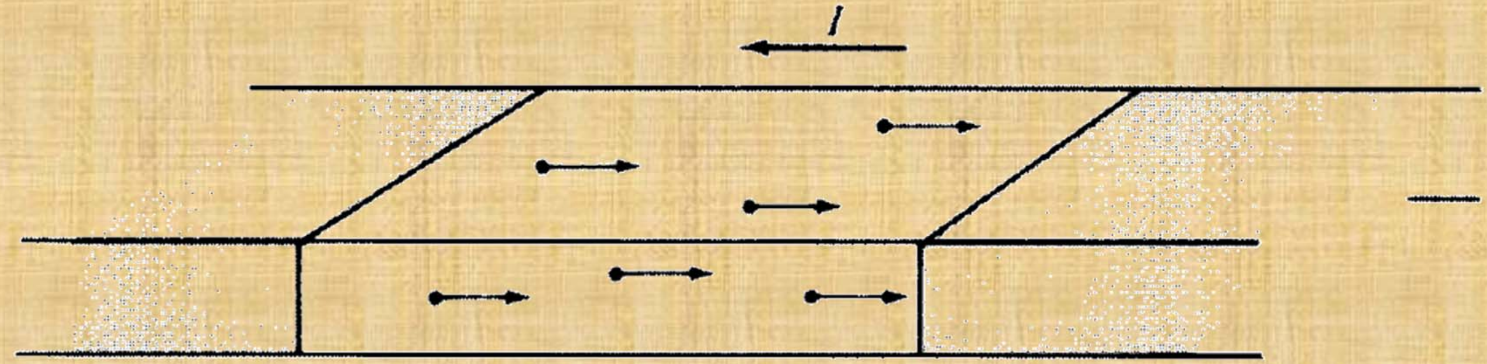
# Conduction

# Conduction

- Transit Time



- Current

$$I = -\frac{|Q|}{\tau}$$

# Conduction…

- Drift
  - Random process
  - In presence of external field
  - Complicated Movement – Scattering Mechanisms
    - Lattice Vibration
    - Ionized Impurities
- Average velocity -- Drift Velocity : $v_d$
  - Semiconductor Material
  - Doping type/concentration
  - Temperature
  - Carrier type
  - Applied electric field

# Conduction

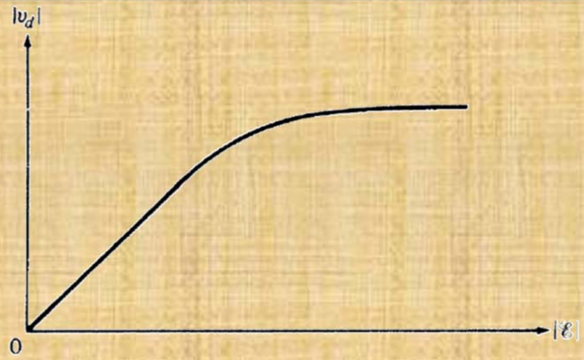
- Velocity Saturation
- In following figure we assume it n-type semiconductor
- If the electron velocity saturated then its move with constant velocity
  - Electron transit time : $\tau = \frac{a}{v_d}$
  - The magnitude I Q I of the total free electron charge found inside the bar at a given time instant is :

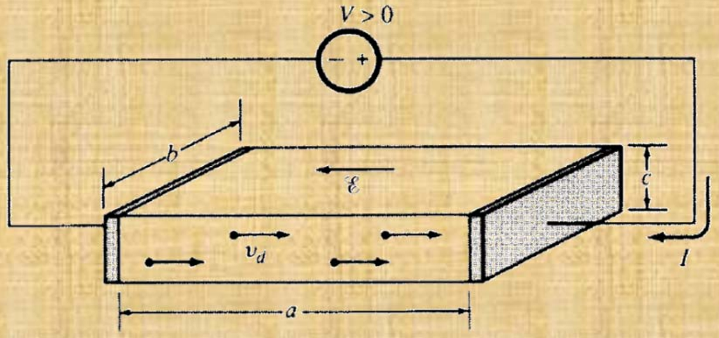
$$|Q| = nq(abc)$$

  - Therefore Current becomes:

$$I = \frac{nq(abc)}{\tau}$$

$$I = nq(bc)v_d$$





# Conduction…

- *magnitude of the charge per unit area:* $|Q'| = \frac{|Q|}{ab}$

$$I = b|Q'|v_d$$

- The Case of Low Electric Fields
  - For such fields, $v_d$ is proportional to $E$ – *Mobility parameter:* $\mu_B$

$$v_d = \mu_B \times E$$

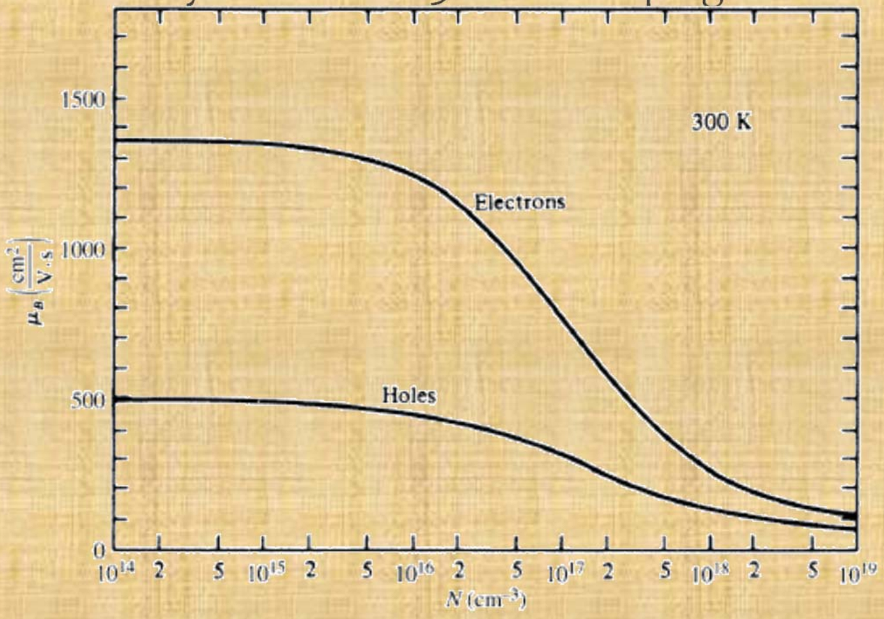
$$E = \frac{V}{a}$$

$$I = \mu_B b/a|Q'|V$$

  - Independent of c, bar thickness
  - The drift current is proportional to the voltage (Ohm's Law)
  - Transit time : $\tau = a^2/\mu_B V$ – Dependency to $a^2$
    - The distance of electrons must travel becomes larger
    - the magnitude of the electric field becomes smaller

# Conduction…

- Electron and hole bulk mobility in silicon at 300 K vs doping concentration



# Conduction…

- Conductance and Conductivity

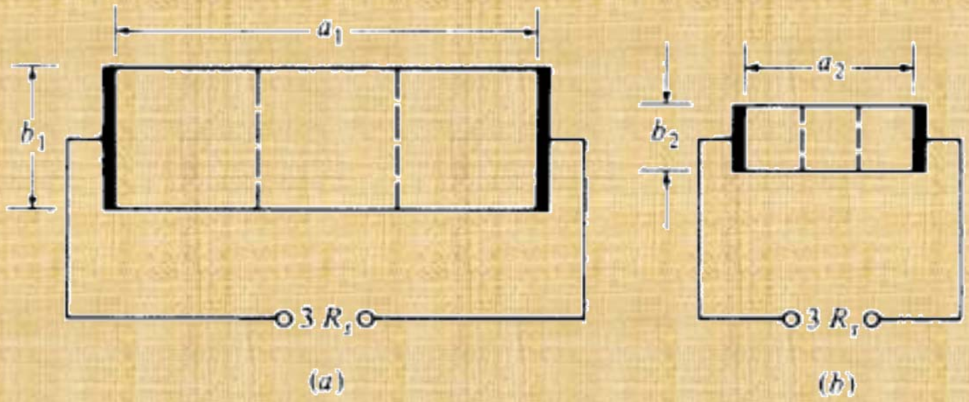
$$I = \mu_B nqVbc/a$$
$$I = GV$$

- Conductance: $G = \frac{\sigma bc}{a} = \mu_B|Q'|b/a$, Conductivity : $\sigma = \mu_B nq$
- The inverse of the conductivity, called the *resistivity*, is also used.
- The resistance of the bar R= 1/G is

$$R = R_s a/b$$

- Sheet resistance: $R_s = (\mu_B|Q'|)^{-1}$
- If a=b: $R_s$=R, Resistance per squares. *R* will be given by *R*, times the number of squares in the path of the current.

# Conduction…



Results analogous to the ones in this section can be given in the case of hole conduction.

# Conduction…

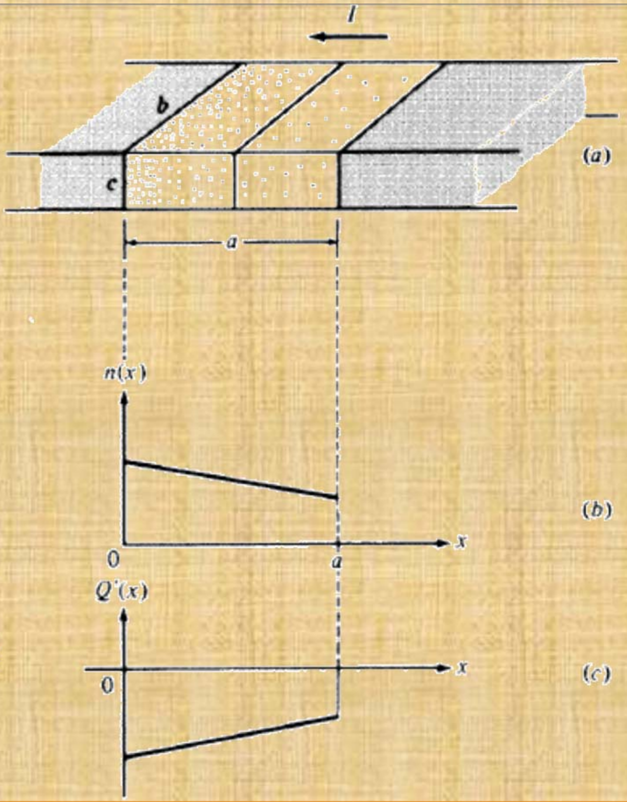
- Diffusion
  - Reason: Concentration Gradient
  - Random motion of the particles tends to make them spread out from regions of high concentration to regions of low concentration
  - Fick's Law
  - Current:

$$I = Dq(bc)(-dn/dx)$$

  - D is Diffusion Constant
  - Diffusion and Mobility : Einstein relationship

$$D = \mu_B \phi_T$$

  - Same equation for hole , the only difference is current positive



# Conduction…

- Current in steady state : Diffusion and drift relation
- Electron charge in slice of Δx : $Q = (-q)n(x)bc\Delta x$
- Charge per unit area : $Q' = \frac{Q}{b\Delta x} = (-q)cn(x)$
- Current : $I = \mu_B \phi_T b \frac{dQ'(x)}{dx}$
- If the plot is straight line

$$\frac{dQ'(x)}{dx} = \frac{Q'(a) - Q'(0)}{a}$$

$$I = \mu_B \phi_T \frac{b}{a}(Q'(a)\text{-}Q'(0))$$

- The total charge $Q = ab\frac{Q'(a)+Q'(0)}{2}$ and therefore the transit time: $\tau = \frac{a^2}{\mu_B(2\phi_T)}\frac{Q'(0)+Q'(a)}{Q'(0)-Q'(a)}$

# Conduction…

- For perfect sink: $Q'(a) = 0$

$$\tau = \frac{a^2}{\mu_B(2\phi_T)}$$

- It is very similar to drift transit time
- in contrast to the drift case, where $\tau$ can be made small by applying a large *V*, here $\tau$ is fixed at a comparatively large value, due to the fixed, small value $2\Phi_T$

# Conduction

- Total current: Contribution of both electron and hole. Also Both drift and diffusion mechanism include in it.
- Four possible current components:
  - Electron
    - Drift
    - Diffusion
  - Hole
    - Drift
    - Diffusion
- In thermal equilibrium implies zero electron current *and* zero hole current.