EEE105
"Electronic Devices"

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Lecture 5

- Current in a Conducting Solid
  - Carrier Density
  - Conductivity
  - Ohm’s Law
- Worked Example

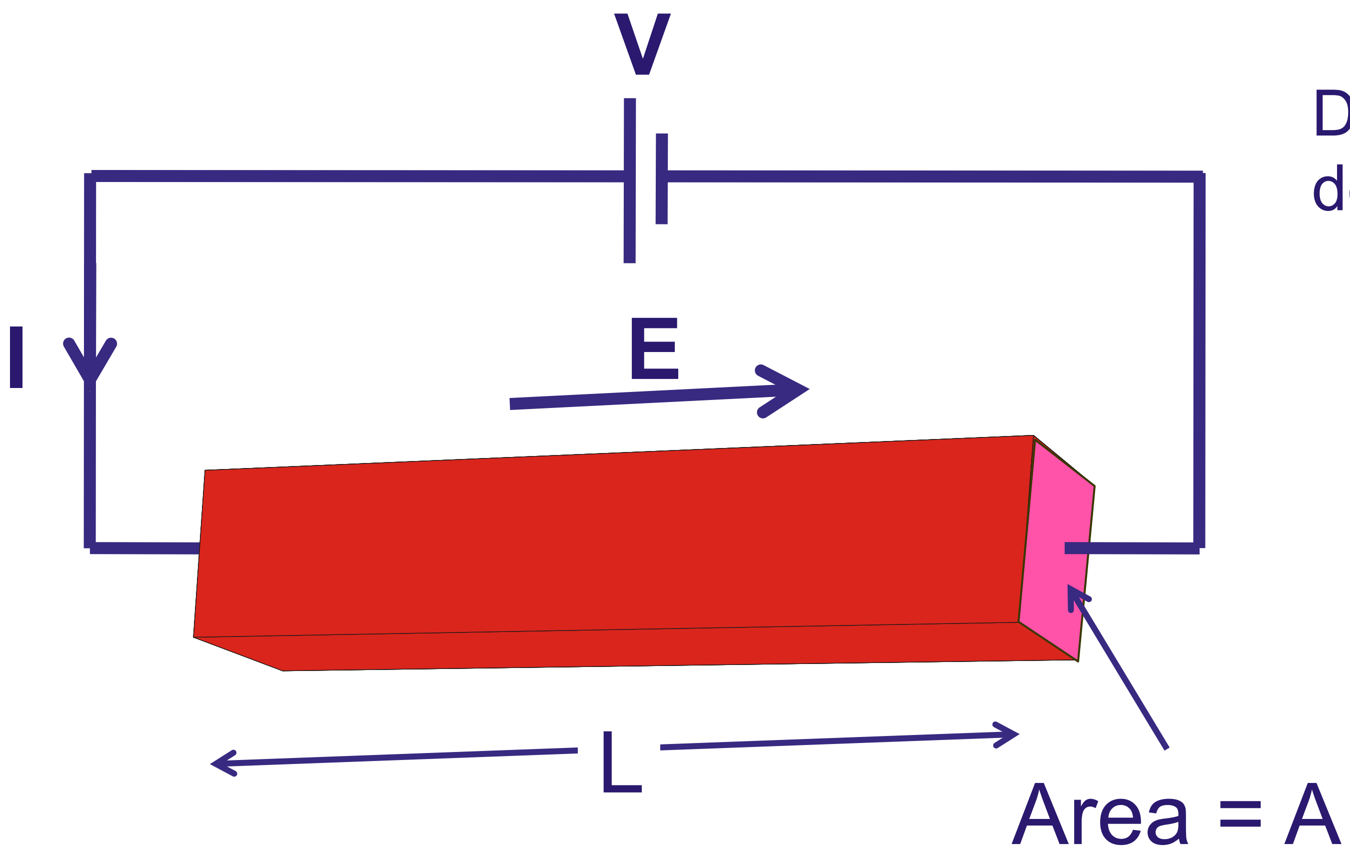
Current in a Conductor

Three causes of current;

1. An electric potential gradient dV/dx (i.e. an E-field)
2. An electron (carrier) density gradient dn/dx
3. A temperature gradient dT/dx

So far only looking at #1 – applying a voltage difference

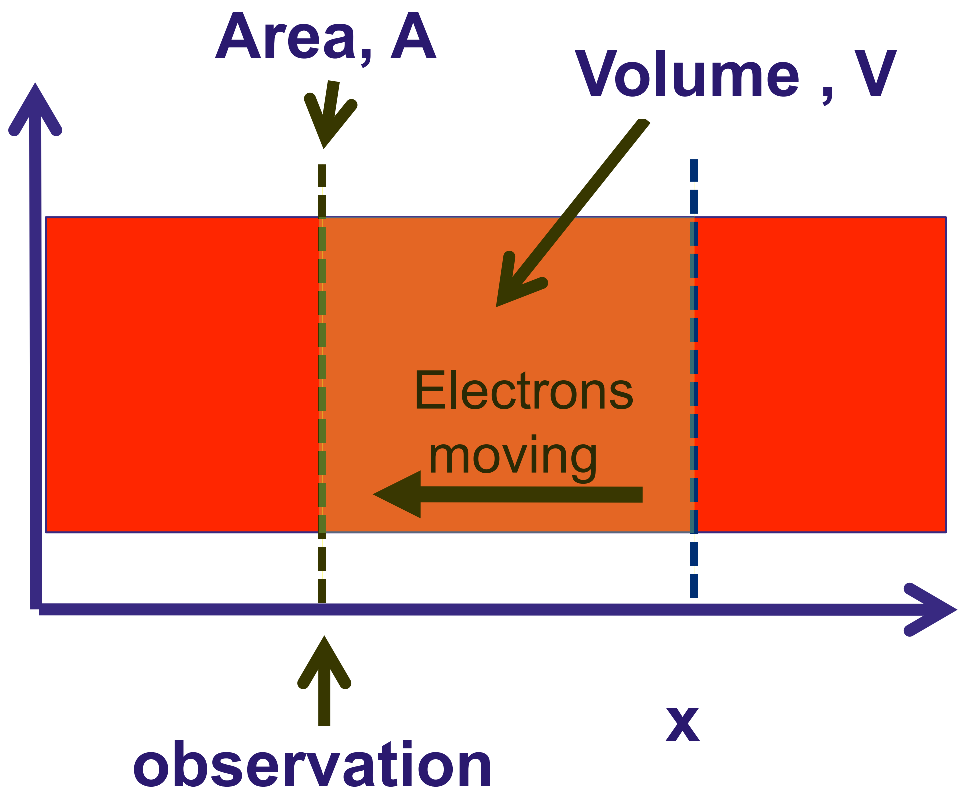
Solid with Free Electrons



Define a current density, J,

$$J = \frac{I}{A}$$

Longitudinal Slice



Have average velocity , v_d of electrons and density of electrons n

In time t, all electrons in shaded region will move past observation point

→ $x = v_d t$

Number of electrons in this volume is

$$n V = n A x = n A v_d t$$

Continued

- Charge on electron =-q (q=1.6x10^{-19} C) so in unit time (a second) the amount of charge flowing past our observation point is the current $I = - n A q v_d$

The current density is given by; $J=I/A=-n q v_d$

n.b.

J and I in opposite direction to electron flow as expected

Sometimes drift velocity written as v or v_d

Sometimes charge on electron written as e or q

Often we use centimetres instead of metres .... be careful!

Eliminate V_d

- The previous equation is only useful if we now the drift velocity, which we have derived $v_d = -\mu E$
- Which gives $J = n\,q\,\mu\,E$
- So the current density in our solid depends upon
  - Carrier concentration - how many carriers
  - E-field – magnitude dv/dx
  - Mobility - how easy the carriers can move
  - (The charge on an electron not negotiable!)

Ohm's Law

$J = n\, q\, \mu\, E$ Can be simplified to $J = \sigma E$

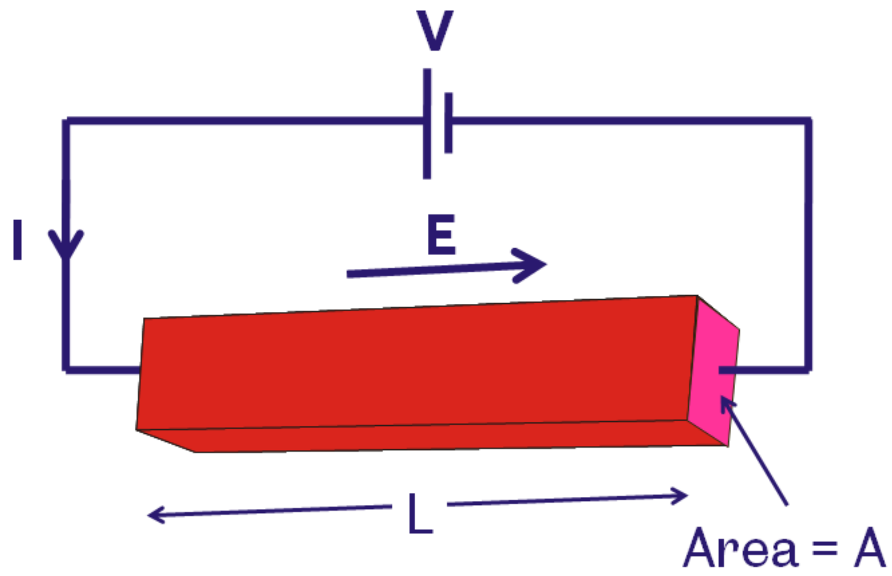
Where the conductivity $\sigma = nq\mu$

Conductivity is inverse of resistivity $\rho = \dfrac{1}{\sigma}$

This is the general form of ohm's law

Ohm's Law (2)

$$J = \frac{I}{A} \qquad E = \frac{V}{L} \qquad J = \sigma E$$



$$\frac{I}{A} = \frac{\sigma V}{L}$$

$$I = \frac{\sigma A V}{L}$$

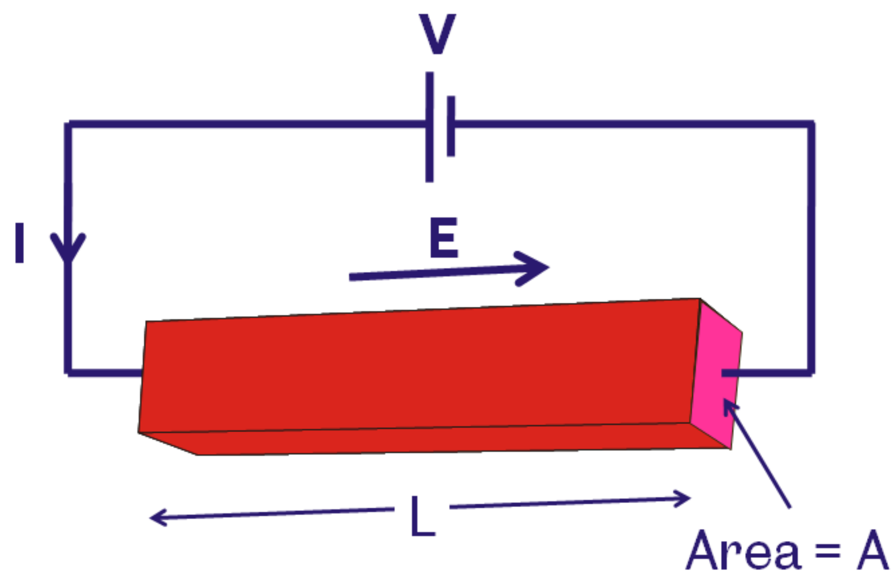
(Ohm's law) is true if $R = \dfrac{L}{\sigma A}$

Drift Velocity Example

- A 2cm long Si rod with cross sectional area of $5mm^2$ has a voltage of 10V applied across its length, giving a current of 3 mA. The rod is known to have a uniform density of free electrons and temperature throughout its length.
  a) What is the average time between collisions in the material?
  b) What is the average drift velocity of the electrons in the rod?
  c) What is the concentration of the electrons in the material?

Given that $\mu=0.12\ m^2V^{-1}s^{-1}$ $m^*=0.98m_e$
($m_e=9.11\times10^{-31}$ Kg), $q=1.6\times10^{-19}$ C

Visualization, Unit Conversion



$L=2\times10^{-2}$ m
$A=5\times10^{-6}$ m^2
$V=10$ V
$I=3\times10^{-3}$ A

$\mu=0.12$ m^{2}V^{-1}s^{-1}

$m^*=0.98m_e$

$m_e=9.11\times10^{-31}$ Kg

a) Determine τ

Definition of mobility $$\mu = \frac{q\tau}{m^*}$$

Rearranging $$\tau = \frac{\mu m^*}{q}$$

$$\tau = \frac{0.12 \times 0.98 \times 9.11\times10^{-31}}{1.6 \times 10^{-19}} = 6.7\times10^{-13}\,\mathrm{s}$$

b) Determine v_d

Drift velocity and E-field related by – $v_d = -\mu E$

E-field? Drop 10V over 2cm $E = \frac{V}{L} = \frac{10}{0.02} = 500\ \mathrm{Vm}^{-1}$

(n.b. OK if temp, n constant over rod)

Hence drift velocity $v_d = -\mu E = -0.12\mathrm{x}500 = -60\ \mathrm{ms}^{-1}$

c) Determine n

Current and voltage provide resistance of rod

$$R = \frac{V}{I} = \frac{10}{3x10^{-3}} = 3.3x10^{3}\,\Omega$$

Dimensions are known -can calculate the conductivity

$$R = \frac{L}{\sigma A} \qquad \sigma = \frac{L}{RA} = \frac{0.02}{3.33x10^{3} \text{ x } 5x10^{-6}} = 1.2\ \Omega^{-1}m^{-1}$$

Know relation between conductivity and carrier density

$$n = \frac{\sigma}{q\mu} = \frac{1.2}{1.6x10^{-19} \text{ x } 0.12} = 6.25x10^{19}\ \ m^{-3}$$

Summary

- Current density is current per unit area flowing in a material
- Current density is increased with increasing carrier density, increased mobility, and increased E-field.
- Conductivity is the reciprocal of resistivity
- The current density of the product of the E-field and conductivity of the material

