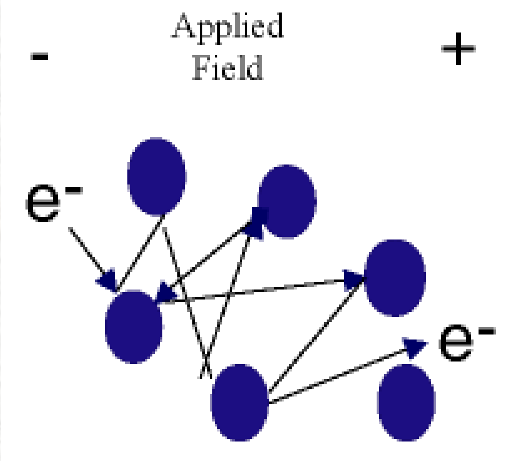
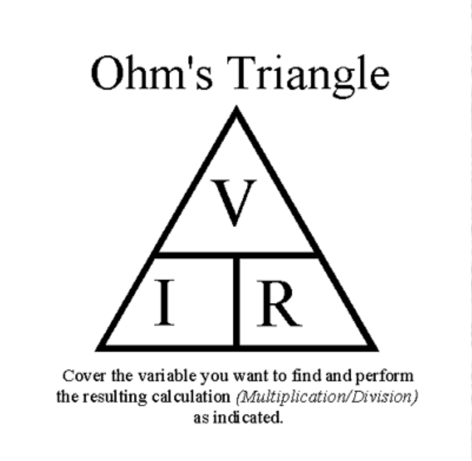
Electronic properties



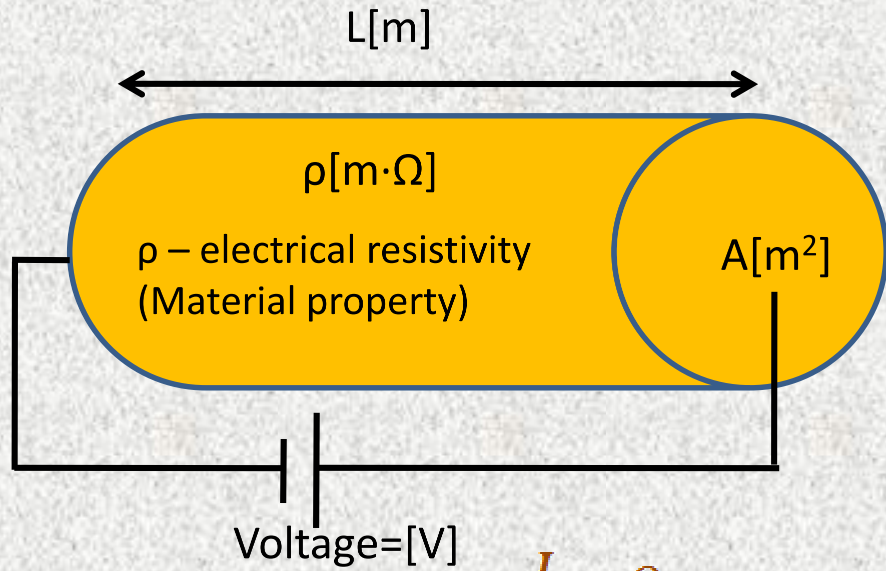


Primer Materials For Science Teaching

Ohm's low

$$I = \frac{V}{R}$$

I – current [A]
V – Voltage [V]
R – Resistance [Ω]



Power dissipation:

$$P = I^2 R = V \cdot I = \frac{V^2}{R}$$

P – Watt [W]

$$\sigma = {}^{1}/_{\rho}$$

σ – electrical conductivity [S/m]

$$R = \frac{L \cdot \rho}{A}$$

Resistance has geometrical dependence

$$J = I/A$$

J – Current density (flux)

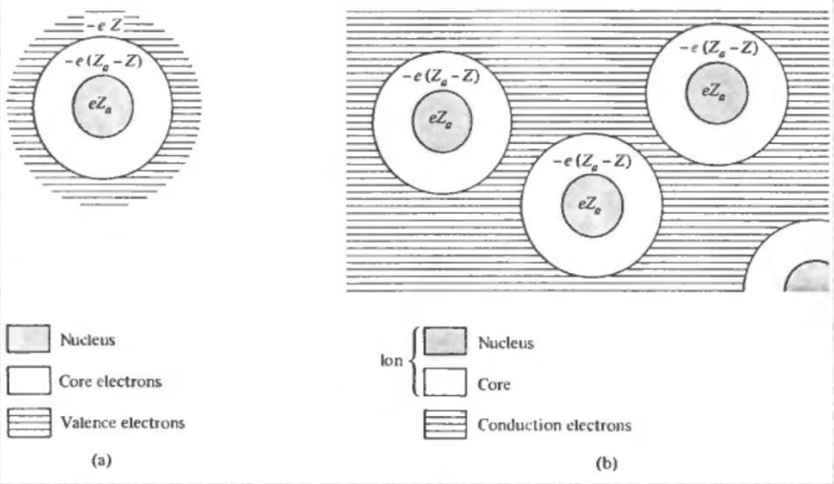
$$J = \sigma \cdot E$$

$$E = V/L$$

E – electric field [V/m]

Drude model

n – electron density
n_i – metal ion density
e – electron charge
m_e- electron mass
μ- mobility
a- atomic (metallic) radius



Assumptions

- All atoms gives their valance electron to the 'sea of electron'
- Ion are localized, Electron moves in straight lines between collisions
- Relaxation time: τ – time between collisions

$$\sigma = \mu n e \qquad \sigma = \frac{ne^2\tau}{m_e}$$

The electrical conductivity related to the relaxation time

$$\mu = \frac{e\tau}{m_e} \qquad \tau = \frac{m_e}{\rho n e^2} = \frac{1}{n_i \pi a^2} \cdot \sqrt{\frac{m_e}{3KT}}$$

Typical relaxation times

Table 1.2
ELECTRICAL RESISTIVITIES OF SELECTED ELEMENTS[a]

ELEMENT	77 K	273 K	373 K	$\frac{(\rho/T)_{373\,K}}{(\rho/T)_{273\,K}}$
Li	1.04	8.55	12.4	1.06
Na	0.8	4.2	Melted	
K	1.38	6.1	Melted	
Rb	2.2	11.0	Melted	
Cs	4.5	18.8	Melted	
Cu	0.2	1.56	2.24	1.05
Ag	0.3	1.51	2.13	1.03
Au	0.5	2.04	2.84	1.02
Be		2.8	5.3	1.39
Mg	0.62	3.9	5.6	1.05
Ca		3.43	5.0	1.07
Sr	7	23		
Ba	17	60		
Nb	3.0	15.2	19.2	0.92
Fe	0.66	8.9	14.7	1.21
Zn	1.1	5.5	7.8	1.04
Cd	1.6	6.8		
Hg	5.8	Melted	Melted	
Al	0.3	2.45	3.55	1.06
Ga	2.75	13.6	Melted	
In	1.8	8.0	12.1	1.11
Tl	3.7	15	22.8	1.11
Sn	2.1	10.6	15.8	1.09
Pb	4.7	19.0	27.0	1.04
Bi	35	107	156	1.07
Sb	8	39	59	1.11

[a] Resistivities in microhm centimeters are given at 77 K (the boiling point of liquid nitrogen at atmospheric pressure), 273 K, and 373 K. The last column gives the r… approximate linear temperature d… ture.
S… Physical and Chemical Constants, Longmans Green, London, 1966.

[μΩ·cm] = 1×10^{-8}[Ω·m]

Table 1.3
DRUDE RELAXATION TIMES IN UNITS OF 10^{-14} SECOND[a]

ELEMENT	77 K	273 K	373 K
Li	7.3	0.88	0.61
Na	17	3.2	
K	18	4.1	
Rb	14	2.8	
Cs	8.6	2.1	
Cu	21	2.7	1.9
Ag	20	4.0	2.8
Au	12	3.0	2.1
Be		0.51	0.27
Mg	6.7	1.1	0.74
Ca		2.2	1.5
Sr	1.4	0.44	
Ba	0.66	0.19	
Nb	2.1	0.42	0.33
Fe	3.2	0.24	0.14
Zn	2.4	0.49	0.34
Cd	2.4	0.56	
Hg	0.71		
Al	6.5	0.80	0.55
Ga	0.84	0.17	
In	1.7	0.38	0.25
Tl	0.91	0.22	0.15
Sn	1.1	0.23	0.15
Pb	0.57	0.14	0.099
Bi	0.072	0.023	0.016
Sb	0.27	0.055	0.036

[a] Relaxation times are calculated from the data in Tables 1.1 and 1.2, and Eq. (1.8). The slight temperature dependence of n is ignored.

Drift velocity

V_{th} – thermal velocity
E – electric field
V_{drift} – drift velocity

$$V_{th} = \sqrt{\frac{3KT}{m_e}}$$

$$J = \sigma E = nev_{drift}$$

- When J = 0 the drift velocity is zero. Meaning that in average each electron has zero displacement
- When J ≠ electron moves with typical velocity of v_{drift}

Electron moves in metal

Example 1

You apply a potential difference of 4.5 [V] between the ends of a wire that is 2.5 [m] in length and 0.64 [mm] in radius. The resulting current through the wire is 18 [A]. What is the resistivity of the wire? What is the heat loss?

$$R = V/I = 0.25[\Omega]$$

$$A = \pi r^2 = 1.29X10^{-6}$$

$$\rho = \frac{R \cdot A}{L} = 12.9X10^{-8}[\Omega \cdot m]$$

$$P = I \cdot V = I^2 \cdot R = 81\ [W]$$

Example 2

The resistivity of Cu is 1.7×10^{-8} Ωm at 300 K and the electron density is 8.5×10^{28} m^{-3}.

(a) Calculate the relaxation time of electrons in Cu at 300 K .

(b) Calculate the mean free path of the electrons using Drude approximation.

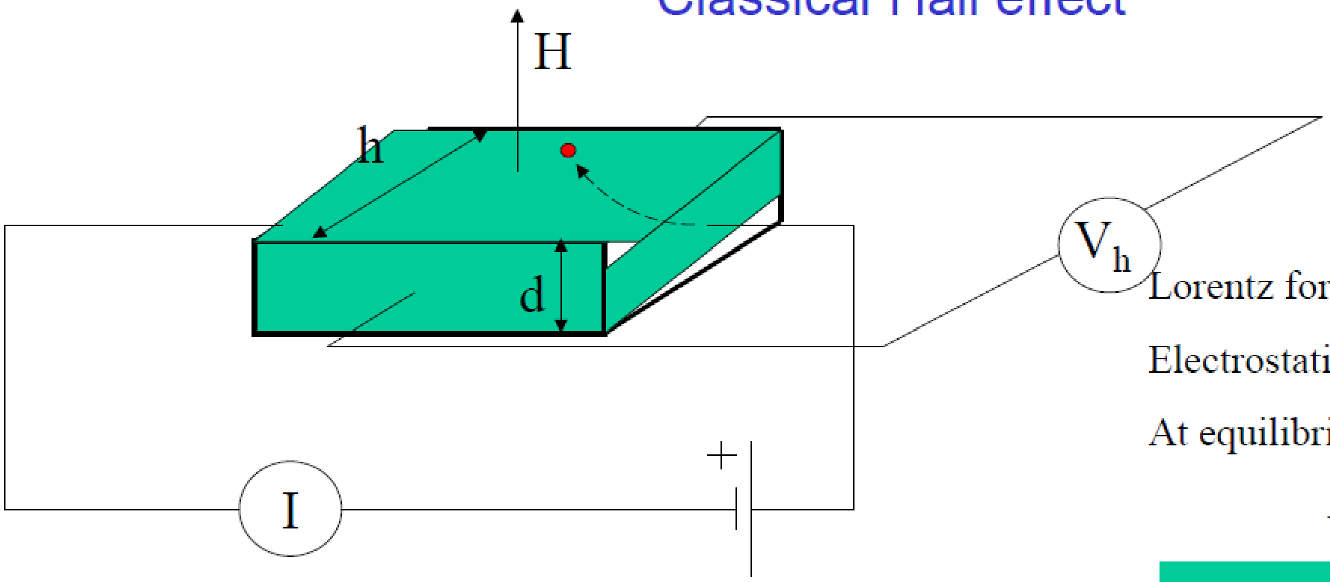
$m_e = 9.1093837 \times 10^{-31}$ Kg

$e = 1.60217663 \times 10^{-19}$ C

a) $\tau := \dfrac{me}{\rho \cdot n \cdot e^2}$ $\quad \tau = 2.46 \times 10^{-14}\,s$

b) $Vther := \left(\dfrac{3 \cdot k \cdot T}{me}\right)^{\frac{1}{2}}$ $\quad lther := Vther \cdot \tau$ $\quad \dfrac{lther}{10^{-9} \cdot m} = 2.874$ nm

Classical Hall effect



Lorentz force: $F_L = e\, v \times H$;

Electrostatic force: $F_E = Ee = V_h e/l$

At equilibrium $F_L = F_E$ and

$$v \times H = V_h/h$$

$$V_h = \frac{HI}{end} = R_h H \frac{I}{d}$$

Current density is related to the velocity as $ven = I/(dh)$ =>

$$R_h = \frac{1}{en}$$

R_h is Hall constant

Classical theory predicts that $-R_h en = 1$

Example 3

Prove that the combination of Hall effect measurements and resitivity measurements permits determination of the electron relaxation time

$$R_h = \frac{1}{e \cdot n}$$

$$\text{Hall voltage } V_h = R_h \cdot \frac{IH}{d} = \frac{H \cdot I}{e \cdot n \cdot d} \Rightarrow n = \frac{H \cdot I}{e \cdot d \cdot V_h}$$

$$\text{Conductivity } \sigma = \frac{ne^2\tau}{m_e} \Rightarrow \tau = \frac{m_e \sigma}{ne^2} = \frac{m_e \cdot \sigma \cdot d \cdot V_h}{H \cdot I \cdot e}$$