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80 Pages
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EXERCISE BOOK
CAHIER D'EXERCICES

NAME/NOM Cole Shanks

SUBJECT/SUJET ELEC 315

ASSEMBLED IN CANADA WITH IMPORTED MATERIALS
ASSEMBLÉ AU CANADA AVEC DES MATIÈRES IMPORTÉES

12107

Lecture 0

9/03/19
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Course Overview:

1 midterm → 25%
1 Final → 50%
Assignments throughout → 15%
Participation (Iclicker) → 10%

Japan Solar Workshop → 10-3:00pm Kaiser

Office hours:

Tuesday → 11:00 - 12:00
4:00 - 5:00

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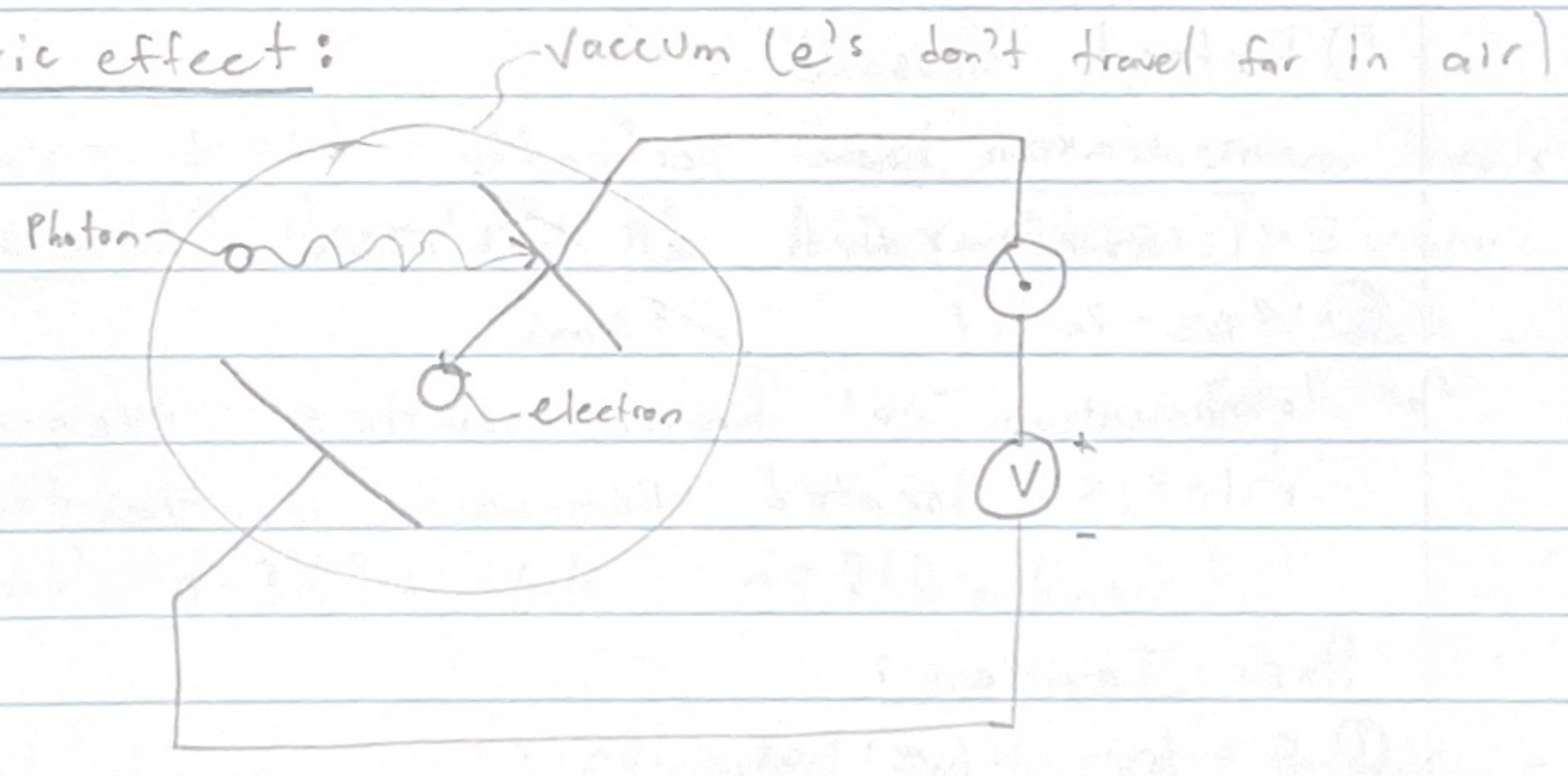
Lecture 1

Photoelectric effect:



Conservation of energy: energy of incoming photon = energy for electron to get out + kinetic energy for the electron

$KE_{Max} = -e \cdot \Theta + h\nu$

Plank's constant
Frequency

Photons:

Energy $= h\nu$
(Momentum) $p = \frac{h}{\lambda}$

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Lecture 2

Conservation of energy: (assuming perfect collision

Photon (energy) = work function + kinetic energy
- we use voltage to slow down approaching electrons

$\therefore$ Photon (energy) = work function + applied voltage
(at the point where current cuts off)

Heisenberg Uncertainty Principle:

① Perfect sinusoid
- momentum known perfectly
- $(-\infty, \infty)$ can't be localized to a point/region

② Wave Packet
- momentum not known (multiple frequencies)
- $(-x, x)$ located somewhere in the region X

Basic Equations:

① $E = h\nu$ (ν) Frequency
(h) Planck's constant

② $\lambda = \frac{h}{p}$

$\sin(kx - \omega t)$ | $k = \frac{2\pi}{\lambda}$ | $\omega = 2\pi f$ | $v = \lambda f$

Kinetic energy:

$KE = \frac{p^2}{2m}$ | $KE = \frac{h^2}{2m\lambda^2}$ | $KE = \frac{-\hbar^2}{2m\psi} \cdot \frac{d^2\psi}{dx^2}$

Shrödinger Equation:

$$i \cdot \hbar \cdot \frac{d\psi}{dt} = \frac{-\hbar^2}{2m} \cdot \frac{d^2\psi}{dx^2} + U \cdot \psi$$

$$E(n) = \frac{n^2 \pi^2 \hbar^2}{2mL^2}$$

6/19

EC

Lecture 3

$$\hbar = \frac{h}{2\pi}$$

(More confined → more discrete)

$\boxed{\text{1D Confinement}}$: $E(n) = \frac{n^2 \pi^2 \hbar^2}{2mL^2}$

(less discrete energy levels)

$\boxed{\text{2D Confinement}}$: $E(n_x, n_y) = \frac{h^2}{8m}\left(\frac{n_x^2}{x_0^2} + \frac{n_y^2}{y_0^2}\right)$

Atomic Orbitals:

$n=1$ (s orbital) $n=2$ (P orbitals) $n=3$ (D orbitals)

(Degrees of degeneracy) = (# of wave functions @ specific energy level)

Lecture 4

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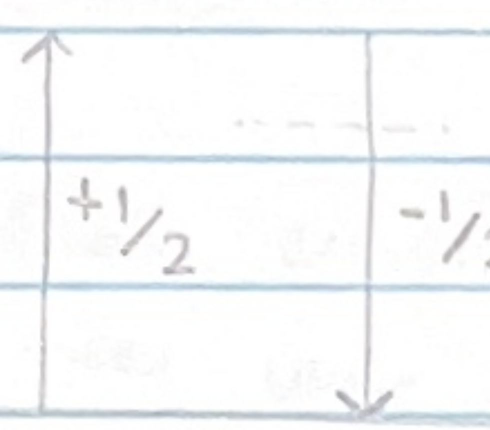
Covalent Bonding: (Bringing two H atoms close together)
- Energy levels split into new more levels
- Solid structure of many atoms can start to have a continuous looking number of energy levels (why solar cell can absorb anywhere)

Electron Spin:



- Quantized (up or down)

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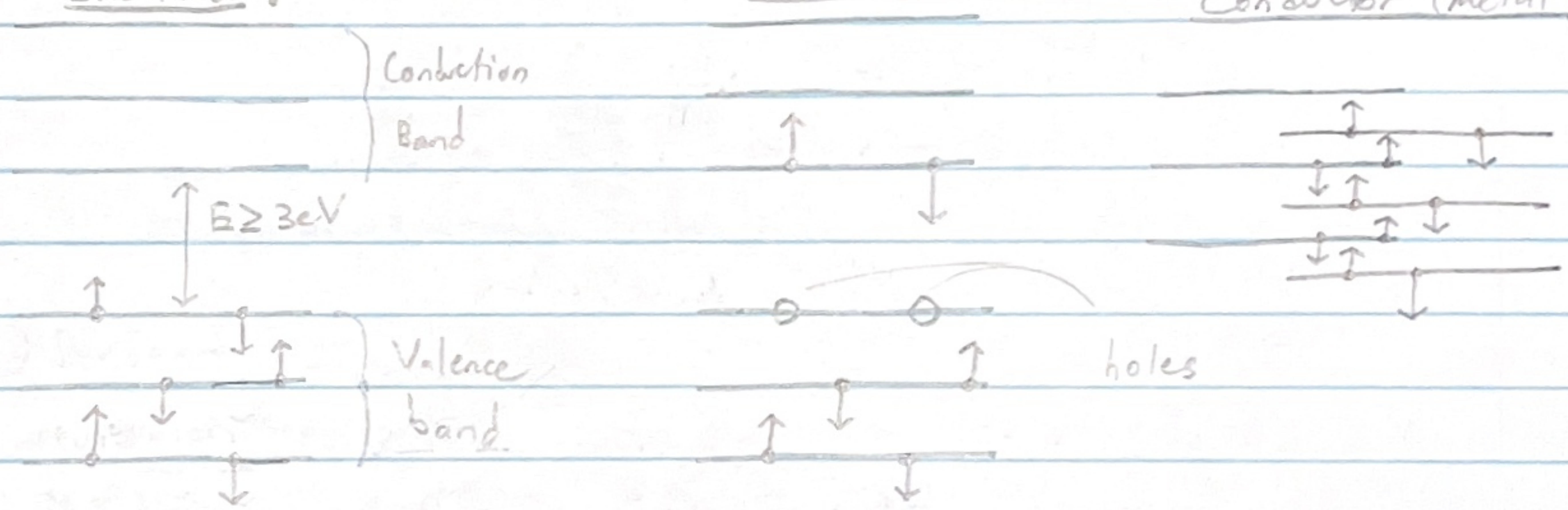
Lecture 5

(solids and Semiconductors)
SLIDE SET

Insulator: **Semi Conductor:** **Conductor (metal):**



$\boxed{Q6\ c\text{-}d}$ (6-c-d) total energy = kinetic energy
$\boxed{Q8g}$ Assume $n_x = n_y = n_z = 1$ (ground state) assume material is silicon

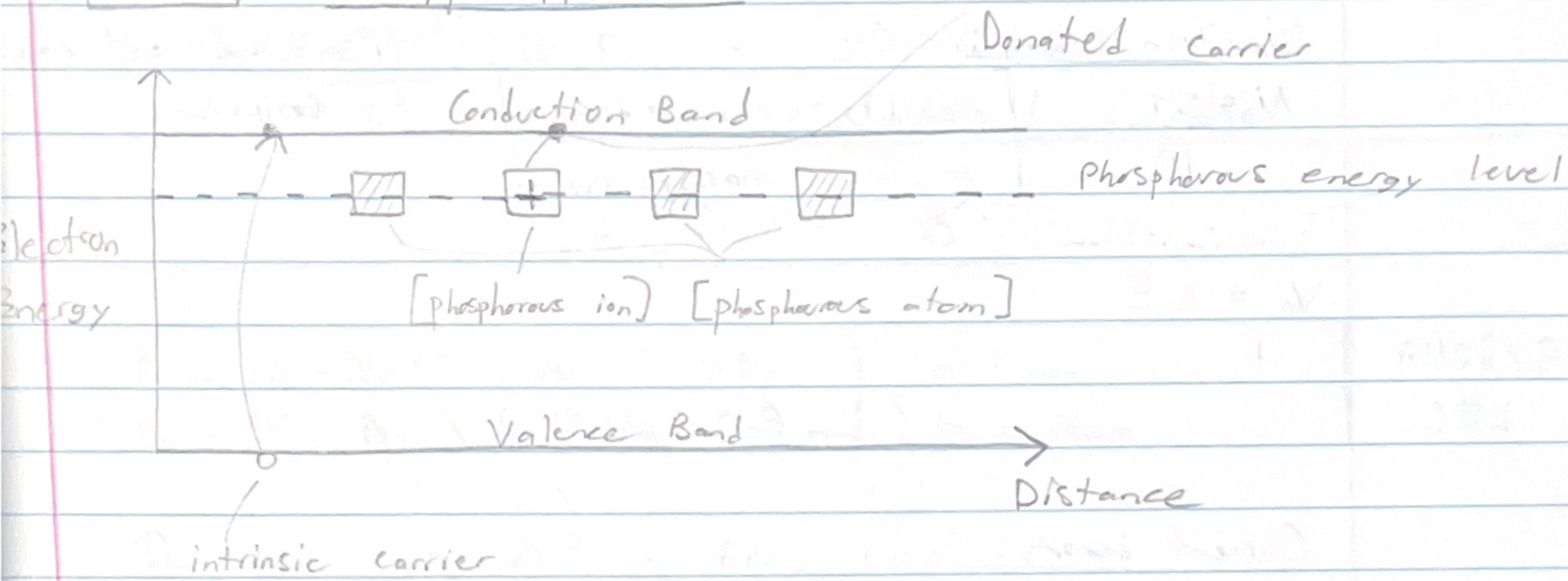
Polycrystalline:
Grain boundaries non-conductive

$\boxed{SS11}$ i subscript means intrinsic ie: undoped

$n_i = p_i \longrightarrow$ # holes in valence band
$\hookrightarrow$ # e's in conduction band

Lecture 6

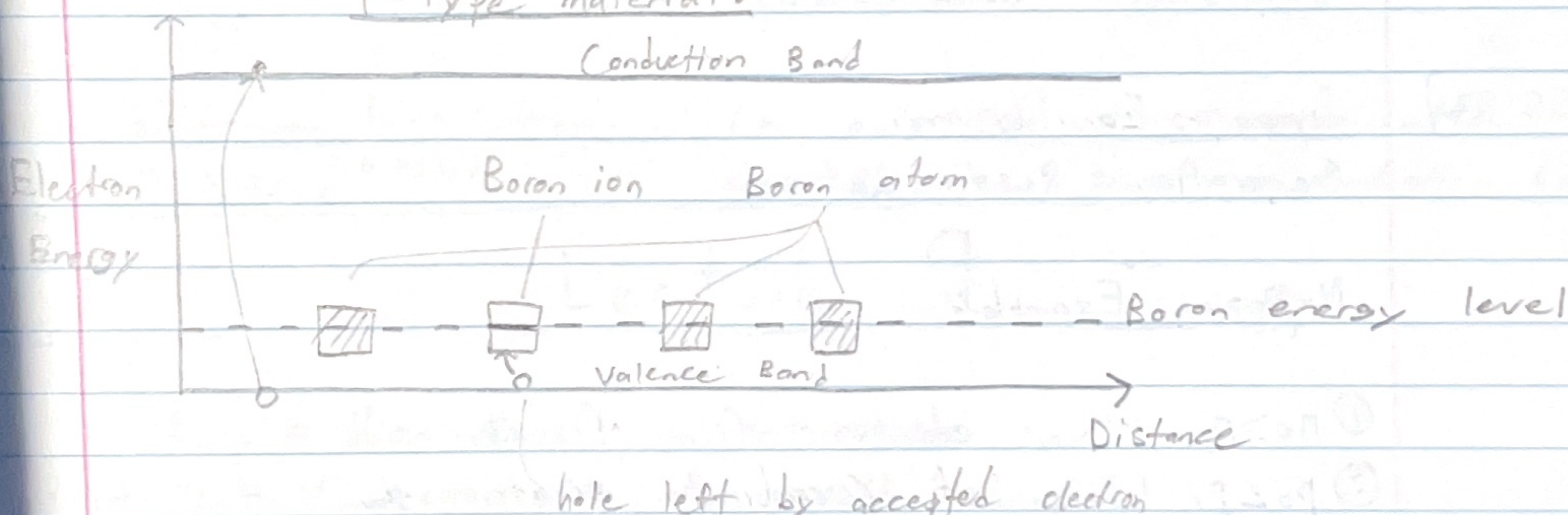
SS 15 **n-Type Material:**



Electron effective mass:

$M_0 = 9.1 \times 10^{-31}$ kg [Free electron mass]

P-Type material:



Current:

$J = \sigma E$ (Current density = Conductivity • Electric field)

What effects Conductivity:

1. time between collisions
2. electron mobility (effective mass)
3. # of carriers per unit volume

Current = $\frac{L \cdot A \cdot n_o \cdot q_e}{T}$ where: $\frac{L}{T} = V_e$

Electron Mobility:

$N = \frac{eT}{m}$ [mobility = $\frac{e_{charge} \cdot time}{mass_{effective}}$]

T = time between collisions

$V_e = NE$

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Lecture 7

Current density:

$J = e\mathcal{E}(n_o N_e + p_o N_h)$

where: n_o = electron density in conduction band

p_o = hole density in valence band

N_e = electron mobility

N_h = hole mobility

SS 52

Dynamic Equilibrium:

Generation = Recombination

N-Doping Example:

1. $n_o > n_i$ (Donor electrons from Phosphorus)
2. $p_o < p_i$ (Rate of recombination greater than at intrinsic)

SS 60

Rate of Generation: [@ Equilibrium] R=G

$G = f_g(Temp)$

Rate of Recombination:

$R = f_r(Temp)n_o p_o$

$n_o p_o = n_i p_i$

$\therefore \boxed{n_o p_o = n_i^2}$

Density of States: (3D) [how many states per unit volume at the given energy level (E)]

$$g_c(E) = \frac{(m_e^*)^{3/2}}{\pi^2 \hbar^3}\sqrt{2(E-E_c)}$$

E_c — conduction band edge

Lecture 8

$n_o = N_D - N_A$ (when $N_D > N_A$)
$p_o = N_A - N_D$ (when $N_A > N_D$)
@ Room temperature

Then, use $n_o p_o = n_i^2$ to find n_o, p_o

Counting electrons:

$$n = \int_{CB} g_c(E) \cdot f(E)\, dE$$

where:
n = total # e's in conduction band
$g_c(E)$ = Density of states
$f(E)$ = occupancy probability

Boltzmann Distribution:
$f(e) \approx e^{-(E-E_F)/KT}$

(Can only use this approximation above the fermi level ie: Conduction band)

Lecture 9

N_D = # donor atoms per unit volume
N_A = # acceptor atoms per unit volume

n-doped material:
$n_o = N_D$ (@ room temperature)

P-doped material:
$p_o = N_A$ (@ room temperature)

Couting holes:

$$P_o = \int_{\text{Bottom VB}}^{\text{Top VB}} g_V(E)(1-f(E))\,dE$$

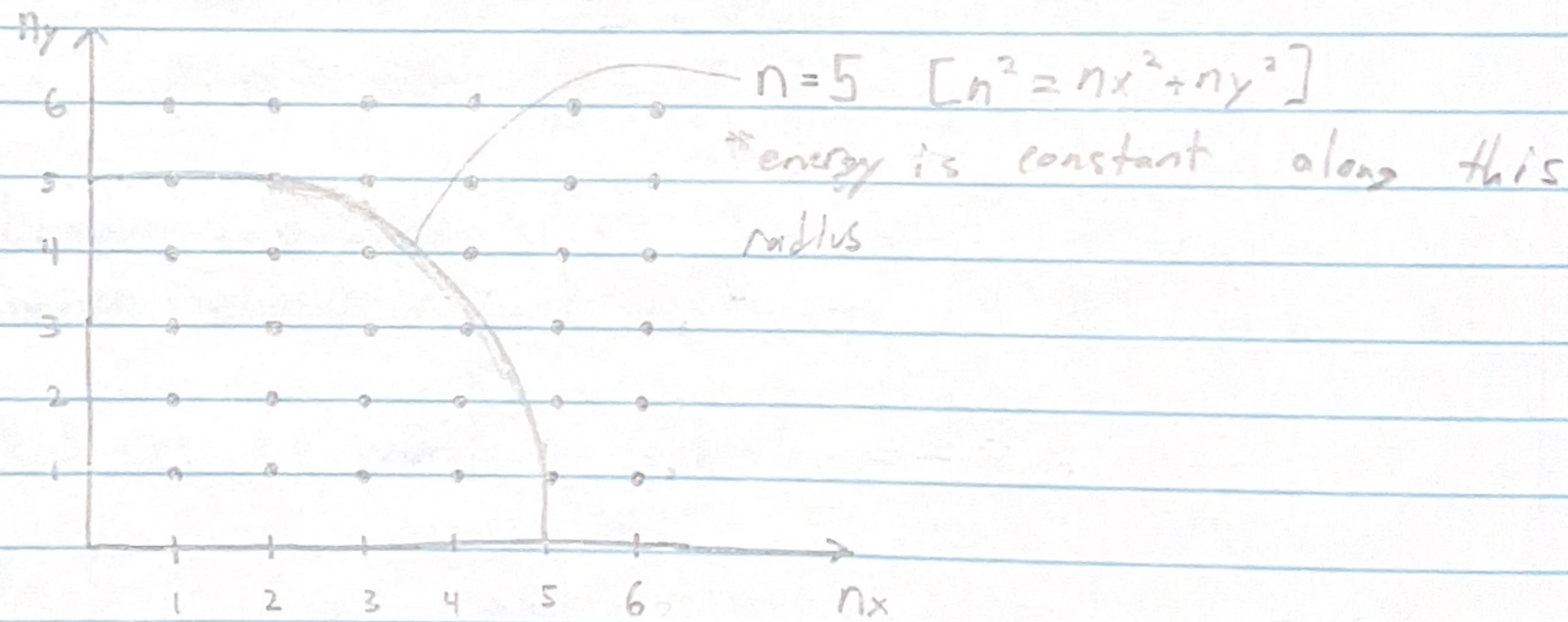
3D box:

$$E = \frac{h^2}{8m}\left[\frac{n_x^2}{L_x^2} + \frac{n_y^2}{L_y^2} + \frac{n_z^2}{L_z^2}\right]$$

2D box: if ($L_z << L_x$ and L_y) and ($L_x = L_y$)

$$E_{2D} = \frac{h^2}{8mL_x^2} \cdot [n_x^2 + n_y^2]$$

Find density of States:



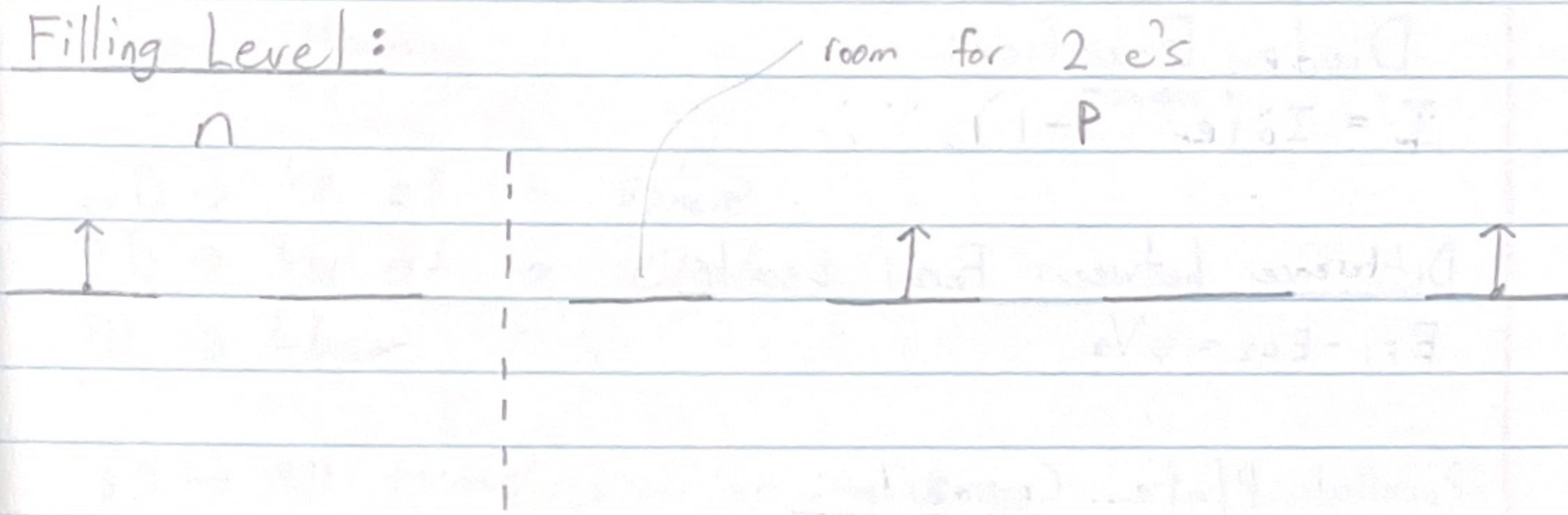
$$N = \frac{\pi n^2}{2}$$

Intrinsic e's:

$n_i^2 = 10^{20}$

Lecture 10

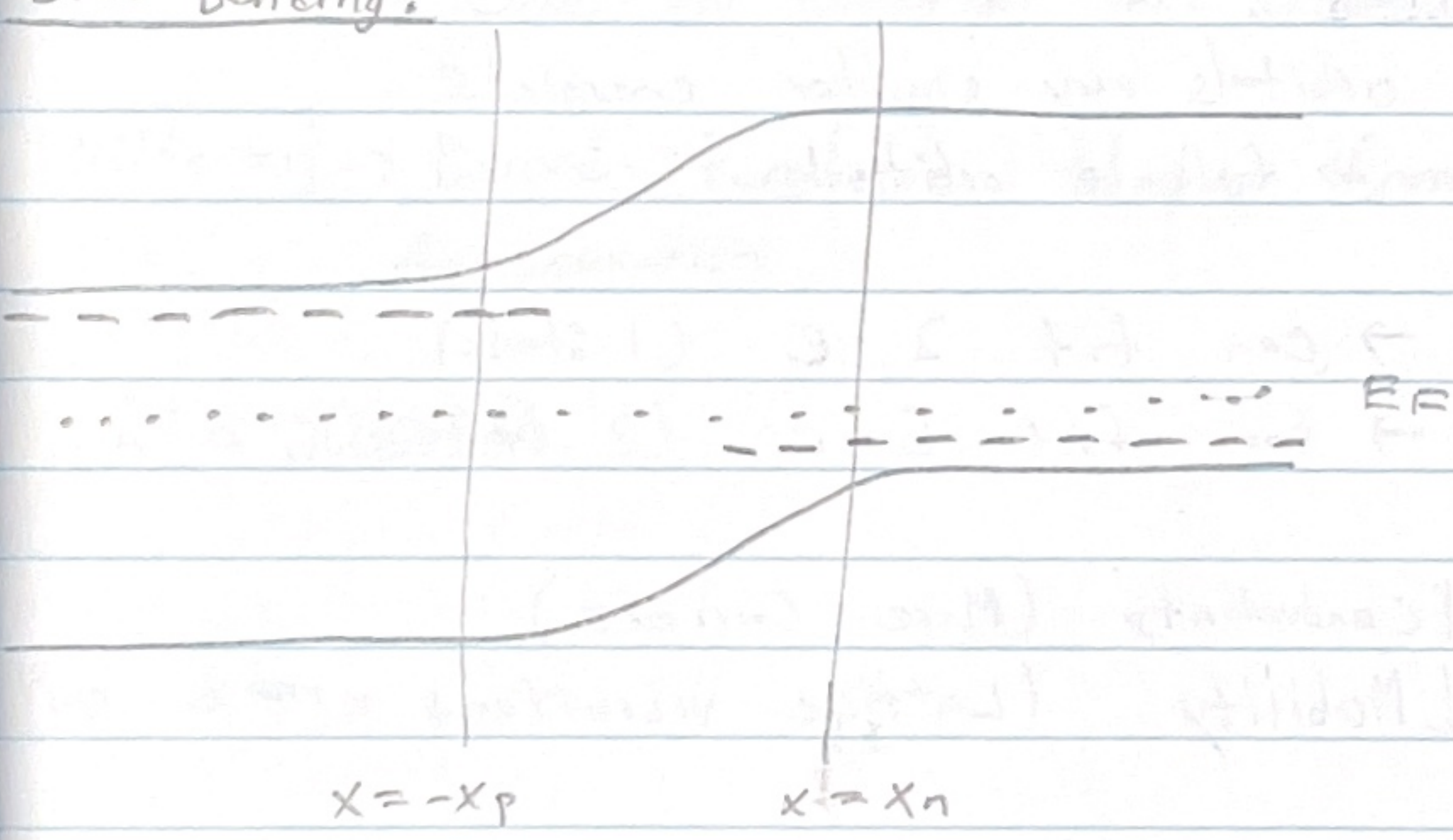
Filling Level:



$E_F = \frac{1}{4}$ $\qquad$ $E_F = \frac{2}{8} = \frac{1}{4}$

Lecture 11

Band Bending:



$\boxed{\text{SS } 173}$ $U(x) \propto \frac{+e\rho}{2\epsilon} x^2$

$\boxed{\text{SS } 179}$ ASN 3 Q3 Derivation

Lecture 12

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Diode Equation:

$I = I_0 (e^{eVa/RT} - 1)$

Difference between Fermi Levels:

$E_{F1} - E_{F2} = eV_a$

Parallel Plate Capacitor:

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

Lecture 13

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Review orbitals:

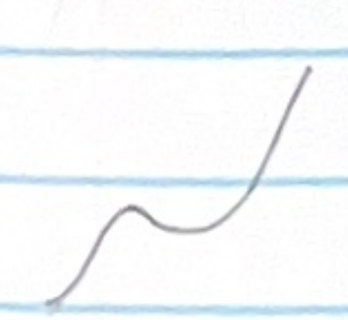
2s and 2p orbitals very similar energies
ie: Berrillyium → full p orbital

S orbital → can fit 2 e (1 state)
P orbital → can fit 6 e (3 states)

Intrinsic Material
- ↑Temp → ↑Conductivity (More carriers)
- ↑Temp → ↓Mobility (Lattice vibrations = more collisions)
- *But $n_i >> N_e$

Doped Material
- ↑Temp → ↓Conductivity
- ↑Temp → ↓Mobility
- $n_0 >> n_i$ so n_0 = Fixed ∴ N_e dominates

↑Temp → ↑Conductivity (Intrinsic Semi-conductor)
↑Temp → ↓Conductivity (Metal)
↑Temp → ↓→↑ Conductivity (Doped Semiconductor)



$\boxed{\text{Midterm}}$ → Derive either 1D, 2D or 3D $g(E)$ on ~~a~~ midterm

3D → 1/8 of a sphere
2D → 1/4 of a circle
1D → Line

3D → All terms similar in size
2D → One term much bigger (ie: small L)
1D → Two terms much bigger (ie small L's)

Silicon Band Gap = 1.12eV

$\boxed{\text{Midterm}}$ → One PN Junction Band diagram (either equ, Frwd, reverse)

$\boxed{\text{Midterm}}$ → Derive Parabolic shape from depletion Approximation

KT = 0.025V

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Lecture 14

** Common Exam Question → SS. 24

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Lecture 15

Polarization:

$P = P_0 e^{-t/\tau} \longrightarrow P(\omega) = \frac{P_0}{1/\tau + j\omega}$

Susceptibility:

$$\chi(\omega) = \frac{P(\omega)}{\epsilon_0 E_0} = \frac{\chi_0}{1/\tau + j\omega}$$

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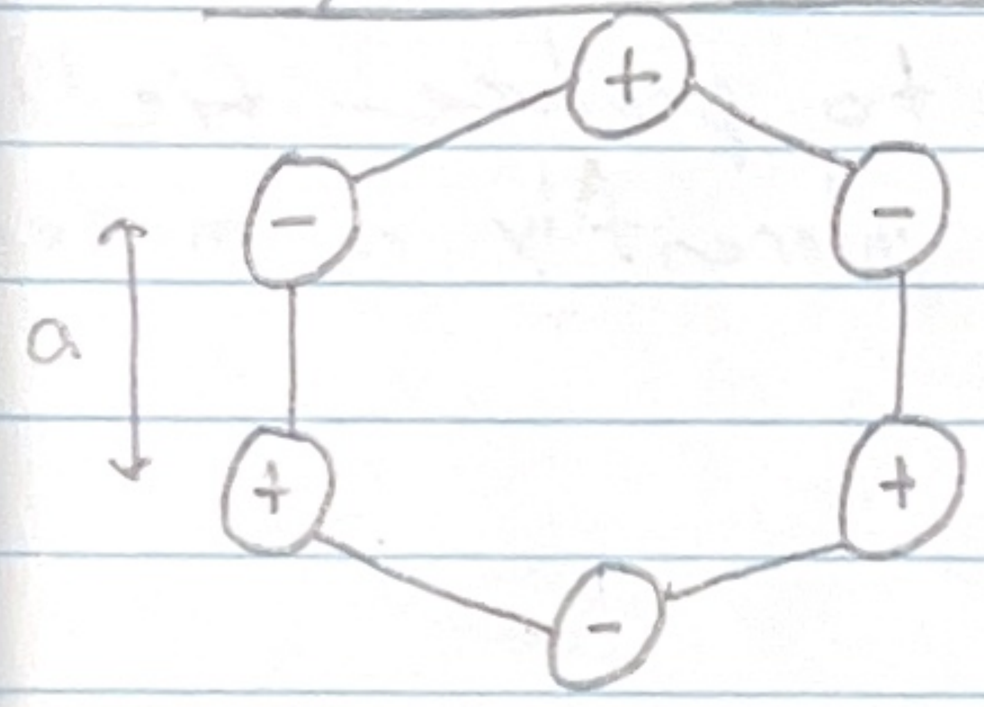
Lecture 15

$\text{Energy} = \frac{1}{2} C V^2$

$eE\lambda \geq E_g$ (For electron to be promoted)

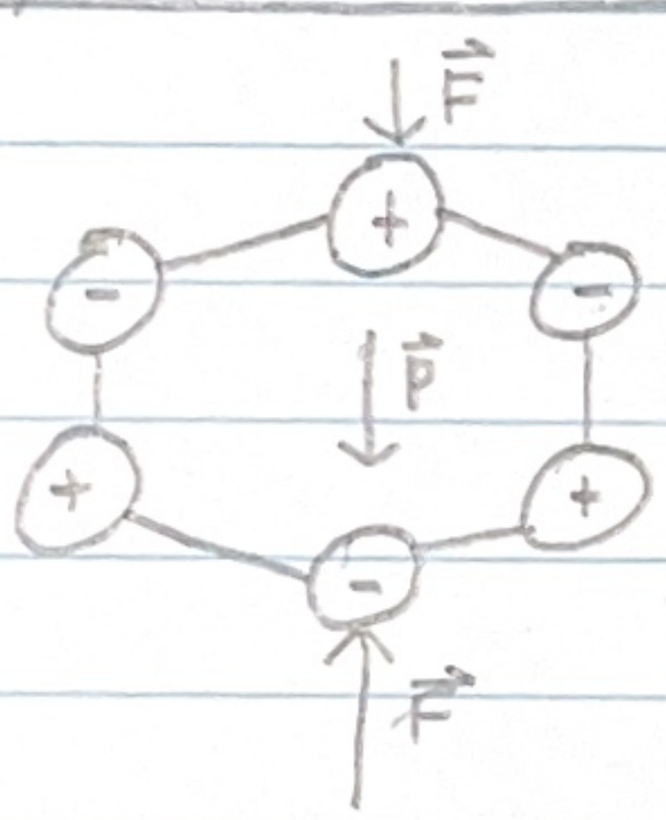
Lecture 16

Crystal Structure A:



- No dipole moment
- $P = 0$

Crystal Structure (B) [compressed]:



- Net dipole moment
- $\vec{P}$ is non-zero

Direct Piezoelectric Equation:

$P_x = d_x T_x$ where:

P_x = Polarization

T = applied stress $\vec{F}/\text{Area}$

d_x = piezoelectric constant

$$\frac{\Delta L}{L} = dE$$

$$E = \frac{\Delta L}{dL}$$

$$\frac{E}{L} = \frac{\Delta L}{dL^2}$$

$$V = \frac{\Delta L}{dL}$$