1776
Auguste Comte, 1798-1857
Immanuel Kant, 1724-1804

II. Reunion in Naturphilosophie

Revolt against Newtonianism
Romanticism
Friedrich Schelling, 1775-1854

HISTORY 336 -- Lecture 14

New Philosophical Trends in 19th Century

I. THE PROBLEM OF KNOWLEDGE

1. In the first two substantive lectures in this course I introduced you first to a set of ideas about nature of the universe and then to a set of notions about method which remained closely associated during the period we've examined since.

   a) By method I mean empiricism -- partly new emphasis on old idea that knowledge comes from observation and experiment, and partly a new program for large scale experimentation involving new fields and an assortment of new instruments.

   b) By "ideas about nature of universe" I mean idea of the universe as a gigantic machine whose parts are neutral corpuscles of matter which move and interact in accordance with God-given laws.

   c) In the 17th century these two sets of ideas are jointly products of philosophical analysis and scientific research.

      i) Perhaps surprising, but until late in the 17th century these two enterprises are very closely related. Often practiced by the same man, whether Aristotle, the Scholastics, Francis Bacon, or René Descartes. For many purposes they're best considered to be a single enterprise.

   d) After the 17th century their position in philosophy changes -- my subject for today -- but they remain closely associated with the advance of science.

This work fairly well, and is not work too long. But...

I've got to keep one chart Naturgeb.! — . Must read Schilling.

i) Many examples in the sciences we've considered.

ii) Partly due to these and partly due to even earlier successes of Newtonian dynamics, the idea of the world as a machine -- of mechanism and with of determinism -- become more and more widely spread.

iii) You will all have heard the story of Laplace's exchange with Napoleon after publication of the Système du monde. It's a sketch of world system. Napoleon asks, "Where does God go in this system?" Laplace replies, "Sire, I have no need for that hypothesis."

iv) Companion for this story is Laplace's famous statement that an intelligence which knew the position and speed of every body in the universe could predict the entire future course of these bodies.

e) Need not, I suspect, tell you that there was resistance to these views.

i) Will return to it a bit later.

ii) But note now that it scarcely came at all from scientists, or at least from those in the established sciences. Here the triumph of mechanism was unqualified.

2. But, interestingly enough, that triumph does not extend to philosophy, though philosophy had had much to do with the origin of mechanism.

a) In philosophy effect of triumph is to create a number of problems that

scarcely been imagined before.

i) Fundamentally, problem is, "How can there be knowledge of nature?"

ii) As it comes to prominence, the field of epistemology becomes a central subject of philosophical concern for the first time.

iii) Previously one has had innumerable books on how to draw sound conclusions in the sciences. Bacon's Novum Organum, Descartes' Discourse on Method and his Rules for the Direction of the Mind are perhaps the last, but they've a long medieval tradition behind them.

ii) What comes next, as a new genre, is books asking how knowledge is possible and what it can be knowledge of. Locke's Essay Concerning Human Understanding and Hume's Inquiry Concerning Human Understanding (1690 and 1748) are only two of the best known works in a tradition that continues today, for example in Wittgenstein's Tractatus.

Russell Our Knowledge of the External World.

b) Source of problem you'll see most clearly if you can recapture any of the things I said about essentialism at beginning of course.

i) Before 17th century knowledge had most often been conceived as knowledge of essences or natures.

ii) These were directly grasped by the senses and intuitive faculties. Redness, hotness, dampness, and other qualities were parts of the nature of the substances in which they were perceived.

c) 17th-century corpuscular mechanism changes all this.

i) Bodies are perceived only indirectly -- by corpuscular interaction

ii) Color, temperature, smell and so on are not in bodies. They're our responses to mechanical stimulation. In some sense they're in us.

iii) At first it's thought -- Descartes and still in Locke -- that at least one can be sure that the primary corpuscles have size, shape and arrangement. But by the end of the 17th century it's beging increasingly recognized that even these previously "primary qualities" are our interpretations from sensations. They're not necessary properties of objects.

iv) Increasingly in the 18th century it's suggested that all any of us can know with complete certainty is our own sensations, and perhaps also the logical truths of mathematics. All else is at best plausible conjecture and, as such, not quite entitled to be called knowledge.

3. This type of response to the problem of knowledge I'm going to here label with the excessively modern name of "positivism".

a) Through the role that it gives to sensation, it has an important bearing on the development of psychology and thus on social science.

i) But until the early 20th century, when the work of Ernst Mach provides some background for the development of relativity and of matrix mechanics, it's got little to do with sciences we're concerned with in course, and I'll therefore slight it.

ii) Want first, however, to supply two bench marks for its development and then turn to an alternate solution that has more important bearing on material in the course.

b) First of these bench marks is in work of David Hume, 1711-1776.

i) Scottish philosopher who's greatest of the critics of the sort of knowledge one can get through the senses.

ii) Agrees that all knowledge of nature comes that way. But insists that all one can know is sensations -- their juxtaposition in space and time, and their similarity.

iii) But this gives no knowledge of bodies -- they're just a habit we get into from seeing similar sensations repeatedly.

iv) Nor of causal connections -- again to be understood psychologically from repetition of temporal order, but that's all we know.

v) None of science's claims to tell us of forces which cause changes of motion and so on can be considered fully justified.

vi) On the other hand, having argued all this with crushing success, Hume proceeds to drop the matter. For practical life, these habits serve well enough. He replaces them with nothing. Things go on as before.

c)

c) By a series of connections that I shall not here trace, this viewpoint moves to France where it is further developed, though usually by lesser figures.

i) Of whom I want here to note just one, Auguste Comte, 1798-1857.

ii) Unlike Hume, he is concerned with the sciences. He takes them to be knowledge by definition, contrasting them with both theology and metaphysics which for him are myth.

iii) On the other hand, he does not claim that they give knowledge about bodies or causes or space and time. Instead he sees their total content as consisting in law-like connections between sensations. That's all science is -- it tells us which sensations must go together and how sensations follow each other in space and time. ALL ELSE WE SHOULD LEARN TO DO WITHOUT.

Bad news for metaphysics

iv) It is for knowledge in this sense that he coins the term positive science, and it is from him that this view has developed since.

v) I shall not, however, follow it further.

4. Instead turn to the rather different sort of answer which the great German philosopher, Immanuel Kant, 1724-1804.

a) Since his thought is both complex and difficult, my few remarks will inevitably be even more of a parody when I deal with him than they have been in discussing Hume and Comte.

i) But in practice I'm after just one aspect of his thought-- the part which provides a basis for subsequent German idealism -- and I'll introduce it without any of his arguments for it.

ii) Though the scope, power, and subtlety of the view will inevitably be lacking, the basic conception I'm concerned with may come thru.

b) Kant accepts Hume's critique of the senses as fundamental. In fact, he says it awoke him from his dogmatic slumbers -- slumbers during

which, I should add, he'd been doing physics, including a theory of the development of the solar system which anticipates Laplace's nebular hypothesis.

i) Because we could not have sensations unless something stimulated them, there must be something external to us.

ii) But we can know nothing of them except their existence. They're Noumena, Things-in-themselves.

iii) But though these noumena are cause of sensation, they don't determine everything about those sensations. Structure of our perceptual and cognitive apparatus also plays a role.

iv) Without this apparatus, couldn't have perceptions. But having it with apparatus determines certain characteristics of our sensatinn

c) In particular, Kant argues, we can only have perceptions if they are arranged in space and time.

i) These, as preconditions of perception, are contributed by us, not by analysis of the perceptions.

ii) Because they are, geometry and arithmetic, which deal with space and time, are also necessarily conclusive for us.

d) And by continuing the argument Kant is able to argue for the necessity of the idea of cause, of matter and its conservation, and of attractive and repulsive forces.

i) All else, including the quantitative laws of force and also everything about chemistry and other sciences, must come from experienc and is thus a lower form of knowledge. TCS-gb bc interested in Kan.

ii) Perhaps this doesn't seem very much. But if you can remember the last pre-vacation lecture, it's exactly Helmholtz's starting point for essay on conservation of force. Complex Kant program over to electricity, chemistry, etc.

iii) Even this much could be important for science.

II. NATURPHILOSOPHIE

1. But conservation of energy could, of course, be gotten in other ways, and the greater importance of Kant's philosophy comes not in this form but after its absorbtion and revision by a movement which Kant would almost certainly have deplored. FOR SCIENCE

   a) This movement is Naturphilosophie or the philosophy of nature, and it's now widely and probably properly regarded as an aberation in Western thought.

      i) It is not a view I've yet managed to unravel, understand, or feel at home with, and I therefore concur in deploring it.

      ii) Nevertheless, its occasionally fruitful impact on 19th-century science seems to me undeniable.

2. Kant's philosophy is, however, only one of the sources for Naturphilosophie.

   a) From Kant comes some of the form of the movement, but not its objective or its drive.

   b) Much more important, in these respects, is a longstanding, though only sporadically expressed, hostility to Newtonianism.

i) Newtonianism deprives nature of all qualitative richness -- bare matter moving forever through an infinite void.

ii) Mechanism cannot treat of life, of organism, of development. It cannot account for beauty or for morality, for any of what's most uniquely valuable as human.

iii) And, through its determinism, it denies the very existence, or at least the significance, of these elements of life. What can morality be in a deterministic universe where no action can freely effect the future.

v) Particularly after the middle of the 18th century there have been numerous outbursts against the pretensions of science in this vein. Not just Germany, but France as well. Rousseau is perhaps the man who gives these attitudes their most forceful expression.

vi) One particularly interesting example of their expression has been in opposition to Lavoisier's chemistry. Again, it deprives chemical species of their qualities and instead substitutes weights and measures.

c) At the end of the 18th century this sort of reaction is heightened by its combination with a far more obvious movement -- romanticism both in the arts and in more widely spread standards of taste and val.

i) Not the place for a lecture on Romanticism, but I remind you that romanticism palces great emphasis upon communion with nature.

ii) But not the nature described by the scientist or even the naturalist. This is nature populated by gothic castles, by gorges and

mountain peaks, by storms and ~~great winds~~ primal forces of all sorts.

iii) It's the "nature" of Coleridge's Ancient Mariner or Kubla Khan., or, in a more moderate vein, of Wordsworth's Prelude.

iv) It is, thus, not a nature to be examined but to be experienced in direct communication with the eternal forces that populate it. Remember the Ode on Intimations of Immortality.

3. All of this takes us very far from science and almost as far from Kant. Kant is concerned with Newtonian science, with measurement and mathematics with logic. He'd have been appalled.

a) Nevertheless, his successors, particularly the three important German philosophers, Fichte, F.W.J. Schelling, 1775-1854, and Hegel, manage to combine important elements of his throught with the prevalent romantic, organismic, and anti-scientific movement of the day to produce a widely influential and, in some of its aspects, intellectually imposing philosophical structure.

i) Schelling is the man who does most to tie it to the science -- he's the man most responsible for Naturphilosophie as such -- and I shall here give him credit for the whole.

b) The first step in the rapprochement comes via a rejection of Kant's notion of the Noumena or Thing-in-itself.

i) With some justice Fichte points out that it's functionless. It's not knowable or in any way describable. Can get on as well without it.

ii) At that point one is left with just the categories of the mind. Everything is ideas -- hence the term idealism.

iii) And since all human minds have very similar impressions, they must all be aspects or facets of a single world-mind, the Absolute which generates all nature and all humanity.

iv) This is a view that some of you will have encountered in studying ~~stoicism (it's not at this level of generality altogether new) and others in studying~~ the New England Trancendentalists (Emerson and the Brook Farm community) who get it from Germany.

v) If labels help, this is idealism, because everything is ideas. It's monism because, in the final analysis, there's only one transcendent idea in which all lesser being participate.

c) To build back towards science, Schelling underlines Kant's idea of the necessity of an attractive and repulsive force at the basis of all experience for of nature.

i) This notion of a polarity of opposite forces is fundamental to Schelling's philosophy, but he sees them not as Newtonian but as organic forces, struggling with each other.

ii) And the first product of this struggle between the primitive polar forces of the absolute is matter, a force-product for Schelling.

d) So far, except for the very important emphasis on organism and on production, i.e., on process, this is not far from Kant who has also seen attraction and repulsion as necessary to very concept of matter.

i) But with Schelling and his followers, who are numerous, this is only the beginning. The metaphor now takes on life of its own, and I cease really to follow it, though I'm convinced this is partly a limitation of my own as a historian of thought.

ii) Be that as it may, the polar forces continue to operate. Another of their products is light, seen as a static tension where matter is dynamic and in motion.

iii) Further operation of these opposites differentiates matter into the qualitatively distinct chemical elements.

iv) Other interactions display the effects of heat, electricity, and magnetism.

v) All these generated successively, in stages, from the basic pair of forces. It is their unity that ultimately underlies the whole and drives it forward.

4. Now it is this idea of a single basic force or pair of forces underlying natural phenomena that underlies Oersted's discovery of electromagnetism and several of the independent routes to the conservation of energy.

a) Faraday's ideas on the unity of all natural forces are also very like this, though he may well have them from a different source, and is surely not guilty of the typical extravagances of Naturphilosophie.

i) These ideas, then, for all their anti-scientific origins and for all the disdain they engender towards exact research and particularly towards mathematical abstraction can be and occasionally were suggestive in physics.

b) But that is not where they proved most important. On the contrary, their greatest suggestive power was in biology.

i) For Naturphilosophie recognizes no barrier between the inorganic and organic.

ii) In fact, the contrast with Newtonianism is clearest of all in the assimilation of inorganic nature to an organismic pattern of creation.

iii) And that pattern does not stop there. It continues from the differentiation of the basic forms of chemical species to the basic forms of living species.

iv) First creating living matter and then diffentiating it into basic forms of life, plants, animals, birds, fish, and men.

v) Carefully examined, say the Naturphilosophen, each of these shows its common origin, its resemblance to the original form of life from which all arose.

vi) And an examination of the specific differences shows also the order in nature by which first the lower and then higher forms were produced.

c) This is not evolution. The process is going on all the time. All forms are always represented.

i) But it's a mode of thought which makes evolution far easier to conceive.

ii) And it also will prove to have a fundamental bearing on such

parts of biology as cell theory and embryology.

ii) Only for that some exact research will also be required.

History 336 -- Lecture 19

Kinetic Theory of Heat

I. MODE OF MOTION VIEWS BEFORE CALORIC

1. This morning I expose you to the most sudden shift of topic in course of semester. From biology back to physics with only twenty-three hours in between.

   a) Actually a bit worse than that, for I'm actually going right back to place we left off at beginning of spring vacation and build on to it.

      i) If it hadn't been for that break I'd have ~~given this lecture~~ treated this subject then.

      ii) So prepare to search memories for issues and concepts developed atmonth and more ago.

   b) Still, there's one advantage to having had this split forced on me.

      i) Said at start of semester that I wanted to trace the gradual triumph of Newtonian science from 18th into 19th century and then, at end of semester, examine its breakdown. Emphasizes structure of course

      ii) Well, topic this morning, ~~xxkxrixxkxx~~ kinetic theory of heat is perhaps greatest triumph of Newtonian ~~xxxxxy~~ world view.

      iii) But by the time it developes between 1850 and 1870, Newtonian views are already encountering difficulties and, ultimately, are drastically changed at beginning of 20th century.

      iv) Some use in juxtaposing triumph in this lecture with breakdown in remaining lectures.

Second part greatly reduced to primary with over subtle third, spoke! Juncture, ok.

This still needs pinching up for consistency. Also, use here for Maxwell + Boltzmann. Might take everything earlier for granted.

Should work on it.

2. I have just said that kinetic theory of heat doesn't emerge until after 1850, and I shall say that when it does emerge then, it's really brought on by acceptance of conservation of energy.

   a) If heat is lost in doing work, gained when work is done, then it can't be a conserved caloric fluid. Must be motion of particles of matter.

   b) But that view, at least in qualitative form, has been around since 17th century.

      i) From time of Galileo, Descartes, Boyle, and Newton in 17th century to time of Black and Lavoisier in 18th it's been the dominant view.

      ii) Furthermore, there's been ample mathematics around to give it the sort of elementary formulation that it gets from most of its early exponents in 19th century.

   c) Ask, then, why did caloric theory intervene. Why wait so long to develop this very consequential theory.

3. Think answer comes in two parts of which first is:

   a) Until work of Black and Lavoisier between about 1760 and 1780, not enough's known about thermal phenomena to tell you what to do with heat as motion of particles.

      i) Heat's been a Baconian field, much experimental work, but not much regularity.

      ii) In particular, concepts of temperature and of heat have been badly intertwined.

iii) Need calorimetric techniques, concepts of specific and latent heats, before one can attach heat firmly to particle motion. Earlier, just don't know what aspect of motion to attach temp to.

(i) Experiment & inspect and or Jochim.

b) On the other hand, when one does get these techniques, they speak directly for a conserved fluid.

i) Very hard to talk in elementary ways about method of mixtures, or freezing, and so on, without doing so in terms of a conserved fluid.

ii) We still do it.

4. But that can't be whole story, for immediately after calorimetric techniques are developed, a number of people do suggest that heat must be quantity of vis viva ($=mv^2$).

a) Some people even try to work out a microscopic theory on this basis.

i) A few powerful results, but not very much gained. Doesn't catch on.

b) Even though Lavoisier himself, in memoir on heat, says it might be fluid or vis viva, he and everyone else acts as though it were fluid.

i) It's the new theory, and it wins the day.

5. To see why people don't get further with mode of motion views even after Black and Lavoisier need to recognize something else about current views.

a) When kinetic theory emerges in 19th century it's closely associated with discussion of gasses. They're the simplest case. Small interatomic forces.

or Laplace

i) Same thing's been true -- remember lecture on Lavoisier/-- for caloric theory.

ii) Gasses are testing ground for theories of heat.

b) But kinetic theory really depends, as we know it, on supposing that the atoms of a gas occupy little volume. Particles move long distances without striking anything. May go from wall to wall.

c) In 17th and 18th century, however, no one conceives gases that way.

i) They're little springs jostling each other for Boyle

ii) They're held in a lattice by repulsive forces for Newton

iii) Or for Lavoisier, they're held in equilibrium by caloric sheaths.

d) If heat is motion during this period, it's taken to be vibratory motion or rotatory motion.

i) And that approach doesn't get you very far.

ii) Need not only characteristics of heat from calorimetry, butalso new image of a gas.

II. THE RUMFORD EPISODE,

1. While this view lasts mode-of-motion view can do nothing for study of heat that caloric theory cannot, and caloric theory can do far more.
   a) That much you've already seen both in considering Lavoisier's chemistry and again as prelude to Carnot.
   b) Therefore skip it here and ask instead, what happens to change the situation.
   c) And again we're confronted with a standard answer, one that has been given again and again for over one-hundred years.
      i) Often given by the physicists who themselves develop the successful caloric theory.
      ii) In the '50s and '60s they look back to start of century and say that caloric theory was disproved by Benjamin Thompson, Count Rumford (1753-1814), in 1798.
      iii) Strange, since they'd many of them been using caloric theory themselves before 1750.
   d) And, in any event, worth a look because it's a classic case of the nature of counter-example in science.
2. Rumford is, in fact, a devotee of the view that heat is motion, and he performs numerous experiments throughout his life to persuade others to his view.
   a) Of all these experiments the most famous and most persuasive is the cannon boring experiment which he performs in 1798 and reads to the

b) It's still remembered and easily accessible when, after 1850, energy conservation convinces people that heat is not conserved and is therefore probably motion.

c) Furthermore, during this same half-century, other arguments point in the same direction. Particularly the one we noted in Helmholtz:

i) Light is not matter but vibration in a medium.

ii) Radiant heat, at least, is like light. Must be motion involved here too.

d) Scientific community ~~xxxxx~~ at large does not come around until after 1850 with energy conservation, but meanwhile there are occasional converts, and most of those instrumental in developing thermodynamics are among them.

i) Thus Sadi Carnot and posthumous notes.

ii) Helmholtz from early stage of development of his memoir.

iii) Joule somewhere en route.

e) It's there to be had when there's occasion.

2. For those who now come back to it in the 19th century, the view of gases involved is different from what it had been before.

a) Gases have become, though Lavoisier and caloric theory, a phase of matter, not separate substances. They are what you get when atoms are so far apart that interatomic forces cease to act.

b) As a result, when people now drop caloric, they're left only with little hard cores at large distances and with no forces between them.

c) This view, unlike the older one which saw gases as a distinct sort of matter and learned nothing about them from their ability to pass into other phases, leads much more directly to kinetic theory than any earlier one had.

3. Under those circumstances it's perhaps no surprise that what we think of as kinetic theory emerges over and over again during the nineteenth century, and in an at least elementary mathematical formulation.

a) Have listed ~~five~~ names on the board and am not sure I've got them all: Herapath, 1816; Waterston, 1845; Joule, 1848; Krönig, 1856; and Clausius, 1857.

i) All except Joule do it independently; he uses Herapath. Another classic case of time's being ripe.

b) Furthermore, two of them do it before knowing anything about conservation of energy -- Herapath and Waterston. But it's unheard.

i) Though they give an argument much like Joule's, they're almost universally ignored.

ii) Both rejected by Royal Society. Waterston's paper is published only long after his death as act of homage.

c) Even Joule's paper, obscurely printed in 1851, is virtually unknown until conservation of energy is accepted.

(who are known

i) It's that acceptance that calls forth work of Krönig and Clausius and it is the latter who really puts the theory in a relatively developed form before the scientific world.

4. Everyone to this point has just allowed 1/3 of molecules to move in each direction, bounce at right angles off of walls. And they've just derived pv = cT, the gas laws. (Waterston's also computed specific heat but it's not in print.)

   a) Clausius allows for particle impinging at any angle, and averages.

   b) Goes from point particles to particles that may have rotational or vibrational energy -- particles with parts -- and shows how spedific heat will vary in these cases.

   c) Introduces the concept of mean free path, distance travelled between collisions, to explain why gases don't diffuse instantly.

   d) Most of the elementary elements of kinetic theory are in the two papers he publishes in 1857 and 1859.

5. Yet, as most of you know, there's still a vitally important element missing.

   a) Can't quite call it statistics, since there's a good deal of talk about probabilities in Clausius.

   b) But can say that it's first consequential use of statistical hypothese in this field or in any other part of physics.

6. It's work of J. C. Maxwell, beginning in 1860, and of Ludwig Boltzman, beginning in 1866.

   a) It's just at this point that the further development of kinetic theory into statistical mechanics becomes too mathematical to handle.

      i) Could do more with more time, but not much.

      ii) Therefore settle for a few very large generalizations. o brief descrip

   b) Of which first is about the mathematics that makes it difficult.

      i) It's not just difficult but also new. This couldn't have been done in 17th century or 18th.

      ii) Depends on much prior work in probability theory -- games of chance, error theory, study of sample populations.

      iii) Therefore not just a straightforward push ahead on route we've so far been examining.

   c) Instead, it's introduction of whole new set of ideas and techniques from realm outside physics into physics, and there's much transformation as a result. In some realms greatly increased power.

      i) Of which one example each from Maxwell and Boltzman.

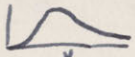
   d) Simple derivations of sort most of you have seen shows you that:

      i) $pV = \frac{1}{3} n m v^2$ $(= RT)$. Last from gas law. n is number of particles m mass, R a known constant.

      ii) Knowing Temp, and so on, can calculate average of v^2. That's all temp depends on.

iii) But some other properties of gas depend not only on this average, but on deviations from average.

iv) What Maxwell is able to do is derive, from very simple and plausible assumptions, a law that will tell you what the proport'n of molecules with other velocities is.

v) Draw. 9. 

vi) Thus get other properties besides those that went in in first plac

e) Boltzmann's step is even more consequential, and plays a role in what happens at beginning of century.

i) From these techniques for analysing not only averages, but deviations from the average, he's able to derive the 2nd Law of Thermodynamics.

ii) You know that one form this has taken is generalization that function called entropy can only increase or stay the same.

iii) He now shows that this is only a statistical regularity. Only true that processes by which entropy will decrease are very very unlikely. But if you waited long enough they'd occur.

f) Totally changes relation of 1st and 2nd law. Before they've both been absolute. Now 1st law stays that way. Other is only probabilistic.

i) An idea that's hotly resisted by many many physicists who have admired thermo for its absolute ness.

ii) Breakdown there is part of story of quantum, to which I return.