Section 17
Intro to Transport – Drift, Mobility, Diffusion, Einstein Relationship

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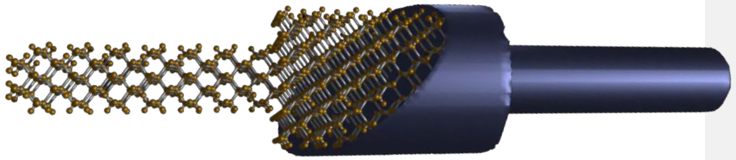
School of Electrical and Computer Engineering

$q \times n$

charge density

- Sections 2-14: Materials
- Section 15: Intro to Non-Equilibrium
- Section 16: Return to Equilibrium via Recombination



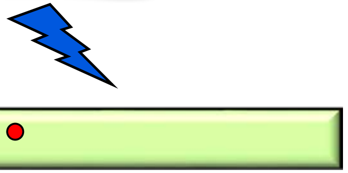
- Materials, composition, crystals
- "known" bulk materials

⇒ Quantum Mechanics Mechanics

- Density of states and masses

⇒ Equilibrium Statistical Mechanics

- Occupation factors



How does the system go BACK to equilibrium?

Transport with scattering, non-equilibrium Stat. Mech.

- Drift-diffusion equation with recombination-generation

Understanding transport in devices

- Diodes, BJT/HBT, MOS

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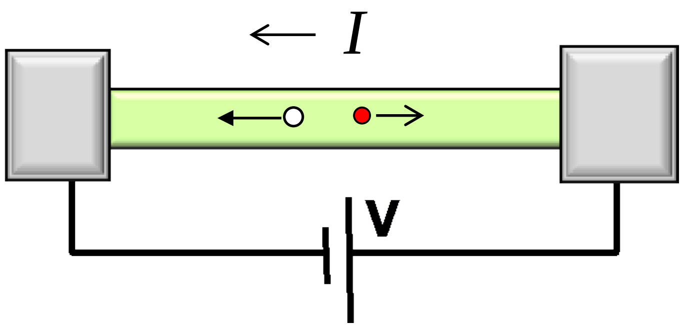

$$I = G \times V$$
$$= q \times n \times v \times A$$

charge density velocity area

- Sections 2-14: Materials
- Section 15: Intro to Non-Equilibrium
- Section 16: Return to Equilibrium via Recombination
- 17.1 Drift Current
- 17.2 Mobility
  - »Matthiessen Rule
  - »High Field Effects
  - »Mobility Measurement
- 17.3 Carrier Concentration from Hall Effect
- 17.4 Physics of diffusion – Einstein Relationship

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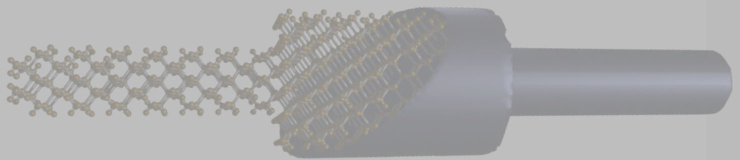

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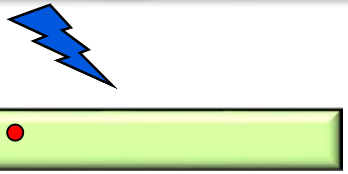

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Summary of Transport Equations ...

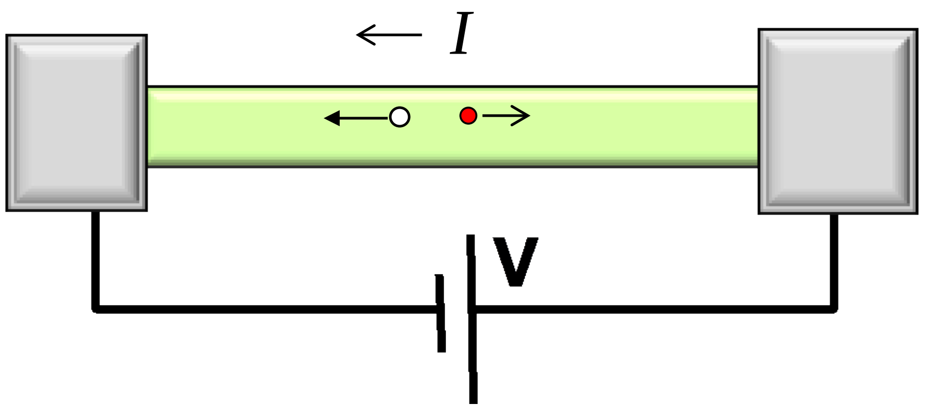
$$\nabla \bullet D = q\left(p - n + N_D^+ - N_A^-\right)$$

$$\frac{\partial n}{\partial t} = \frac{1}{q}\nabla \bullet \mathbf{J}_N - r_N + g_N$$

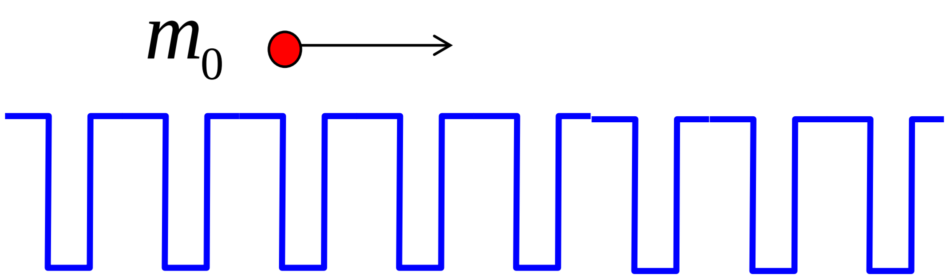
$$\mathbf{J}_N = qn\mu_N E + qD_N \nabla n$$

$$\frac{\partial p}{\partial t} = -\frac{1}{q}\nabla \bullet \mathbf{J}_P - r_P + g_P$$

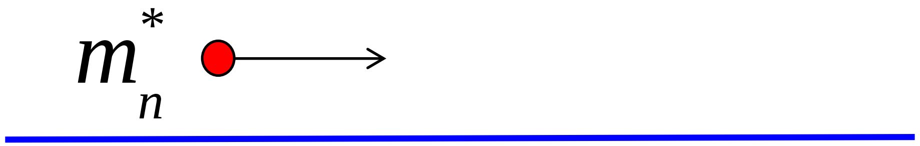
$$\mathbf{J}_P = qp\mu_P E - qD_P \nabla p$$



Meaning of Effective Mass ...



$$\left(-\frac{\hbar^2}{2m_0}\frac{d^2}{dx^2}+U_{crys}(x)+U_{ext}(x)\right)\psi = E\psi$$



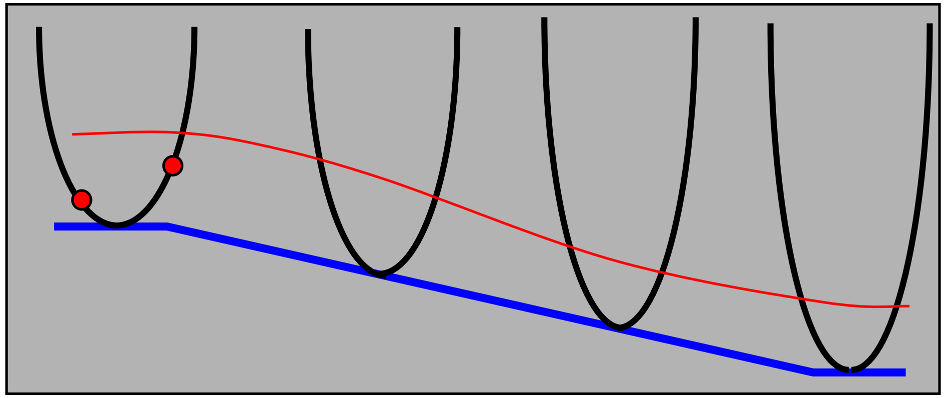
$$\left(-\frac{\hbar^2}{2m_0^*}\frac{d^2}{dx^2}+U_{ext}(x)\right)\phi = E\phi$$

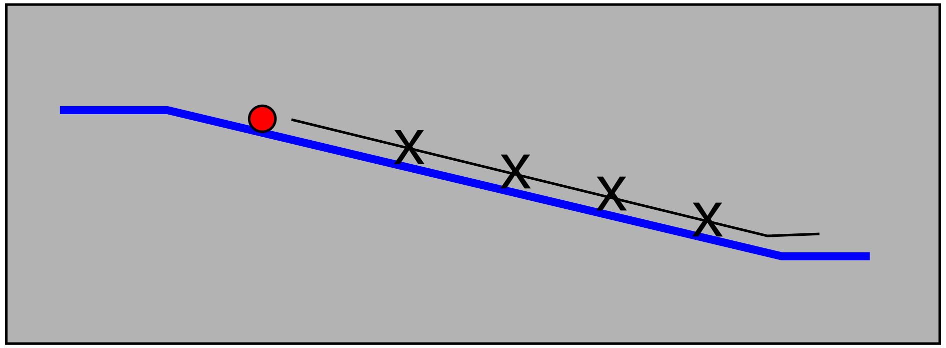
Drift by Electric field ….

$$J_n = qn\mu_n\mathcal{E}$$

$$\frac{d(m_n^*\upsilon)}{dt} = -q\mathcal{E} - \frac{m_n^*\upsilon}{\tau_n}$$

$$\upsilon(t) = -\frac{q\tau_n}{m_n^*}\mathcal{E}\left[1 - e^{-\frac{t}{\tau_n}}\right]$$

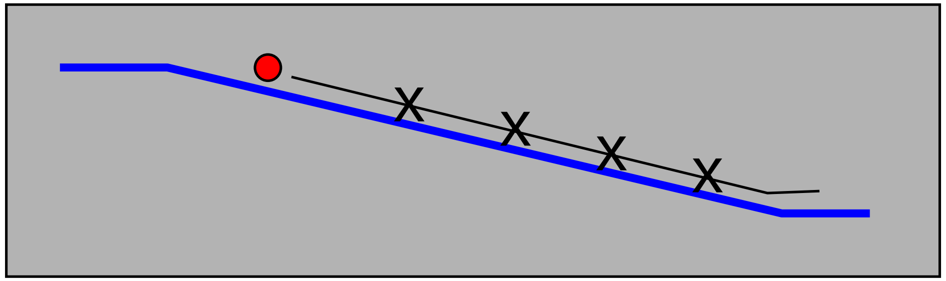




Consider system to be in local equilibrium

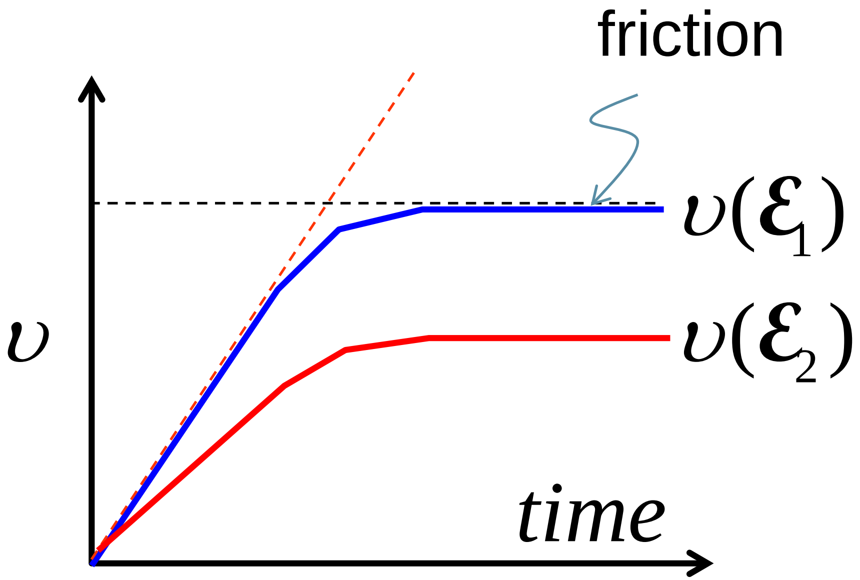
Drift by Electric field ….

$$\upsilon(t) = -\frac{q\tau_n}{m_n^*}\mathcal{E}\left[1 - e^{-\frac{t}{\tau_n}}\right]$$



$$= -\frac{q\tau_n}{m_n^*}\mathcal{E} \quad (t \to \infty,\ 1\text{-}2\ \text{ps})$$

$$\equiv \mu_n \mathcal{E}$$



$$J_n = qn\mu_n\mathcal{E}$$

(Theory valid once t > 1-2 ps)

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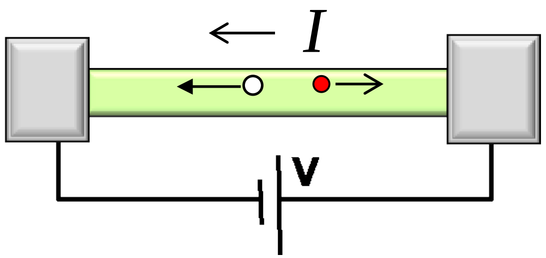

I = G x V
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charge density velocity area

Transport with scattering, non-equilibrium Stat. Mech.
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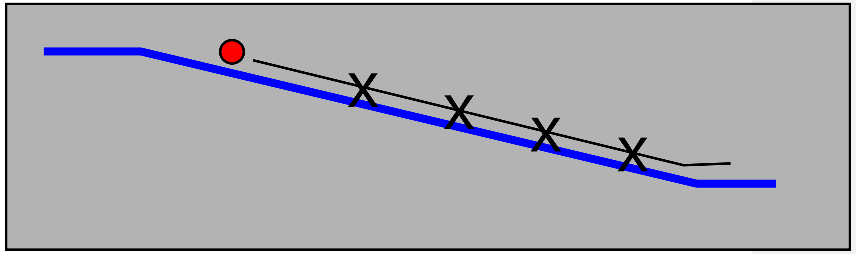
Vid
- 17.1 Drift Current $J_n = qn\mu_n\mathcal{E}$ status

Vid
- 17.2



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- 17.3

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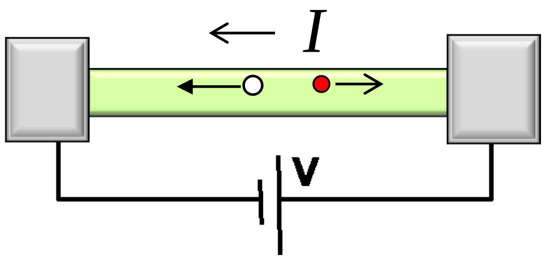
- 17.4

Consider system to be in local equilibrium

- Drift, diffusion, and recombination-generation
  => elemental processes in semiconductor device physics.
- Measurement of mobility and carrier concentration
  => characterize semiconductor devices.



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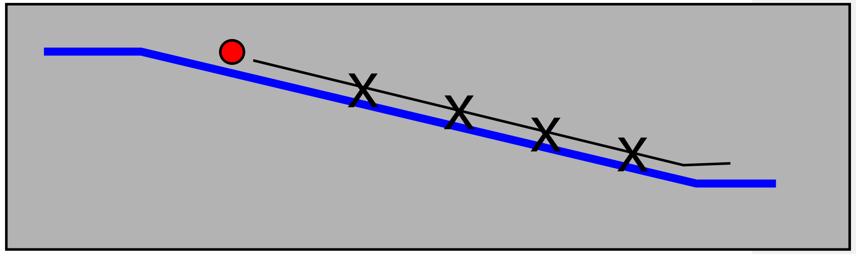
- 17.1 Drift Current $J_n = qn\mu_n\mathcal{E}$
- 17.2 Mobility
  - »Matthiessen Rule

status



- 17.3
- 17.4

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