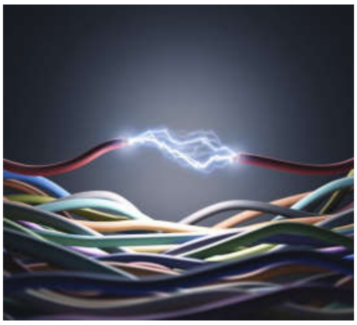
ELECTRICAL CONDUCTION



REVISED SCHEDULE

Class Test – 1

Day: 15 May 2019

Syllabus: Lectures 2–4

Electrical Conduction

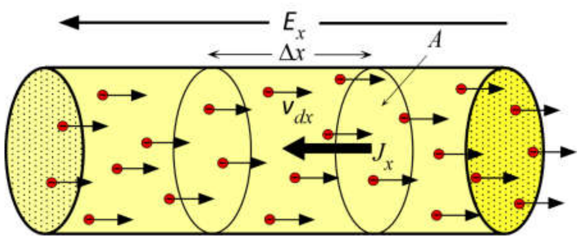
- Electrical conduction involves the motion of charges in a material under the influence of an applied electric field.
- Metals → the valence electrons from form a sea of electrons that are free to move within the metal → conduction electrons.
- **Drude model** describes electrical conduction in solids.

- The **Drude model** of electrical conduction was proposed in 1900 by *Paul Drude* to explain the transport properties of electrons in materials (especially metals).
- **Drude model** assumes the microscopic behavior of electrons in a solid classically and looks much like a pinball machine, with a sea of constantly jittering electrons bouncing and re-bouncing off heavier, relatively immobile positive ions.

The Drude Model

- The electric current density: $J = \dfrac{\Delta q}{A\Delta t}$

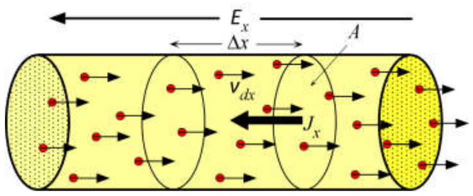
  Δq: net quantity of charge flowing through an area A in time Δt.



- Conduction electrons move around randomly in the metal → no net flow of charge.
- When an electric field E_x is applied, conduction electrons acquire a net velocity in the x direction.

Drift Velocity

- The average velocity of electrons in the x direction or the drift velocity, v_{dx}:



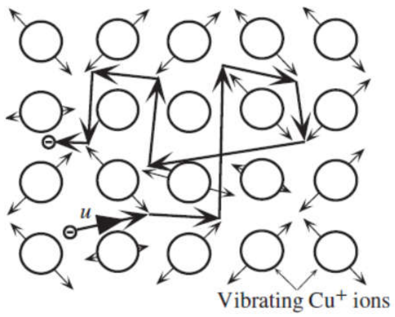
$$v_{dx} = \frac{1}{N}[v_{x1} + v_{x2} + v_{x3} + \cdots + v_{xN}]$$

v_{xi} : x direction velocity of the ith electron

N : number of conduction electrons

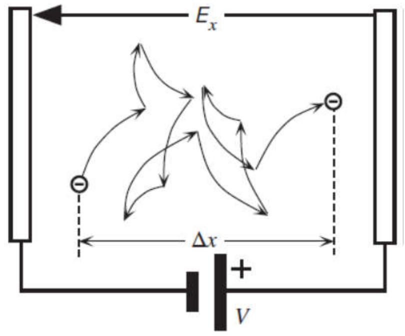
- Assume $n = N/V \rightarrow$ number of electrons per unit volume
- In time Δt, electrons move a distance $\Delta x = v_{dx}\,\Delta t$, and Δq crossing A is $enA\,\Delta x$.
- The current density in the x direction: $J_x = \frac{\Delta q}{A\Delta t} = \frac{enAv_{dx}\Delta t}{A\Delta t} = env_{dx}$
- Time-dependent current: $J_x(t) = env_{dx}(t)$

Random Motion of Conduction Electrons



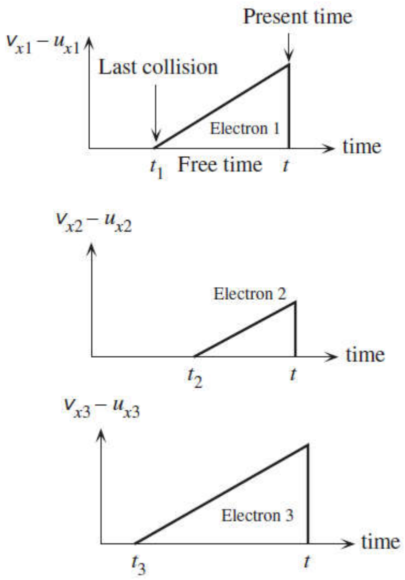
- The kinetic energy originates from the electrostatic interaction of these electrons with the positive metal ions and also with each other.
- Conduction electrons move about randomly (with a mean speed u) being frequently and randomly scattered by thermal vibrations of the atoms.
- In the absence of an applied field there is no net drift in any direction.

Under Applied Electric Field



- Conduction electrons experience a force of eE_x in the opposite direction of E_x.
- A net drift along the x direction is superimposed on the random motion of the electron.
- The electron accelerates along the x direction under the action of the force eEx, and then it suddenly collides with a vibrating atom and loses the gained velocity → there is an average velocity in the x direction

Drift Velocity



Let u_{xi} be the velocity of electron i in the x direction just after the collision (initial velocity). Since eE_x/m_e is the acceleration of the electron, the velocity v_{xi} in the x direction at time t will be

$$v_{xi} = u_{xi} + \frac{eE_x}{m_e}(t - t_i)$$

$$v_{dx} = \frac{1}{N}[v_{x1} + v_{x2} + v_{x3} + \cdots + v_{xN}]$$
$$= \frac{eE_x}{m_e}\overline{(t - t_i)}$$

$\overline{(t - t_i)}$: average free time between collisions.

Mean Free Time

$$\overline{(t - t_i)} \equiv \tau$$

τ: Mean free time, mean time between collisions, or mean scattering time

$$V_{dx} = \frac{e\tau E_x}{m_e}$$

- τ is directly related to the microscopic processes that cause the scattering of the electrons in the metal — lattice vibrations, crystal imperfections, and impurities, to name a few.
- $1/\tau$ represents the mean frequency of collisions or scattering events. During a small time interval δt, the probability of scattering will be $\delta t/\tau$.

9

Drift Mobility

$$V_{dx} = \mu_d E_x$$

μ_d: drift mobility

$$\mu_d = \frac{e\tau}{m_e}$$

- μ_d represents the ease of electron conduction under an electric field.
- If the electron is not highly scattered, then the mean free time between collisions will be long, τ will be large, and μ_d will also be large; the electrons will therefore be highly mobile and be able to "respond" to the field.

10

Ohm's Law and Conductivity

$$J_x = env_{dx}$$

- Using the expression for drift velocity v_{dx}: $J_x = en\mu_d E_x$
- Ohm's Law: $J_x = \sigma E_x$
- $\sigma = en\mu_d \rightarrow$ Conductivity
- A large μ_d does not necessarily imply high conductivity, because σ also depends on the concentration of conduction electrons n.