Digital Computer Laboratory
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SUBJECT: GROUP 63 SEMINAR ON MAGNETISM XII

To: Group 63

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Switching Time

When the polarity of a magnetic field applied to a ferromagnetic material is switched, there is a lag in the magnetization change of the substance. We may look at the cause of this lag qualitatively by considering the boundary potential picture given in Figure 7 and shown again in Figure 20.

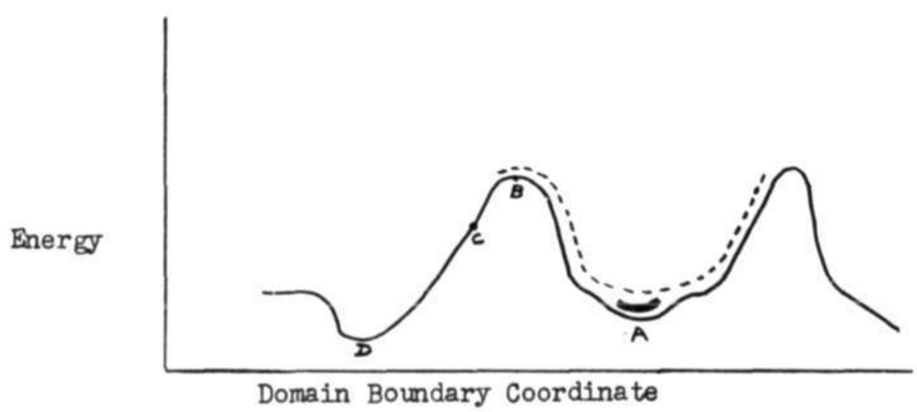
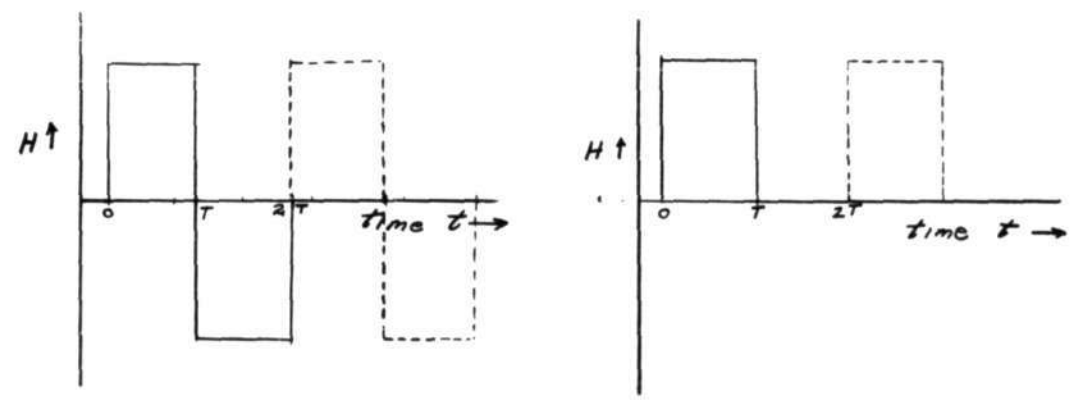


Figure 20

If the magnetic field strength is small, the energy involved is small and little boundary motion is involved (indicated by the heavy line at A in Figure 20). For larger fields, involving energies of the order of magnitude of the domain boundary energy, the switching time will be greater. There are various causes of this which must be considered, such as the damping factor, increased amplitude, and a varying force constant which decreases to zero at the crest B. For a field just great enough to result in the domain boundary crossing the crest there will be a still greater lag upon reversing the field because the boundary must return across the crest. If the boundary moves from position A to position C by the action of a magnetic field, removal of the field will cause the domain wall to move to position D rather than return to A.

It should be noted that the time lag will not, in general, be the same for a unidirectional field pulse as for a reversing field. To illustrate this, let us assume that the positive pulse of the reversing field is of the same shape and magnitude as that of the unidirectional pulse. (Figure 21)



(a) Alternating Magnetic Field Pulse (b) Unidirectional Magnetic Field Pulse

Figure 21

In this case, assuming identical starting conditions, the lag of $\vec{B}$ to $\vec{H}$ during the time interval from 0 to T will be the same in both cases. During the interval from T to 2T, the reversal of the magnetization in the case of the reversed magnetic pulse (Figure 21(a))will be greater, since the magnetic force acting to reverse the magnetization will be greater in this case. It should be noted, however, that owing to the lag of $\vec{B}$ during the interval from 0 to T, $\vec{B} > 0$ at time $t = T$. Therefore, the lag of $\vec{B}$ to $\vec{H}$ during succeeding pulses becomes progressively greater for the case of alternating magnetic pulses. This is not true when the magnetic pulses are unidirectional.

Returning to Figure 19; as the magnetic field is greatly increased to the point where the domain boundary energy is quite small compared to the field energy, the switching time would decrease. Thus we expect the switching time τ to have a maximum, as shown in Figure 22. This maximum would occur in the region of magnetic field values corresponding to domain boundary energies.

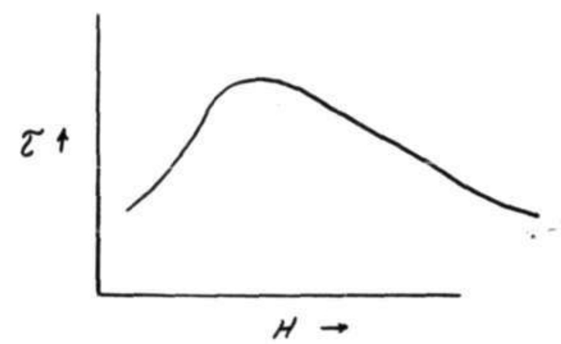


Figure 22

This time lag has an interesting effect upon a ferromagnetic material in a magnetic field varying with very high frequencies. Since the induction $\vec{B}$ lags the magnetic field $\vec{H}$, we find that even for large values of $\vec{H}$ the domain boundary at point A in Figure 19 may not have time to cross the crest before the field reverses. As a result there is very little change in $\vec{B}$, and the permeability of the material is considerably reduced. However, if the frequency of the external field is the same as the natural frequency of the boundary motion, resonance may be expected to occur, resulting in a high value of permeability at this frequency.

Coupled Harmonic Oscillator

In the previous lecture we discussed the optical properties of a dielectric on the basis of our study of the harmonic oscillator. Our next general topic is to be the phenomenon of magnetic resonance, which can be understood with the help of a more complicated oscillating system.

We previously described the elementary magnet as having a net angular momentum vector $\vec{J}$ which processes about the field. $\vec{J}$ is limited to certain discrete orientations, each of which has some relative probability. This is shown in Figure IV, Appendix II for a particular value $\vec{J} = 3/2$. The particle in each orientation of $\vec{J}$ has an energy proportional to the field $\vec{H}$ and to the component of $\vec{J}$ parallel to the field. Thus, each orientation of $\vec{J}$ represents a different energy, and is said to be a different state.

Since the perpendicular component of $\vec{J}$ rotates around $\vec{H}$ (Figure 22), it appears as a harmonic oscillator to an impinging plane radiation wave front. According to Bohr, the various states of the system should be treated as a number of coupled oscillators. They will then be found to have certain modes of oscillation, which interact to give beat frequencies equal to the difference between the frequencies of the various modes. Bohr considered these beat frequencies as the natural frequencies of the system, and assumed that radiation interacts with these natural frequencies in the same way as it does in ordinary dielectrics.

In order to see what Bohr had in mind, we will solve a coupled oscillator problem.* This is of particular importance because the techniques involved are frequently used in wave mechanics.

The oscillating system we consider involves two pendulums, of masses m_1 and m_2, with m_1 suspended from a point directly above the point of suspension of m_2. Both masses may be considered as point masses suspended from weightless strings, and the strings are of such length that both masses are at the same level when at rest. In addition, the two pendulums are coupled by a spring with a force constant <u>k</u>. System is shown in Figure 23.

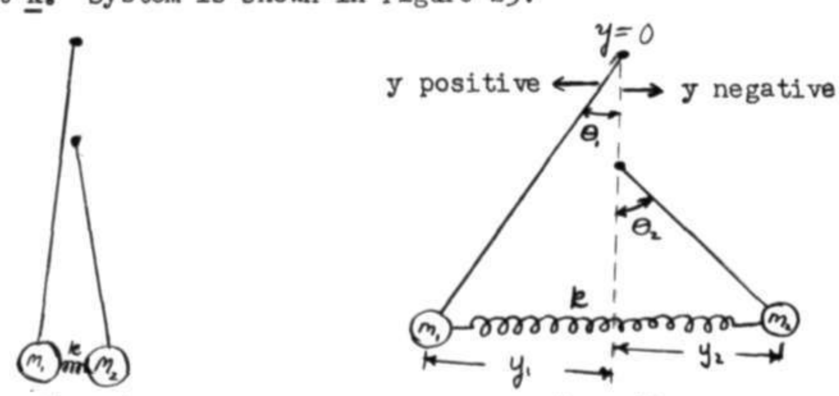


Figure 23

* Slater and Frank, <u>Introduction to Theoretical Physics</u>, McGraw-Hill Co, Chapter 11.

Displacements y_1 and y_2 are as shown in Figure 23, and are assumed small (angular displacement proportional to horizontal displacement).

Then the equations of motion are:

$$m_1 \frac{d^2y_1}{dt^2} + k_1 y_1 + k(y_1 - y_2) = 0 \qquad \text{(XII-1)}$$

$$m_2 \frac{d^2y_2}{dt^2} + k_2 y_2 + k(y_2 - y_1) = 0 \qquad \text{(XII-2)}$$

wherein $k_1 = m_1 g \theta_1$

$k_2 = m_2 g \theta_2$

We shall further assume weak interaction between pendulums. As a first approximation we can eliminate $-ky_2$ in XII-1 and ky_1 in XII-2. We would then have two unperturbed systems of a pendulum attached by a spring to a fixed point.

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