Mobility Depends on Temperature and Doping

Temperature: e^-'s and h^+'s scatter off lattice and off impurity atoms

As T ↑, more scattering by vibrating lattice atoms

As T ↓, less " " " " "

At low T, have larger effect on e^-'s.

$$\frac{1}{\mu} = \frac{1}{\mu_L} + \frac{1}{\mu_I}$$

← Lattice ← Impurity

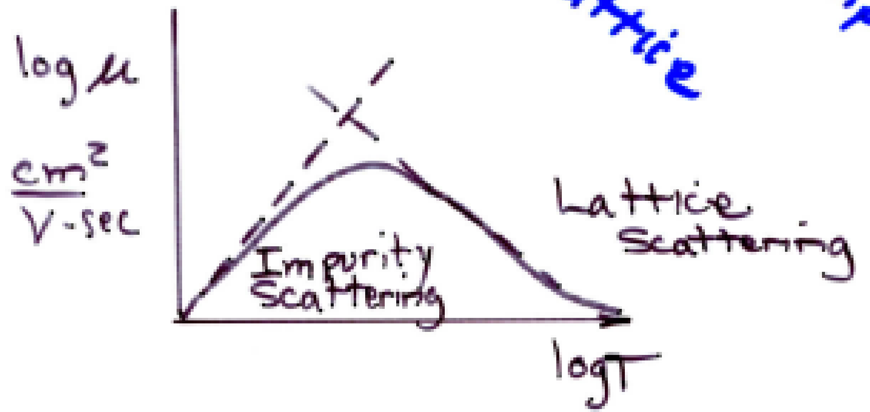
Mechanism with lowest mobility dominates

$$\frac{1}{\mu} = \frac{1}{\mu_L} + \frac{1}{\mu_I}$$

Lattice

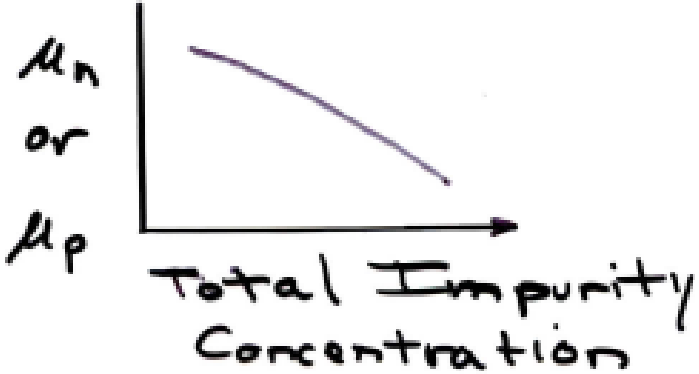
Impurity

Mechanism with lowest mobility dominates



$$\left(\frac{1}{\tau} = \frac{1}{\tau_1} + \frac{1}{\tau_2} \right)$$

<u>Doping</u>: μ decreases with increasing doping (since more scattering sites)



Example: $T = 300K$

Intrinsic: $\mu_n = 1350 \ \frac{cm^2}{V\text{-}sec}$

10^{17} Si: $\mu_n = 700$ "

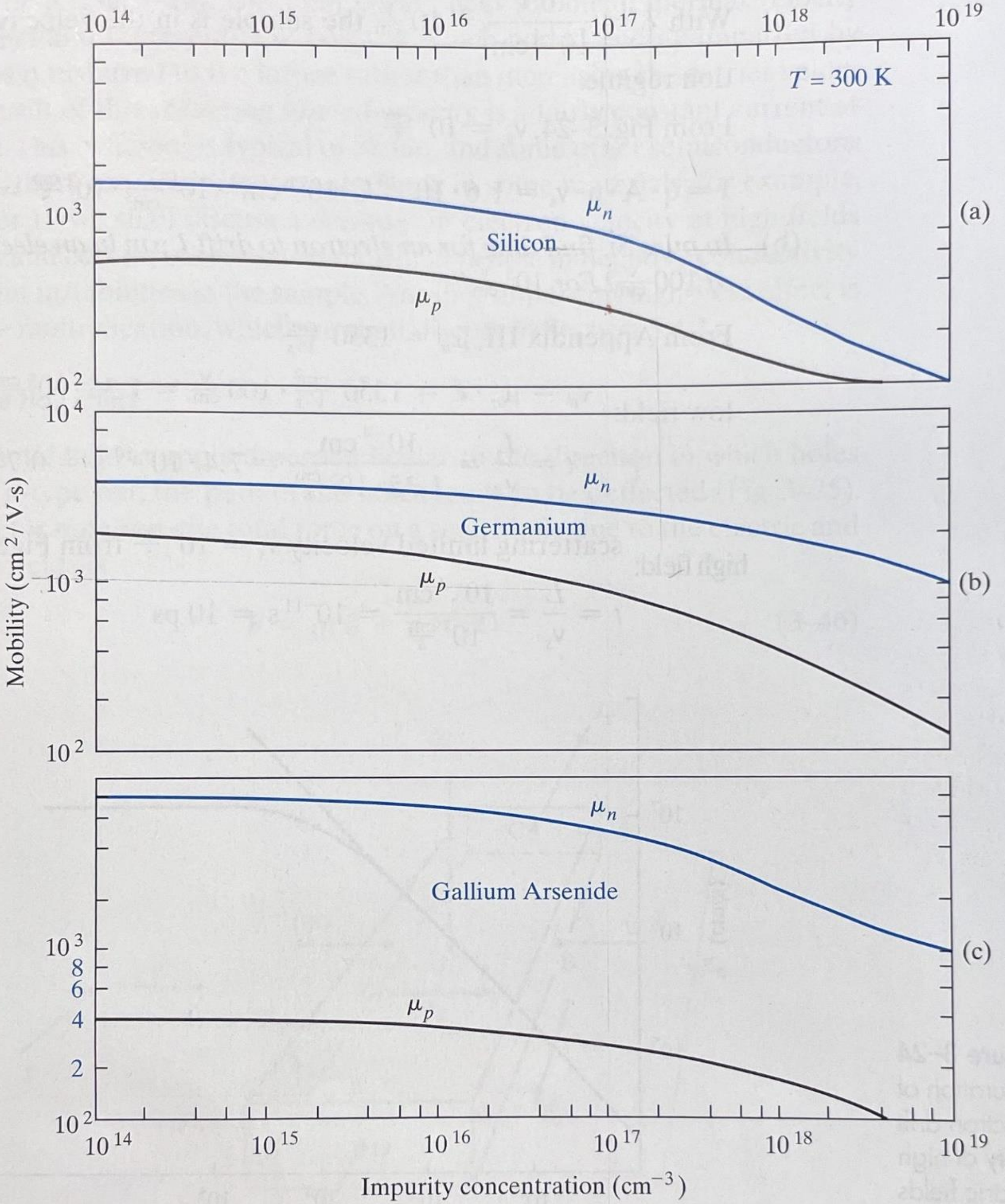
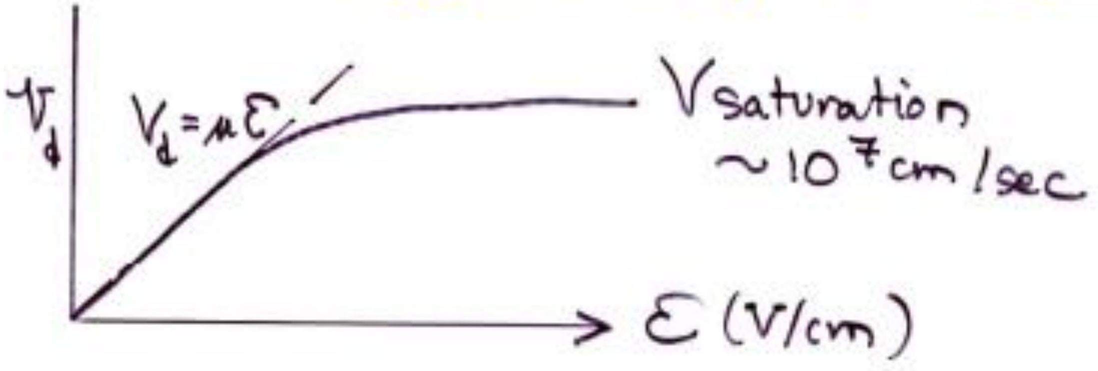


Figure 3–23
Variation of mobility with total doping impurity concentration ($N_a + N_d$) for Ge, Si, and GaAs at 300 K.

High Field Saturation: Scattering-Limited Velocity

At $\mathcal{E} < \mathcal{E}_{saturation}$, $J = -q n v_d =$

Above $\mathcal{E}_{saturation}$, J sublinear dependence on $\mathcal{E}$



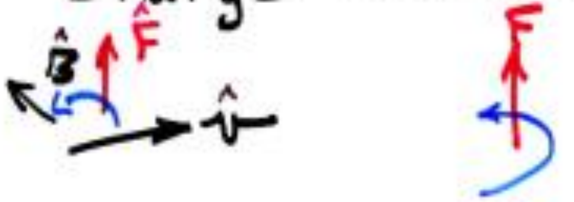
For $\mathcal{E} > \mathcal{E}_{saturation}$, energy transferred into heat from lattice scattering

Also, e^-'s can scatter, change k, and move to lower μ band.

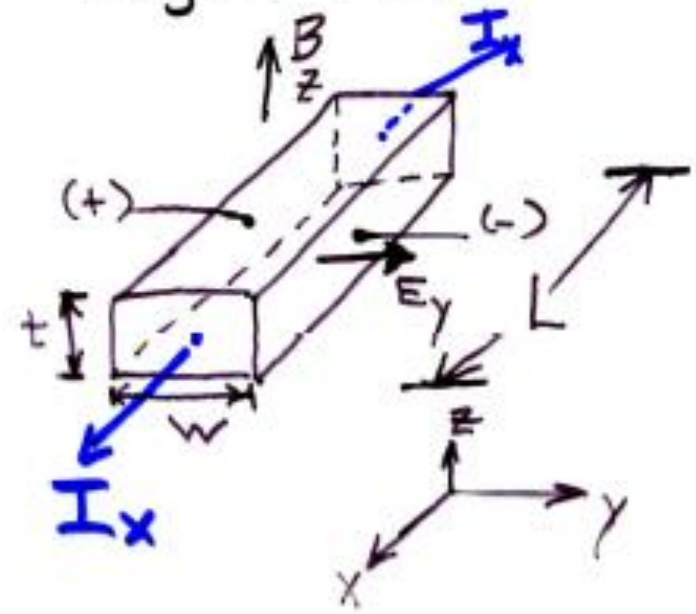
We can measure carrier concentration via Hall Effect

$$F = q(\vec{\mathcal{E}} + \vec{v} \times \vec{B})$$

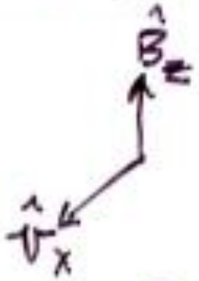
Total Force on a Single (+) charge (hole)



Right-Hand Rule:



- (+) charge moves in a current along + x.



- Magnetic field along +Z
- So force is along $-y = -q v_x B_z$

As a result, (+) charges move along $-y$ and pile up until their $\mathcal{E}$ field, $\mathcal{E}_y$, nulls out $-q v_x B_z$.

Since no current can flow in steady-state along $\hat{y}$, the forces must <u>balance</u>.

$$F_y = 0 = q\mathcal{E}_y - v_x B_z q = q(\mathcal{E}_y - v_x B_z)$$

$$\mathcal{E}_y = v_x B_z \qquad \text{Hall Effect Voltage}$$

$$J_x = q \rho_0 v_x$$

$$\rightarrow \mathcal{E}_y = \frac{J_x}{q p_o} B_z = J_x R_H B_z$$

$$R_H \equiv \qquad = \underline{\text{Hall}}\ \text{Coe}\underline{\text{fficient}}$$

So measure Hall Voltage for known J and B.

to get

$$p_o = \frac{1}{q R_H} =$$

Doping

$$P_0 = \frac{(I_x/wt)B_z}{q\,(V_{AB}/w)} = \frac{I_x B_z}{q\,t\,V_{AB}}$$

Known I and B (w factored out)

Resistivity

$R = \boxed{}$ so

$$\rho(\Omega\text{-cm}) = R\,\frac{wt}{L} = \boxed{}$$

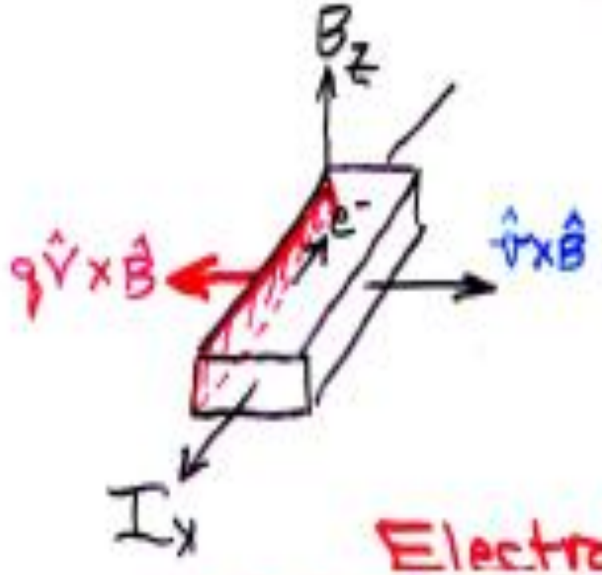
Known V and I

Mobility

$J = q P_0 v$ so $\sigma \cancel{\mathcal{E}} = q P_0 \mu_0 \cancel{\mathcal{E}}$

Then $\mu_0 = \dfrac{\sigma}{q P_0} = \dfrac{1/\rho}{q P_0} = \dfrac{1/\rho}{1/R_H} = \boxed{}$

Measure R_H and ρ over wide T range to get p_o (and n_o) and μ_p (and μ_n) versus T



Note: For electrons, opposite sign of Hall field. so we can tell if material is n-type or p-type

$q\hat{v}\times\hat{B}$ ← same
$\hat{v}$ ← opposite
q ← opposite

Electrons move in same direction and pile up on same side as holes; opposite sign so opposite field.

Fermi Level Equilibration

No variation in Fermi Level at equilibrium

Material 1	Material 2
$N_1(E)$	$N_2(E)$
$f_1(E)$	$f_2(E)$

$\rightarrow x$

E_F constant

At Equilibrium

$$N_1(E) f_1(E) \cdot N_2(E)[1-f_2(E)] = N_2(E) f_2(E) \cdot N_1(E)[1-f_1(E)]$$

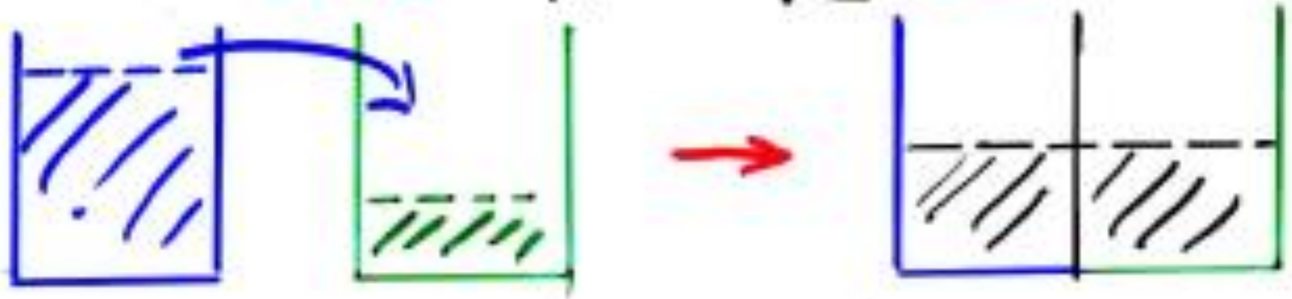
Charges Redistribute across Interface

Until Probability of transfer from 1 → 2

= " " " " 2 → 1

$$f_1(E) = f_2(E) \qquad \left[1+e^{(E-E_{F1})/kT}\right]^{-1} = \left[1+e^{(E-E_{F2})/kT}\right]^{-1}$$

$$\rightarrow E_{F1} = E_{F2} \leftarrow$$



Before Contact $\qquad$ After Contact

Current flows until equilibrium reached.