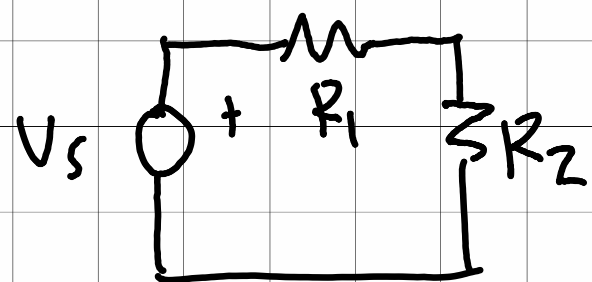
ME133 Lecture 4 1/13/2022

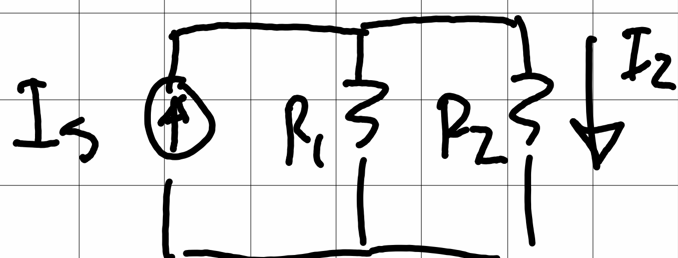
Last time:

- Series & Parallel circuits



$$V_2 = \frac{R_2}{R_1 + R_2} V_s$$

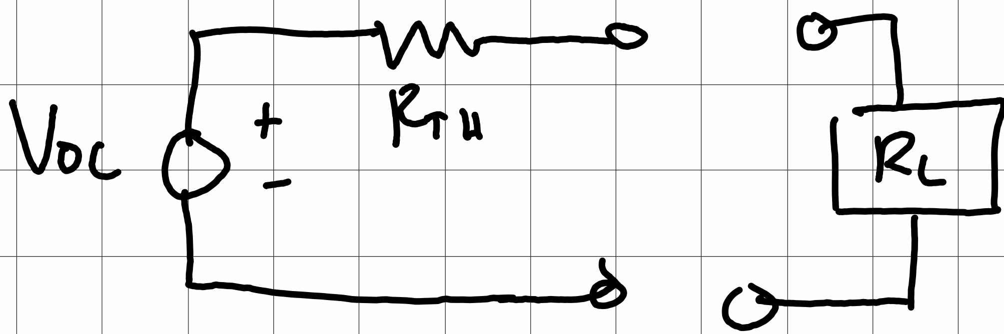
Voltage divider



$$I_2 = \frac{R_1}{R_1 + R_2} I_s$$

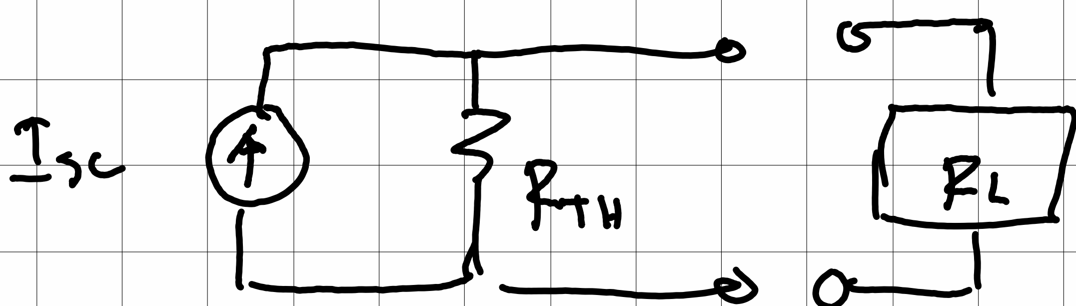
Current divider

Thevenin Eq:



$$V_L = \frac{R_L}{R_{TH} + R_L} V_{oc}$$

Norton Eq.



$$I_L = \frac{R_{TH}}{R_L + R_{TH}} I_{sc}$$

Today:

- AC Circuits
- Transformer

] CH. 2

Today [
- Semiconductor physics
- Junction Diodes

- Bipolar
- Field effect

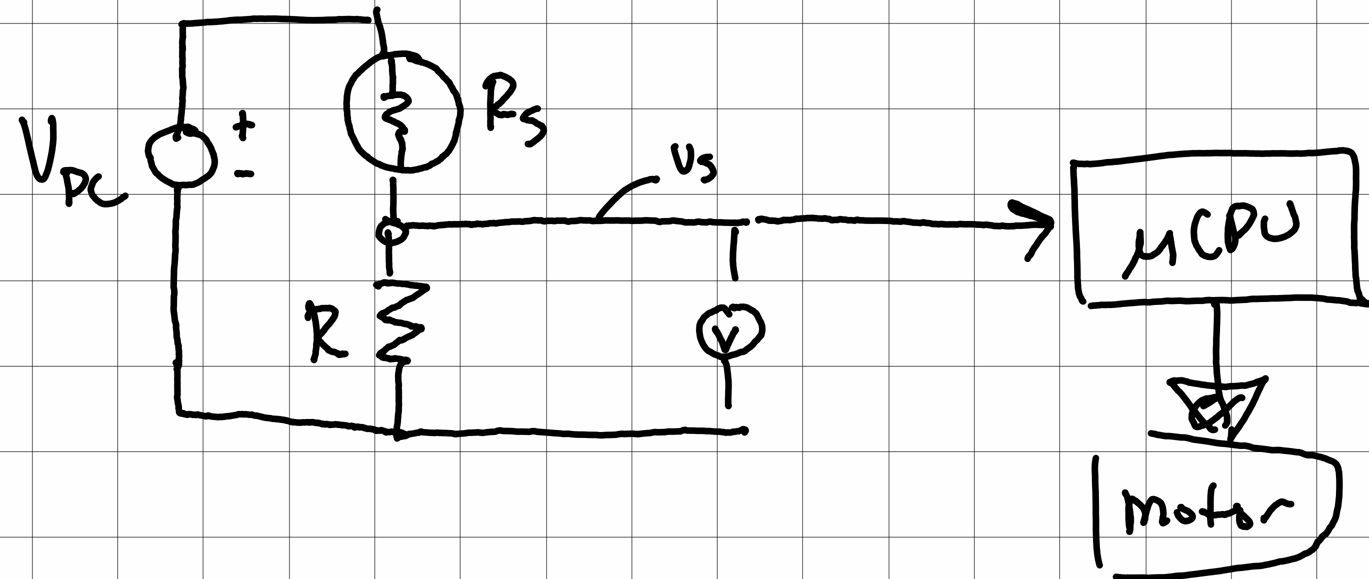
> transistors

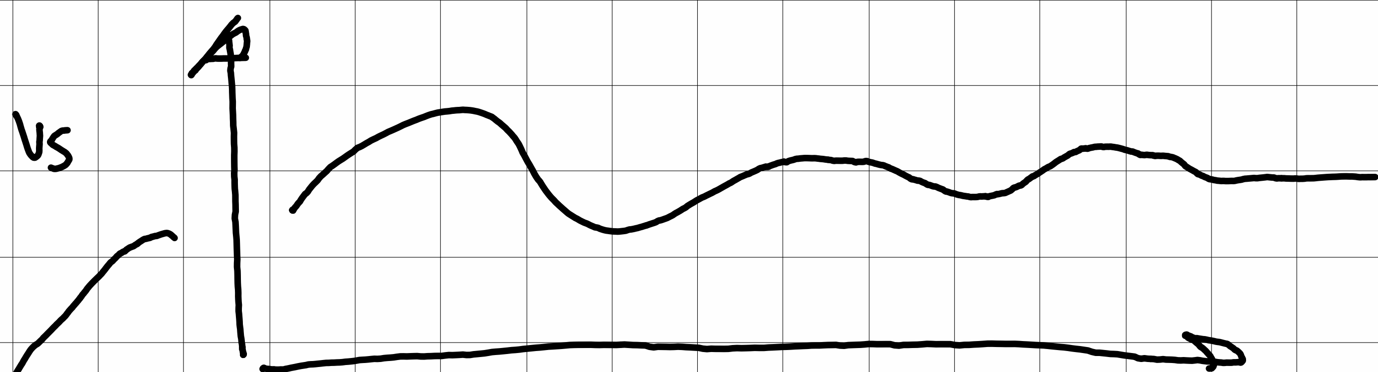
AC circuits

Why?

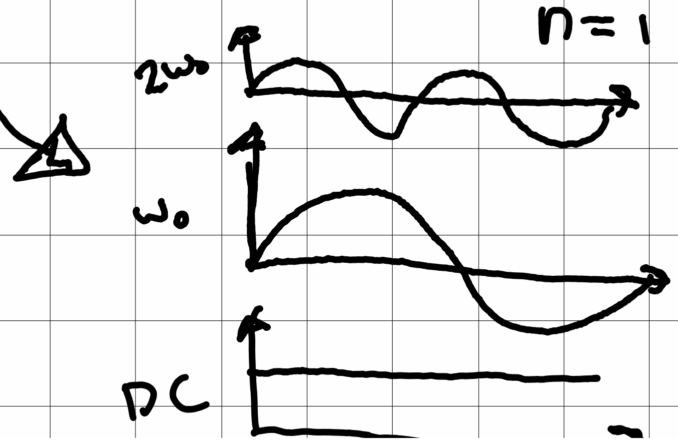
- most electrical signals are not pure DC ($V = C$)
  → even when your system is powered by DC.

Example:



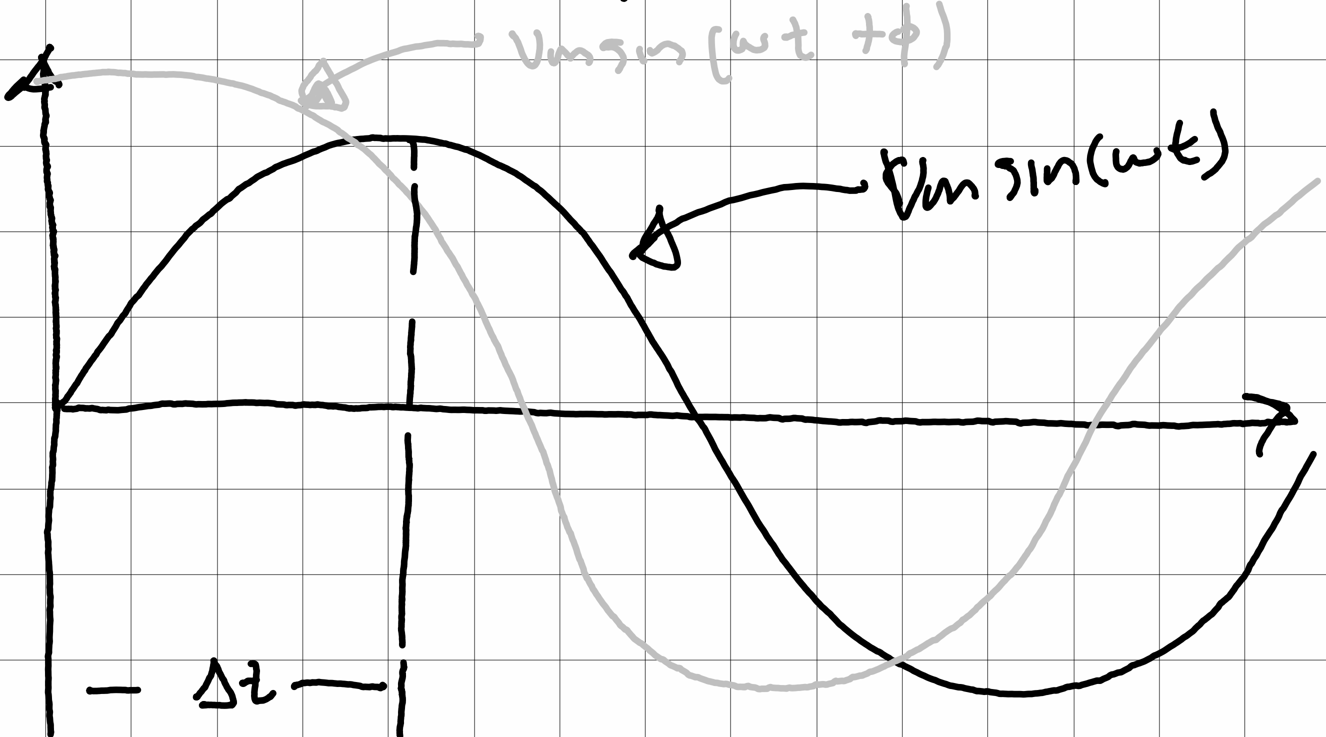


$$V(t) = C_0 + \sum_{n=1}^{\infty} C_n \cos(n\omega_0 t + \phi_n)$$



one freq. is AC!

$$\underbrace{V(t) = V_m \sin(\omega t + \phi)}_{\text{AC signal}}$$



$$\phi = \omega \Delta t \quad (\text{rad})$$

- AC power is more efficient for transmission over long distances

- AC power is easy to generate with rotating machinery

- AC power is easy to use for driving rotating machines

Let's focus on steady state analysis: current & voltage of every element are AC signals with the same freq. as the excitation freq.

Euler's formula:

$$\underbrace{e^{j(\omega t+\phi)}}_{\text{phasor}} = \cos(\omega t+\phi) + j\sin(\omega t+\phi)$$

$j = \sqrt{-1}$

phasor

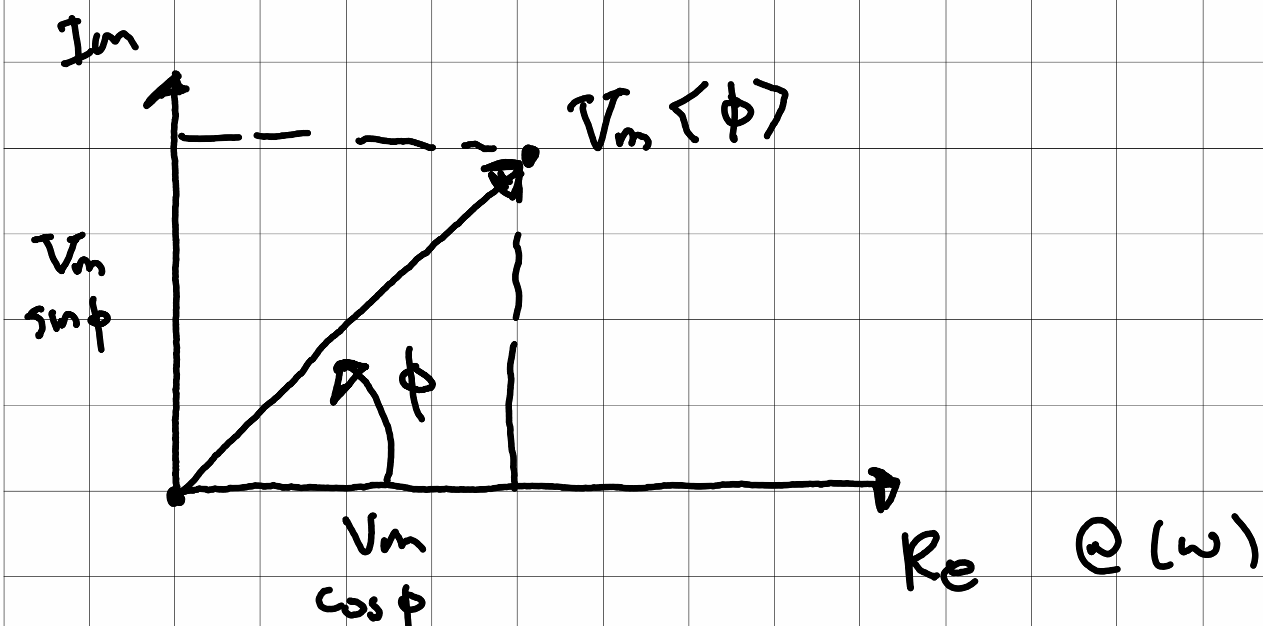
phase vector represents sinusoids

We can treat $\bar{V}$, I in AC circuits as phasors:

$$\bar{V} = \bar{V}_m e^{j(\omega t + \phi)} \quad \text{(exp. form)}$$

$$= \bar{V}_m \angle \phi \quad \text{(phasor form)}$$

$$= \bar{V}_m \left[\cos(\omega t + \phi) + j \sin(\omega t + \phi) \right]$$



Ohm's law can be generalized for AC:

$$V = R I$$

$$V = Z I$$

impedance

in general impedance is a function of freq.

$$Z = f(\omega)$$

Resistor: $V = RI$

$Z \equiv R$ (no freq. dependence)

Inductor: $V = L\dot{I}$

$$I = I_m e^{j(\omega t + \phi)}$$

$$\dot{I} = j\omega I_m e^{j(\omega t + \phi)}$$

$$\therefore V = L\dot{I} = Lj\omega I_m e^{j(\omega t + \phi)}$$

$$\therefore V = L\dot{I} = Lj\omega \underbrace{I_m e^{j(\omega t + \phi)}}$$

$$= \underbrace{Lj\omega}_{Z_L} \, I$$

$$Z_L = j\omega L$$

$$e^{j\phi} = \cos(\phi) + j\sin(\phi)$$

if $\phi = 90°$

$$e^{j(90°)} = 0 + j$$

$$\boxed{\therefore Z_L = \omega L \langle 90° \rangle \qquad \frac{V}{I} = Z_L}$$

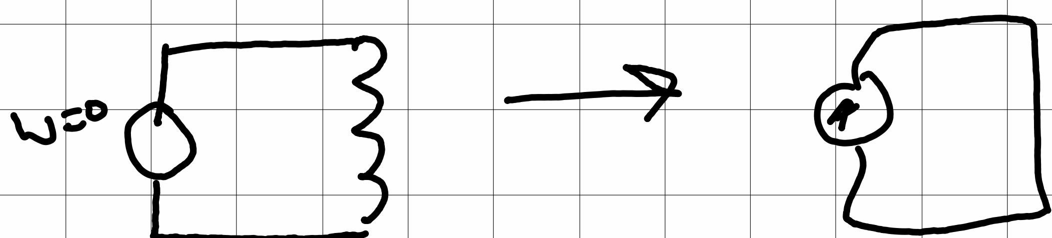
Voltage leads current by 90°

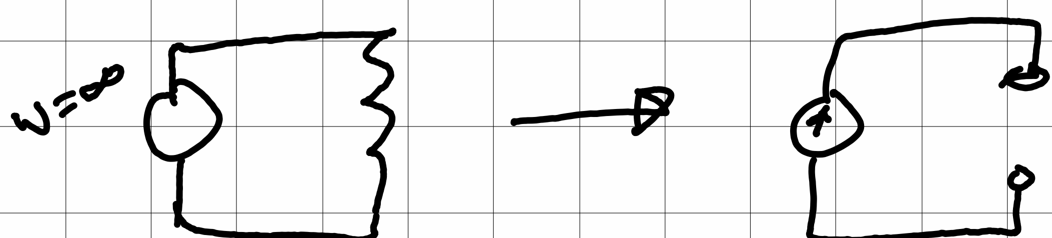
$$Z_L = \omega L \angle 90^\circ$$

$\omega \to 0$ (DC) $\quad Z_L \to 0$

inductor acts like a short circuit at low frequency.

$\omega \to \infty \quad Z_L \to \infty$ (open circuit)





Capacitor:

$$I = C\dot{V} = C\frac{dV}{dt}$$

$$V = V_m e^{j(\omega t+\phi)}$$

$$\Rightarrow \dot{V} = j\omega V_m e^{j(\omega t+\phi)}$$

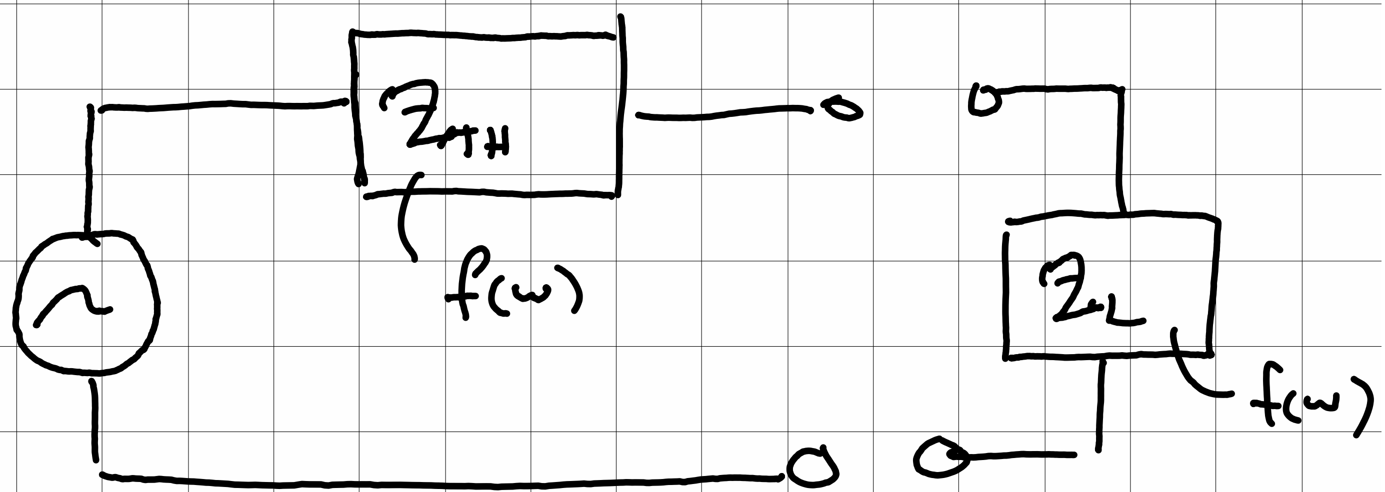
$$= j\omega V$$

$$I = j\omega C V$$

$$V = \underbrace{\frac{1}{Cj\omega}}_{Z_C} I$$

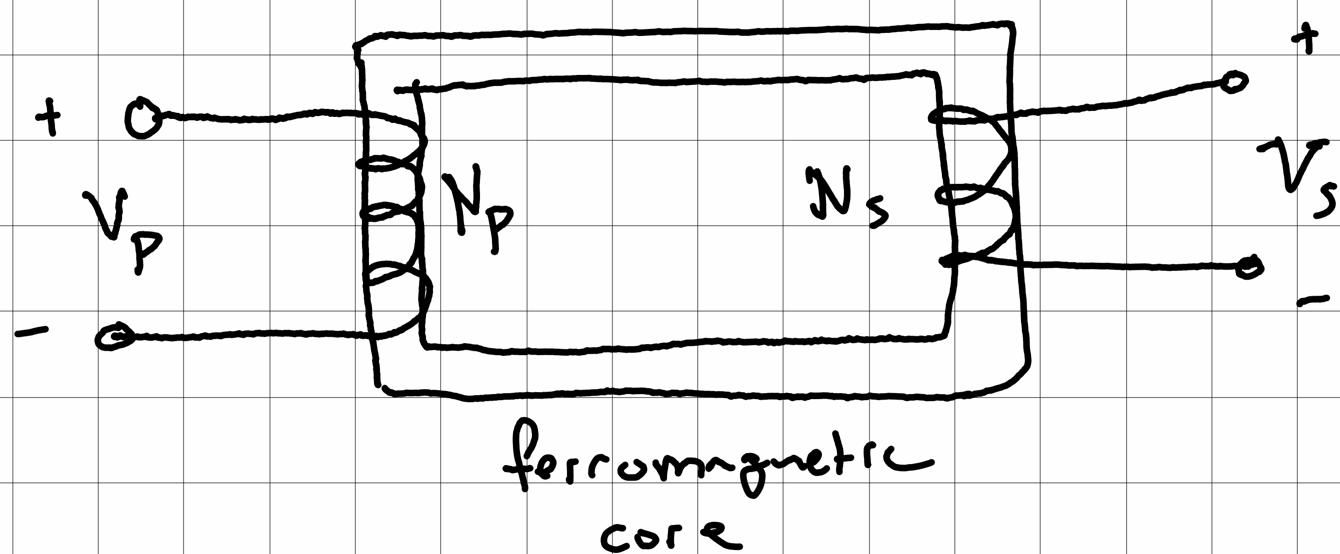
$$\boxed{\begin{gathered} Z_C = \frac{1}{\omega C}\angle(-90^\circ) \\ \\ V = Z_C I \end{gathered}}$$

Everything we discuss (Northon & Thevenin) applies to AC circuits



Transformers

- Changes the <u>relative</u> amplitude of voltages/current in AC circuit



$$\frac{V_p}{N_p} = \frac{V_s}{N_s} = -\frac{d\phi}{dt} \leftarrow \text{flux}$$

$$\boxed{\therefore\ V_s = \frac{N_s}{N_p} V_p}$$

like gears in a mechanical system

$N_s > N_p \rightarrow \frac{N_s}{N_p} > 1$ step-up trans.

$N_s < N_p \rightarrow \frac{N_s}{N_p} < 1$ step-down

From conservation of energy:

$$\boxed{P_{in} = P_{out}} \rightarrow \underline{\text{ideal}}$$

$\eta P_{in} = P_{out}$

$$V_p I_p = V_s I_s \rightarrow I_s = \frac{V_p}{V_s} I_p$$

$$\boxed{V\uparrow\ I\downarrow}$$

$$\boxed{I_s = \frac{N_p}{N_s} I_p}$$

CH. 3 Semiconductors

- sensors
- signal processing
- display

Focus: diodes
transistor

Physics

- metals (e.g. conductors) have a large number of weakly bound electrons
- under an $\underbrace{\text{electric field}}_{\text{voltage}}$

these electron flow! → current.

- other materials (e.g. insulators) have valence electrons which are tightly bound

- therefore under an electric field, no current flows

- semiconductors : have properties somewhere in between conductors & insulators

  ex: silicon, geranium

- current-carrying characteristics depend on environmental forces: temp. or light.

- properties of semiconductors can be significantly changed by by **doping** :

  inserts quantities of other elements into the lattice structure of the semiconductor types of dopants:

- **donor**: enhances electron conductivity

  n-type
  (negative)

- **acceptor**: reduces electron conductivity

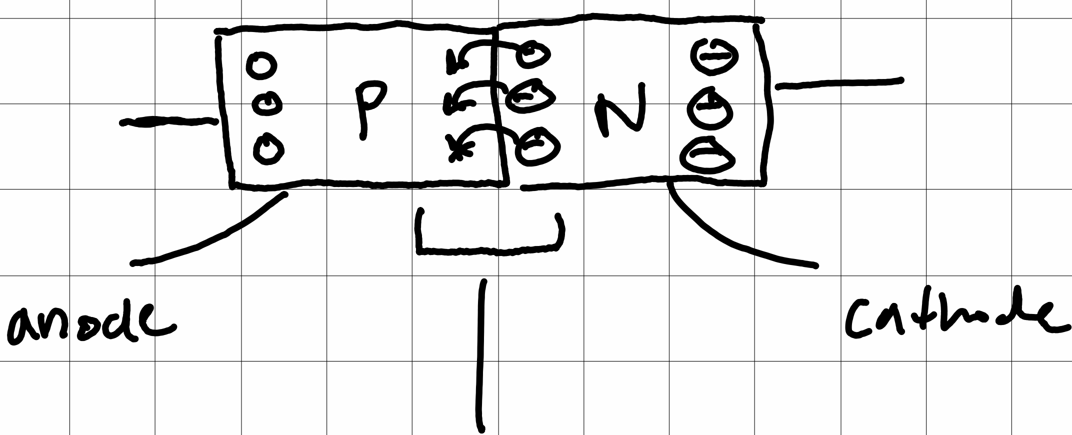
  p-type
  (positive)

The purpose of doping is to control the number of charge carriers

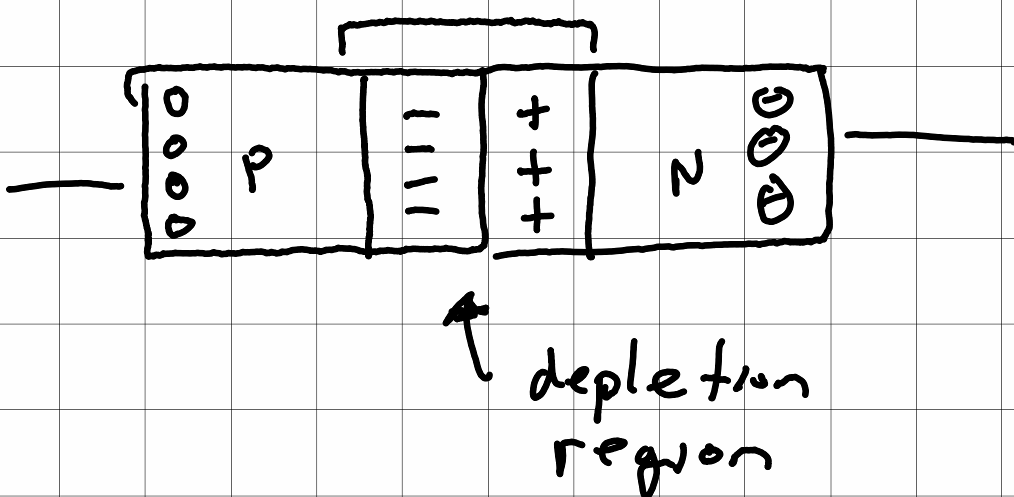
- n-type: charge carrier e^-
- p-type: charge carrier is hole (+)

The interaction of p- & n-type areas forms the basis of semiconductor electronics.

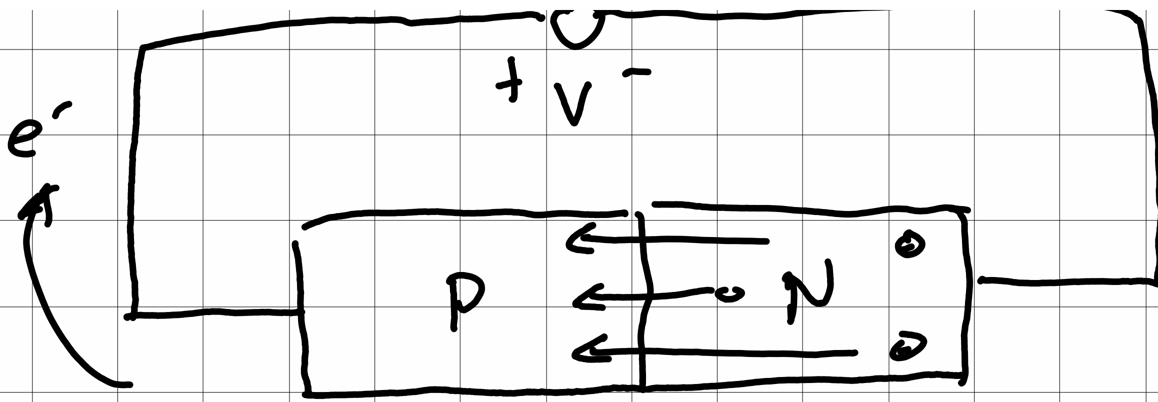
Junction Diode : pn-junction



electrons from cathode diffuse to occupy the holes in the anode



contact potential ~ silicon 0.7 V



forward bias

- positive V on anode
  - V > 0.7 (silicon) overcome the contact potential
- depletion region shrinks
- current flow through!

$$I_D = I_0\left(e^{\frac{qV_D}{kT}} - 1\right)$$