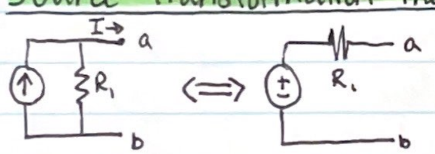
ECE 2000I MASTER PACKET - NOTES:

CH1
- $\vec{E}$ field is same direction as current
- ~~Load~~ anything that excites the circuit + provides a signal
- Four dependent sources - CCVS, CCCS, VCVS, VCCS
- connect VOLTAGE in SERIES, CURRENT in PARALL

CH2
- essential-node: connection point with 3 or more device
- Kirchoffs Current Law: $\Sigma I_{node\ out} = 0$
- Kirchoffs Voltage Law: $\Sigma V_n = 0$
- To find Req: 1) turn off all independent sources
  2) apply test current or test voltage
- To find $V_{Thevenin}$: leave port open
- To find I_{NORTON}: Short circuit across ports

CH3
- Nodal Analysis: a systematic method used to find the voltages at every essential node in a circuit
- Mesh Analysis: method to determine every current in a circuit
- nodes of a grounded end will have a voltage of zero, the other a voltage of the voltage source
- Floating Voltage Source: VS where control variable is unknown
  ↳ add "dummy" variable for missing one
- Nodal analysis works in all circuits, but Mesh only in planar

CH4
Source Transformation Theorem:



- resistor values are the SAME, but the voltage drops across them are NOT

- $V_{Thevenin}$: equivalent voltage across a circuit
  I_{Norton}: equivalent current across a circuit

$R_{eq} = R_N = R_{TH}$

- homogeneity // Scalability: $f(\alpha x) = \alpha f(x)$
  additivity: $f(x+y) = f(x) + f(y)$
- Superposition: the total voltage // current can be found through adding the individual values due to all inputs
  ↳ NOT applicable to power

- Superposition steps
  1) turn off all independent sources, but leave dependent ones untouched
  2) find desired variable by solving the circuit
  3) repeat process for all independent sources
  4) add all results together
  - $V_{out} = \alpha V_{in} + \beta V_{in}$
  - only works with linear quantities (work + pwr aren't linear)
- Maximum Power Transfer Theorem: Q: at what resistance value is the max pwr absorbed?

$$\boxed{I_L = \frac{V_{th}}{R_{th} + R_{Load}}}$$

$$P_L = \frac{V_{Th}^2}{(R_{Th} + R_L)^2} R_L \Rightarrow \boxed{P_{Lmax} = \frac{V_{Th}}{4R_L}}$$ *$R_L = R_{Th}$*

additional previous equations

$\vec{F}_{electric} = \vec{\mathcal{E}} q$	$I(t) = \frac{dQ}{dt}$	$P(t)_{pwr} = \frac{dE}{dt}$	$P_{inst. pwr} = IV = I^2R = \frac{V^2}{R}$
Conductance: $G = \frac{1}{R}$	$R = \frac{\rho l}{A}$ R = resistance, ρ = resistivity, l = length, A = cross. sec. area	$V = IR$	

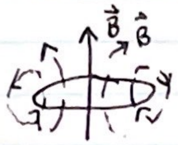
CH5
- Capacitors + inductors store energy
  - capacitors store energy in $\vec{\mathcal{E}}$lectric field
  - inductors store energy in magnetic field

* Capacitance eqn: $\boxed{q = CV}$ q = charge, V = voltage
  - capacitors depend soley on geometry + material properties ☺ + does NOT depend on voltage
- Current through a capacitor: $\boxed{i_c(t) = C\frac{dV_c(t)}{dt}}$ V is continuous

$$\boxed{V_c(t) = V(t_0) + \frac{1}{C}\int_{t_0}^{t} i(x)\,dx} \Leftrightarrow \boxed{V_c(t) = V_c(\infty) + [V_c(t_0) - V_c(\infty)]e^{-\frac{1}{RC}(t-t_0)}}$$

- energy stored in capacitor: $\boxed{W_{cap} = \frac{1}{2}CV_c^2}$ $\boxed{\tau = R_{eq}C_{eq}}$

* Inductance eqn: $\boxed{L = \frac{\Phi}{I} = \frac{\mu_0 N^2 S}{l}}$ l = length of solenoid, N = # of turns, S = surface area of coil



flux linkage: $\boxed{\lambda = N\Phi}$

*L does NOT depend on current ☺

- Faradays Law: an induced current will occur if there is a varying magnetic field
- if an inductors loop is open, ther is NO I_{EMF} but still V_{EMF}
- $\boxed{\oint_c \vec{E}\cdot dl = -\frac{d}{dt}\int_S \vec{B}\cdot d\vec{s}}$ $\oint_c \vec{\mathcal{E}}\cdot dl = V_{emf}$, $\int \vec{B}\cdot ds = \Phi$ $\Rightarrow$ $\boxed{V_{EMF} = \frac{-d\Phi}{dt}}$
- Voltage across an inductor: $\boxed{V_L(t) = L\frac{di_L(t)}{dt}}$

$\boxed{i_L(t) = i(t_0) + \frac{1}{L}\int_{t_0}^{t} V_L(x)dx} \Leftrightarrow \boxed{i_L(t) = i_L(\infty) + [i_L(t_0) - i_L(\infty)]^{[-\frac{R}{L}(t-t_0)]}}$

- energy stored in inductor: $\boxed{W_L = \frac{1}{2}LI_L^2}$ $\boxed{\tau = \frac{L_{eq}}{R_{eq}}}$

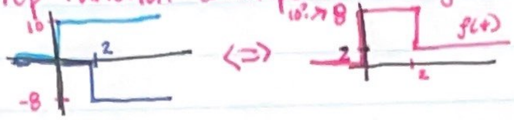
- capacitors use two dialectric plates
- super capacitors use interactions between ions in an electrolytic which allows higher capacitance
  - ↳ must be low voltage devices
- batteries - energy dence device: [hold ↑ energy, ↓ space]
  SC's + capacitors - power dence device [↑ discharge, ↓ voltage]
- Capacitors act as OPEN CIRCUIT in DC condition (V source otherwise)
  Inductors act as SHORT CIRCUIT in DC conditions (I source otherwise)
- Voltage is always continuous in capacitors
  current is always continuous in inductors
- $\boxed{\int_{-\infty}^{t} p(x)dx = w(t)}$

CH 6
- to decrease the transient duration, decrease τ
- natural response: the responce due to the energy initially stored
  forced response: the resut of having an independent source in the circuit aftr switching
- Step Function: $u(t) = \begin{cases} 0 & t<0 \\ 1 & t>0 \end{cases}$ 

for $u(t-t_0) = \begin{cases} 0 & t<t_0 \\ 1 & >t_0 \end{cases}$  + $u(-t) = \begin{cases} 1 & t<0 \\ 0 & t>0 \end{cases}$ 

offset   invert

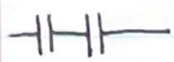
step function example: sketch $f(t) = 10u(t) - 8u(t-2)$



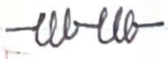
Load Behaviors:

in series:

$R_{eq} = R_1 + R_2$

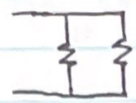


$\frac{1}{C_{eq}} = \sum_{i=1}^{n} \frac{1}{C_i}$

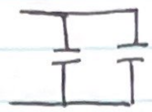


$L_{eq} = L_1 + L_2$

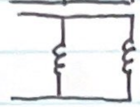
in Parallel:



$\frac{1}{R_{eq}} = \sum_{i=1}^{n} \frac{1}{R_i}$



$C_{eq} = C_1 + C_2$



$\frac{1}{L_{eq}} = \sum_{i=1}^{n} \frac{1}{L_{eq}}$

* resistors + inductors act alike, + opposite to capacitors behavior! *

CH7 $\boxed{v(t) = V_m \sin(\omega t + \phi)}$

↳ time period T: time it takes for signal to repeat itself

↳ frequency: $\boxed{f = \frac{1}{T} = \frac{\omega}{2\pi}}$

↳ radial frequency: $\boxed{\omega = 2\pi f}$

↳ phase shift ϕ: $v(t)$ will LAG by ϕ degrees

- the load in a circuit does NOT change the currents wave type
- in Lin. systems, the output signal will (in steady state) have the same frequency as the input signal
- imaginary number (j): $\boxed{j = \sqrt{-1}}$
- rectangular form: $\boxed{x = \underset{\text{real}}{a} + j\underset{\text{imaginary}}{b}}$

Polar form: $\boxed{x = r\angle\theta}$ r = length / magnitude of complex # ; $\angle\theta$ = angle

$\boxed{x = r\angle\theta = re^{j\theta}}$

- $|x| = r$ + angle $(x) = \theta$

Addition + Subtraction - rectangular form

$x = a + jb$, $y = c + jd$ $\Rightarrow$ $\boxed{x - y = (a-c) + j(b-d)}$

Multiplication + Division - polar form

$x = r_1\angle\theta_1$, $y = r_2\angle\theta_2$ $\Rightarrow$ $\boxed{xy = r_1 r_2 \angle\theta_1 + \theta_2}$ + $\boxed{\frac{x}{y} = \frac{r_1}{r_2}\angle\theta_1 - \theta_2}$

Taking the reciprocal - Polar form

$X = r\angle\theta \Rightarrow \boxed{\frac{1}{X} = \frac{1}{R}\angle{-\theta}}$

Squaring or Taking the Square Root - Polar

$X = r\angle\theta \Rightarrow$

$\boxed{\sqrt{X} = \sqrt{r}\angle\frac{\theta}{2}}$ + $\boxed{X^{\frac{1}{n}} = r^{\frac{1}{n}}\angle\frac{\theta}{n}}$

$\boxed{X^2 = r^2\angle 2\theta}$ + $\boxed{X^n = r^n\angle n\theta}$

Complex Conjugate - Both Rectangular + Polar

$X = a + jb = r\angle\theta \Rightarrow \boxed{X^* = a - jb = r\angle{-\theta}}$

- aditionally: $\boxed{j = 1\angle 90°}$ + $\boxed{\frac{1}{j} = -j = 1\angle{-90°}}$
- angle in class will always be $-180 \leq \theta \leq 180$
- Phasors are NEVER a function of time

★ $\boxed{x(t) = A\cos(\omega t + \phi) \Rightarrow \hat{X} = A\angle\theta = Ae^{j\theta}}$ ★

↳ $y(t) = B\sin(\omega t + \phi) \Rightarrow B\cos(\omega t + \phi - 90°)$ ← MINUS 90°

- phasors must be in cosines ($-90°$ if in sine)
- Eulers Identity: $\boxed{e^{\pm j\theta} = \cos\theta \pm j\sin\theta}$
- the ^ means phasor representation ($\hat{x}$)
- leading is a positive phase shift

  Lagging is a negative phase shift
- in the phasor domaine, the wave is now a vector with a magnitude equal to the peak value of the wave, + an angle that represents the phase shift of the wave.
- Kirchoffs law remains valid in the phasor domain

$\boxed{\sum_{n=1}^{N} \hat{I}_n = \hat{I}_1 + \hat{I}_2 + \ldots + \hat{I}_N = 0}$ + $\boxed{\sum_{n=1}^{N} \hat{V}_n = 0}$

$$\boxed{\hat{V}(\omega) = Z(\omega)\,\hat{I}(\omega)}$$

Impedence (Z): a complex number (NOT a phasor) that is equal to the ratio of the phasor voltage over the phasor current of an element

↳ impedence is only defined for AC signals + measured in (Ω)'s

- in general, impedence is a **function** of **frequency**
- Impedence accounts for resistance + reactants effects
- **Admittance** (Y): $\boxed{Y = \frac{1}{Z}}$ [Similar to how conductance, G, is the inverse of resistance]
  units: siemens

↳ Admittance is NOT a phasor, but a complex number

RESISTORS:

- $\frac{v(t)}{R} = \boxed{i(t) = \frac{1}{R} V_m \cos(\omega t + \theta)}$
- the impedence of a resistor is equal to its resistance

$$\boxed{\hat{V}(\omega) = V_m \angle\theta^\circ} + \boxed{\hat{I}(\omega) = \frac{1}{R} V_m \angle\theta^\circ} \quad \boxed{Y = \frac{1}{Z} = \frac{1}{R} = G}$$

- the **voltage drop** across a resistor is always in **phase** with the **current** through it

CAPACITORS:

$$i_c(t) = C\frac{dv_c(t)}{dt} = C\frac{d}{dt}\left(V_m \cos(\omega t + \theta^\circ)\right)$$

$$\Rightarrow \boxed{i(t) = -\omega C V_m \cos(\omega t + \theta^\circ - 90^\circ)}$$

$$\boxed{\hat{I}(\omega) = \underbrace{j\omega C}_{a}\ \underbrace{V_m \angle\theta}_{b}} \Rightarrow \boxed{\hat{I}(\omega) = j\omega C\,\hat{V}(\omega)} + \boxed{\hat{V}(m) = \hat{I}(\omega) Z}$$

- **Impedence** of a capacitor: $\boxed{Z = \frac{1}{j\omega C} = \frac{-j}{\omega C}}$ $\boxed{\text{admittance: } Y = \frac{1}{Z} = jC\omega}$
- **Current** (I) **LEADS** the voltage (V) by 90° or
  Voltage (V) LAGS the current by 90°

INDUCTORS:

$$V_L(t) = L\frac{di_L(t)}{dt} = -\omega I_m L \sin(\omega t + \theta^\circ)$$

$$\Rightarrow \boxed{v(t) = -\omega L I_m \cos(\omega t + \theta^\circ - 90^\circ)}$$

$$\boxed{\hat{V}(\omega) = \underbrace{j\omega L}_{a}\ \underbrace{I_m\angle\theta^\circ}_{b}} \qquad \boxed{\hat{V}(\omega) = j\omega L\,\hat{I}(\omega) = \hat{I}(\omega) Z}$$

- Impedence of an Inductor: $\boxed{Z = j\omega L}$ admittance: $Y = \frac{1}{Z} = \frac{1}{j\omega L}$
- Current LAGS the voltage by 90° or Voltage LEADS the current by 90°

THE GENERAL LOAD:

$$\boxed{v(t) = V_m \cos(\omega t + \theta_v)} + \boxed{i(t) = I_m \cos(\omega t + \theta_i)}$$

- $Z_{Load} = (V_m\angle\theta_v)/(I_m\angle\theta_i)$
  - ↳ the angle of impedence is equal to the phase difference between the voltage + current

$$\boxed{Z_{LOAD} = R + jX}$$

← imaginary part: reactance

↑ real part: resistance

- Impedence (Z) acts as a resistor + capacitor
  Admittance (Y) acts as an inductor

CH8
- capacitors favor HIGH freq, impede LOW freq
  inductors favor LOW freq, impede HIGH freq
  [favor - short circuit; impede - open circuit]
- we only add phasors in the same frequency, signals with different frequencies solved in time domain
- Average Power:

$$\boxed{P = \frac{V_m I_m}{2}\cos(\theta_v - \theta_i)}$$

recall average: $X = \frac{1}{T}\int_{t_0}^{T+t_0} x(t)\,dt$

- inductors + capacitors do NOT consume power

- Instantaneous Power Equation (phasor)

$$\boxed{P(t) = \frac{V_m I_m}{2}\cos(2\omega t + \theta_v + \theta_i) + \frac{V_m I_m}{2}\cos(\theta_v - \theta_i)}$$

- The effective value for a periodic signal $x(t)$ can be calculated by taking its Root Mean Square

$$\boxed{X_{eff} = X_{rms} = \sqrt{\frac{1}{T}\int_{t_0}^{t_0+T} x^2(t)\,dt}}$$ therefore $$\boxed{P = V_{rms} I_{rms}\cos(\theta_v - \theta_i)}$$

- for maximum power efficency: $\boxed{Z_{Load} = Z_{eq}^*}$ $* =$ conjugate
- Power Efficieny: $\boxed{n = \frac{P_{Load}}{P_{Source}}}$

max PWR

- $\boxed{\omega = 2\pi f}$
- Impedence is minimized when $\boxed{X_L = X_C}$
- Resonance Frequency: the frequency where the total impedence in the circuit is a minimum, or, the total current is a maximum

$$\boxed{f_{res} : \frac{1}{2\pi\sqrt{LC}}}$$

- Shorthand:

$V_{rms} = \frac{V_{max}}{\sqrt{2}}$	$I_{rms} = \frac{V_{max}}{\sqrt{2}}$	$P = \frac{1}{2} RE\{\tilde{V}\tilde{I}\}$

- $$\boxed{P_{Load,MAX} = \frac{|V_{th}|^2}{8R_{eq}} = \frac{|V_{Th\,rms}|^2}{4R_{eq}}}$$

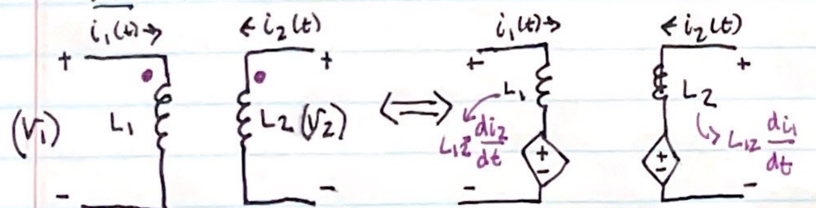
CH9 mutual inductance: $\boxed{L_{12} = \frac{N_2 \Phi_{12}}{I_1}}$

$L_{11} =$ self inductance

$L_{11} > L_{12}$, $\Phi_{11} > \Phi_{12}$ ALWAYS

$L_{12} = L_{21}$

- polarity of induced voltage depends on direction of windings
- The current entering the dotted terminal of one inductor introduces a positive voltage orientated towards the dotted terminal of the other inductor



- V_1 is the SUM of both the induced voltage by the current $i_1(t)$ [self inductance] + the voltage induced by the current i_2 going through L_2 [mutual inductance]

- Passive Sign Convention:

$$\boxed{V_1(t) = L_1 \frac{di_1(t)}{dt} + L_{12}\frac{di_2(t)}{dt}} + \boxed{V_2(t) = L_2\frac{di_2(t)}{dt} + L_{12}\frac{di_1(t)}{dt}}$$

- the polarity of the dependent source will follow the dot
  - ↳ if the dot is at the top of inductor, + sign on V. source is @ top]
- the sign of the induced voltage will depend on whether the current enters or leaves the dot
  - ↳ if I enters dot, Vinduced is POSITIVE
  - ↳ if I leaves dot, Vinduced is NEGATIVE } I + V are separate
- mesh analysis is often the best solution method
- Pinstantaneous between $t_1 + t_2$
  - ↳ $P = V_1(t)\,i_1(t) + V_2(t)\,i_2(t)$

$$\boxed{P = i_1(t_1)L_{12}\frac{di_2(t)}{dt} + i_2(t)L_2\frac{di_2(t)}{dt}}$$

$W_L = \frac{1}{2}Li^2$ add if same dot convention, subtract if opp.

- Coupling coefficient: $0 \le k \le 1$ $\quad \boxed{k = \frac{L_{12}}{\sqrt{L_1 L_2}}}$ for non neg energy: $L_{12} \le \sqrt{L_2 L_1}$
- (Self) inductance: $\boxed{\Phi = \int_S \vec{B} \cdot ds}$ → surface area $\quad L = \frac{\Phi}{I}$
- mutual inductance: $\boxed{\Phi_{12} = \int_S \vec{B}_1 \cdot ds_2}$ $< \Phi_{11}$

"flux through 2 due to 1"

mutual inductance

$$\boxed{L_{12} = \frac{N_2 \Phi_{12}}{I_1} = \frac{\lambda}{I}}$$

$L_{1?} > L_{21}$

$L_{12} = L_{21}$

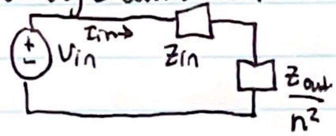
$$\boxed{L = \frac{\Phi_{11} N_1}{I_1}}$$ ← self inductance

$$\boxed{\frac{V_2(t)}{V_1(t)} = \frac{N_2}{N_1} = n}$$ ← N = number of turns

IDEAL TRANSFORMER

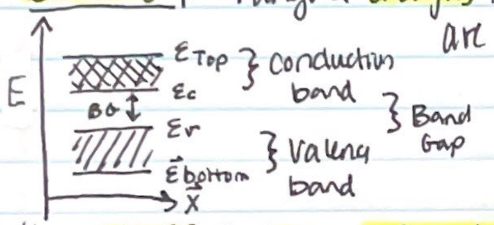
$$\boxed{\frac{i_2(t)}{i_1(t)} = \frac{-N_1}{N_2} = \frac{-1}{n}}$$

- no power lost in ideal transformer
- ideal transformer has Coupling Coefficient (k) = 1
- both primary + secondary have same flux
- transformers are AC-AC converters, Buck converters are DC-DC
- impedence as seen by Vin is affected by Z second coil
  - ↳ Reflected Impedence: $\boxed{\frac{Z_{out}}{n^2}}$ ⇒



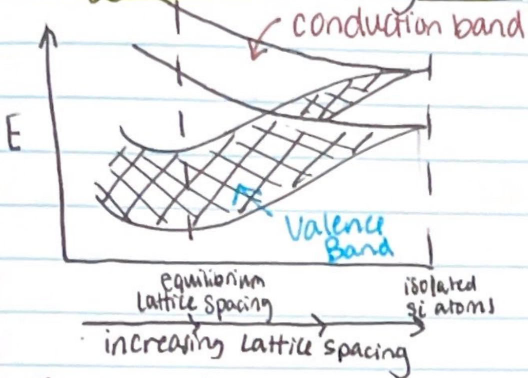
$\boxed{CH10}$

- electron energy levels increase the further orbitals you travel
- **Aufbau Principle**: the lowest energy orbitals are filled first
- **Pauli Exclusion Principle**: there is a max of 2 electrons per orbital + opposite spin
- **Hund's Rule**: equal energy orbitals are filled with 1 electron each in parallel spins before any get a second electron of opp. spin
- **Ionic Bond**: taking an electron from another atom + the resulting ions are held together by electrostatic attraction of opp. charged. ptcls.
- **Constructing band** - made up of anti-bonding orbitles
  valence band - the band of bonding molecular orbitals
- molecular orbital energies in silicon crystals are dependent on bond length
  ↳ less spacing + bond length, more intractions
- **Band Gap**: range of energies that electrons within the crystals are unable to obtain



- the LOWER the temp, valence band filled, conduction band empty
  ↳ no electrons in conduction band + cannot carry current from lack of excited electrons in valence band
- "Excited" electron requires Energy ≥ band gap
  ↳ it is NOT a "free" electron bc it cannot leave the crystal entirely
- **Conduction Band** carries current from Excited electrons
  Valence Band carries current from positive holes
  ↳ ↑E for hole, it moves ↓ energy band diagram
  ↳ ↑E for electron, it moves ↑ energy band diagram
- increase carriers, increase conductivity (+ vice versa)
- Concentration of carriers depends on the Energy required for an electron to jump from valence band → conduction band
  ↳ *SMALLER BAND GAP => HIGHER CONDUCTIVITY*
- Conductors like metals have overlapping energy bands + have no band gap

Energy Focused Bonding Model:



- intrinsic Semi-conductor: extreamly pure semi-conductor
  - ⇒ impure atoms negligable
- carrier electricity: electrons traveling due to energy given that breaks bonds
- Electron Carrier: when electrons jump along "holes" from electron(s) that broke off
- carriers in semiconductors: electrons (-) + holes (+)
- Carriers in Pure (intrensic) Semi-Conductors

$$\boxed{n = p = n_i}$$

n = free electron concentration; $p = n^+$ concentration; n_i: intrinsic concentration

- Doping: intentionally introducing impurities to add or remove electrons
  - ⇒ donors: give electrons ; acceptors: take electrons
- "n type semi-conductors": $n > p$ (donor doped)

  "p type semi-conductors": $n < p$ (acceptor doped)
  - ⇒ the larger value, p or n, is majority carrier, + the smaller is the minority carrier
- Recombination: when e^- + hole encounter + cancel out, releasing $\vec{E}$
- Generation: when e^- absorbs $\vec{E}$, producing e^-/hole pair
- @ equilibrium, the rates of recombination + generation are =
- $$\boxed{np = n_i^2}$$
- diffusion: the evenness of the carrier concentration with respect to position
- $$\boxed{F_n = -D\frac{dn}{dx}}$$

  F = particle flux density; D = proportionality constant; $\frac{dn}{dt}$ = particle concentration derivative
- $$\boxed{\vec{F}_{electric} = -q\vec{\mathcal{E}}_{field}}$$
- $$\boxed{J_{N\,Drift} = q\mu_n n \mathcal{E}_x} \quad \boxed{J_{P\,Drift} = q\mu_p p \mathcal{E}_x}$$

  J = drift current density; n = electron concentration; μ_n = electron mobility

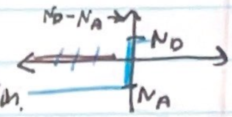
$$\boxed{J = J_n + J_p}$$ ← total Current Density

Einstein Relation:

electrons: $\boxed{\dfrac{D_n}{\mu_n} = \dfrac{KT}{q}}$ holes: $\boxed{\dfrac{D_p}{\mu_p} = \dfrac{KT}{q}}$

T = temp (Kelvin)
K = constant
$\frac{KT}{q}$ @ room temp = 0.0259V

CH 11
- a PN junction is necessary wherever a semi-conductor transitions from a p-type to an n-type
- Doping Profile: the difference between the donor concentration + acceptor concentration.

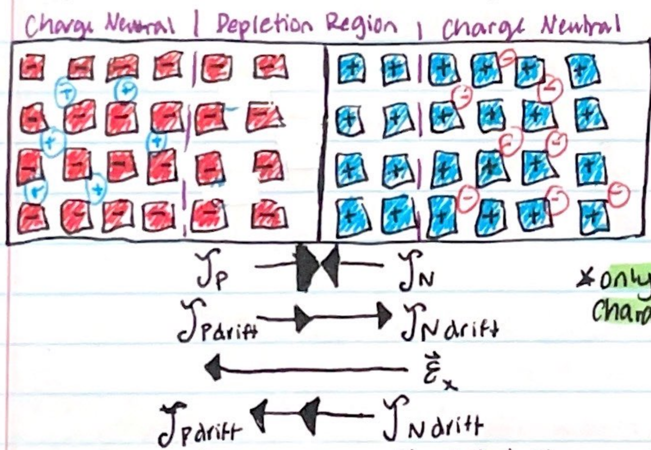


- Diffusion: holes diffuse from p-side to n-side while electrons diffuse from n-side to p-side

Depletion Region

- region of reduced majority carrier concentration near the junction, as the majority carriers from each side difuse across the junction leaving behind fixed ionized dopant atoms + that then results in a charge imbalence
- this charge imbalency creates an $\vec{E}$ field, + creating drift currents that pull e^- back to n side, + holes back to p-side of junction
- As more carriers difuse across the junction, the drift currents increase with $\vec{E}$ field UNTIL equilibrium is reached

Equilibrium Situation inside a pn Junction:



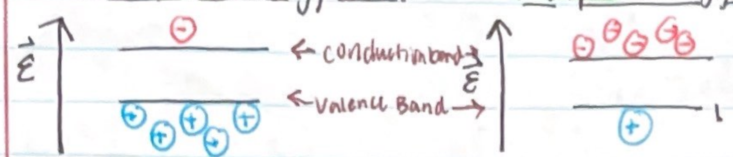
boxes are ionized dopant atoms:
[+] - donors
[−] - acceptors

*only majority characters are important

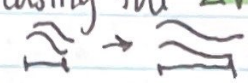
- in the depletion region, the total charge concentration is dominated by ionized dopant atoms $\boxed{\rho = q(p - n + N_D^+ - N_A^-)}$

ρ = total charge density
$N_D^+ + N_A^-$ = concentration of ionized donors + acceptors

- P doped Energy Band   N doped Energy Band



- Increasing the ΔVoltage increases band gap width



Rest of Ch 11-13 Not included