Electricity
1st Year - Semester 2
Syllabus

Direct currents: current density, movement of electrons, Ohm's law, resistivity and conductivity, Drude theory, heating effect, emf.

Direct current circuits: series and parallel resistors, Kirchoff's law, Wheatstone bridge, Thevenin's theorem, potentiometer.

Measuring instruments: galvanometer, ammeter, voltmeter, ohmmeter.

Electrostatics: Coulombs Law, electric field, potential energy and electrical potential, charge distribution, conducting bodies.

Gauss' law: application to spheres, lines, planes, potential gradient near conductors, parallel plates.

Dipoles: potential, moment, electric field, force on, energy of.

Capacitance and capacitors: sphere, parallel plates, cylindrical capacitor, series and parallel.

Electrostatic energy: point charges, distribution charge, conducting sphere, energy of a capacitor.

Essential & Recommended Texts

Essential text:

Fishbane, Gasiorowicz and Thornton: "Physics for Scientists and Engineers"

Recommended text:

Alonso and Finn: "Physics"

DIRECT CURRENTS

Introduction

Current: Rate of charge flow, $I = dq/dt$ Units: amps

Potential and potential difference: work done to move unit +ve charge from point A
to point B.
Potential=Work/unit charge,
Units: volts

Electric field: Force which acts on a unit +ve charge at a particular point.

        Force = field x charge
        $F = Eq$ $E = F/q$

Since work = force x distance = F x L

potential = work/charge = (force x distance)/charge = field x distance = EL

### Drude theory of metals - Free electron model

In metals the valence electrons are no longer associated with a single atom but are free to move under the influence of external forces. The metal is therefore considered to be a container of free electrons.

In a single metallic atom the potential energy of an electron located at a distance r from the nucleus will take on the following form:
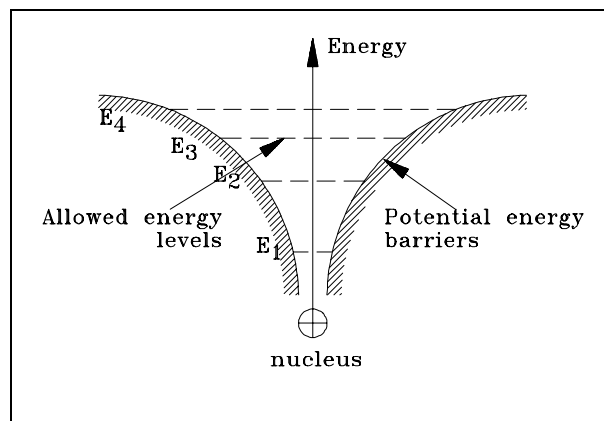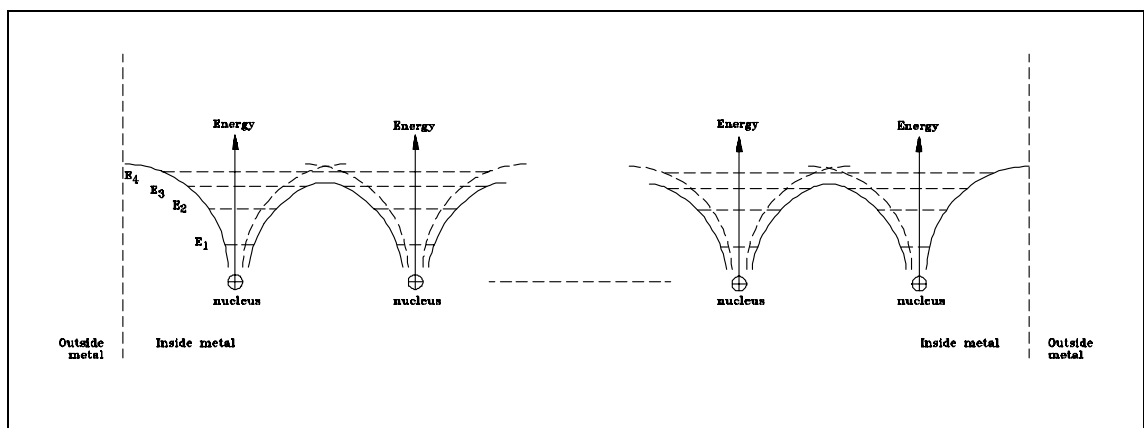

The electron can
only be in allowed energy levels and are thus bound to the atom.

When more than one atom is incorporated in a metal lattice the potential energy barriers add and the net profile is depressed due to the influence of the other atoms. This causes the least tightly bound electrons (valence) lying in the outermost energy levels to have higher energies than the binding energies of the atoms in the lattice. The net result is that these atoms are no longer associated with an individual atom but are free to move.
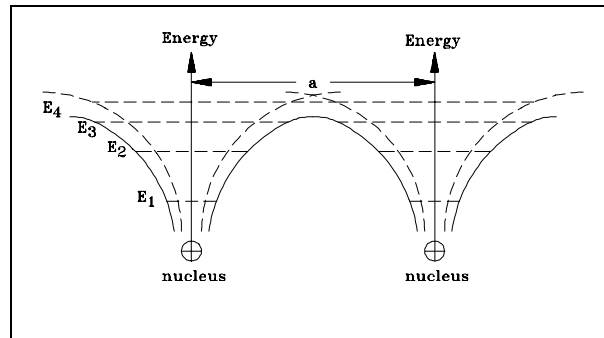
At the surface the potential energy barriers are not depressed by neighbouring atoms and so the surfaces have potential barriers which are insurmountable by the electrons, they are therefore trapped within the boundaries of the metal by these barriers.

The Drude theory postulates that these free electrons form a gas which under the influence of an applied electric field move (current) and that drag forces, from the metal lattice atoms, slow the electrons - resistivity (see later notes).

Electrical Current

Metals contain free electrons which move in a random nature due to thermal effects.

When the metal is formed into a wire and a battery is connected to both ends an electric field is set up at every point within the wire. If the potential difference is V volts and the wire is of length L metres then the field **E** will have a value of V/L volts per metre at every point. The field causes the electrons to move in a direction which is opposite to it, i.e. -**E** and therefore a current of electrons flows through the wire. If the electrons have a net charge of q coulombs and they pass through a cross section of the wire in time t seconds then the current i (amps) is q/t. This equation holds if the flow of charge is constant. If the flow is not constant then the current varies with time and is therefore defined by the differential equation:

$$i = dq/dt$$

Units of current: Ampere = Coulomb/second

Question: If we have a conductor which has a varying cross section, will the
             current remain a constant value at each point within the conductor?

Answer:

As electrons move under the influence of the electric field they acquire a drift velocity
v_d which is limited by interactions with the conductor ions (explain ions) which
causes the transfer of kinetic energy from the electrons to the ions and this in turn
manifests itself as lattice vibrations (heat - see later notes). The direction of the drift
velocity is in the opposite direction to the field i.e. -**E**.

Electric currents can flow through any conducting medium i.e. gas liquid or solid. The
charge carriers in solids (metals) are usually electrons (mention semiconductors) but
in gases and liquids the charge carriers can be positive and/or negative ions.

Question: Give an example of a conducting gas present in the lecture theatre?

Answer:

As charges can be negative or positive then it is necessary to define a convention for
current flow. *It is assumed that current flows in the direction which positive charges
move under the influence of an electric field.* Therefore in metals, where the charge
carriers are negative electrons the current flows in the opposite direction to the charge
flow.

Current density

The current density **J** is a vector quantity describing a point within the conductor and
is the rate of charge flow per unit area through an infinitesimal area. If the current is
uniformly distributed across the conductor of section A, then the magnitude of the
current density for all points on that cross section will be:

$$j = i/A \qquad \text{Units: } Am^{-2}$$

The direction of **J** is again defined as the direction of the net flow of positive charges
at the particular element, therefore an electron at this point would move in the -**J**
direction.
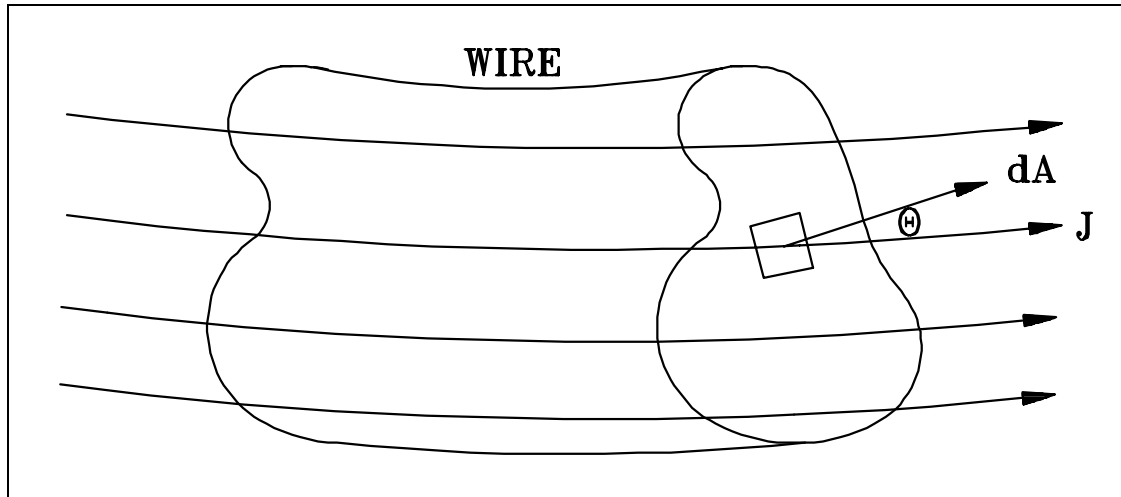
In the general case where the current is not uniform throughout the conductor then we divide the area into infinitesimal areas dA. The differential current which flows through dA is di where:

$$di = \mathbf{J}.d\mathbf{A} = J\, dA \cos \Theta \qquad \Theta \text{ is the angle made between } \mathbf{J} \text{ and } dA$$

This shows that di is maximised when Θ is 0 i.e. when the current density $\mathbf{J}$ is perpendicular to the area dA.

The total current passing through the total area A is therefore the sum of the differential elements:

$$I = \int \mathbf{J}.d\mathbf{A}$$

If we consider a group of electrons each with charge q then the number of these charges in a unit volume is termed the number density n_q. If the electrons have a velocity $\mathbf{v}$ then in time Δt then the total charge passing through an area A will be ΔQ. This is the amount of charge which is contained in the volume $A(v\Delta t)$. Therefore the amount of charge will be:

$$\Delta Q = \text{the charge per unit volume x volume} = (n_q q)(Av\Delta t)$$

The current is then given by the charge passing through the area in unit time:

$$I = \Delta Q/\Delta t = n_q q A v$$

As the current density $\mathbf{J}$ is I/A then:

$$\mathbf{J} = n_q q \mathbf{v}$$