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Digital Computer Laboratory
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SUBJECT: **GROUP 63 SEMINAR ON MAGNETISM, APPENDIX IV**
A THEORY OF CONTACT POTENTIAL MEASUREMENTS

To: Group 63

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The free energy of electrons varies between different metals. When two different metals are brought into electrical contact electrons therefore flow from one metal to the other in order to minimize the free energy of the system; while this process goes on an electrical potential difference is set up which increases with increasing charge transfer, and which opposes contimed electron flow until equilibrium is reached. The resulting potential difference, called "Contact Potential", is ordinarily too small to be measured directly. Measurement is made in five steps:

A Two metal plates are connected by a wire, so that electrons can flow from one plate to the other.

B The plates are made to approach each other with the connections maintained.

C The connection is broken when the plates are a distance "d_1" apart.

D The plates are separated, remaining electrically disconnected, so that the potential difference increases.

E The potential difference is measured at a distance $d_2 > d_1$.

During step A a potential difference ΔV_{cp} is set up between the plates, which equals the contact potential.

During step B this potential difference is maintained by means of free electron transfer between the plates, so that no net work is done in the process for:

$$\delta W = F\,\delta d + \Delta V\,\delta q, \qquad \text{(D-1)}$$

where F = force between the plates,
d = distance between the plates
ΔV = potential difference between the plates
q = charge on plates
δ indicates change during a small portion of the process.

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For a plate condenser the capacitance C is given by:

$$C = \frac{kA}{4\pi d}, \quad \text{where } k = \text{dielectric constant}, \; A = \text{area of plates}$$

The difference in potential is given by:

$$\Delta V = \frac{q}{C} = \frac{4\pi d\, q}{k\, A} \qquad \text{(D-2)}$$

and the field by:

$$E = \frac{\Delta V}{d} = \frac{4\pi\, q}{k\, A}$$

The electrical force between the plates is:

$$F = Eq = \frac{4\pi\, q^2}{k\, A} \qquad \text{(D-3)}$$

From equations (D-1), (D-2), and (D-3) we find

$$\delta W = \frac{4\pi\, q^2}{k\, A}\, \delta d + \frac{4\pi d\, q}{k\, A}\, \delta q = \frac{4\pi\, q}{k\, A}\, \delta\, (qd)$$

Thus no work is done as long as $\delta\,(qd) = 0$, i.e. as long as qd remains constant. Since $\Delta V = \frac{4\pi\, qd}{k\, A}$, ΔV then remains constant, and at plate separation d_1, we find:

$$q = \frac{\Delta V_{cp}\, k\, A}{4\pi d_1} \qquad \text{(D-4)}$$

This gives the plate charge for two metals with contact potential ΔV_{cp}, when made into a plate condenser of area A, plate separation d_1.

After process C is completed, the charge given by equation (D-4) is trapped, and can no longer be changed. Thus in equation (D-4) $\delta q = 0$ during step D.

Then for step D we find from equations (D-1) and (D-3):

$\delta W = \frac{4\pi\, q^2}{k\, A}\, \delta d$, and hence the potential difference at the end of step D is found by integration and substitution of equation (D-4):

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$$\Delta V_f - \Delta V_{cp} = \frac{\int \delta W}{q} = \frac{4\pi q}{k A} (d_2 - d_1) = \frac{\Delta V_{cp}}{d_1} (d_2 - d_1) \qquad \text{(D-5)}$$

where ΔV_f is the final contact potential measured.

Solving equation (D-5) for ΔV_{cp} gives:

$$\Delta V_{cp} = \frac{d_1}{d_2} \Delta V_f \qquad \text{(D-6)}$$

where d_1 and d_2 are the measured distances and ΔV_f the measured potential difference as described above.

Fig. VI shows the five-step process on a ΔV vs. d diagram:

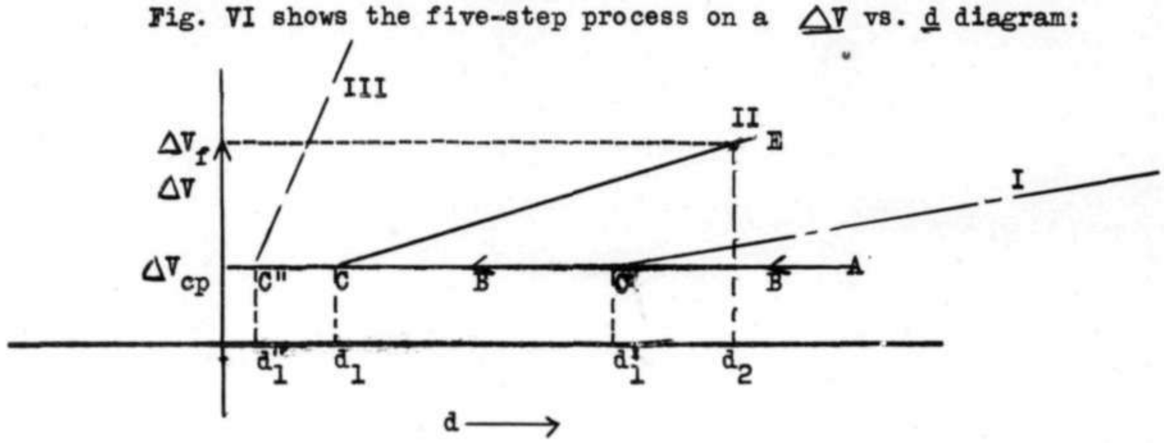

Fig. VI: Contact potential measurement with three different choices for the distance at which the plates are disconnected.

It is seen from equation (D-5) that the slope of the slanted portion of the curve is inversely proportional to d_1. Fig. VI is drawn for three choices of d_1. If d_1 is chosen too large, then an impractically large separation d_2 is required to increase the potential difference to a measurable value. If, however, d_1 is chosen too small, then ΔV_f becomes very sensitive to the accuracy in d_2, which is also undesirable.

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