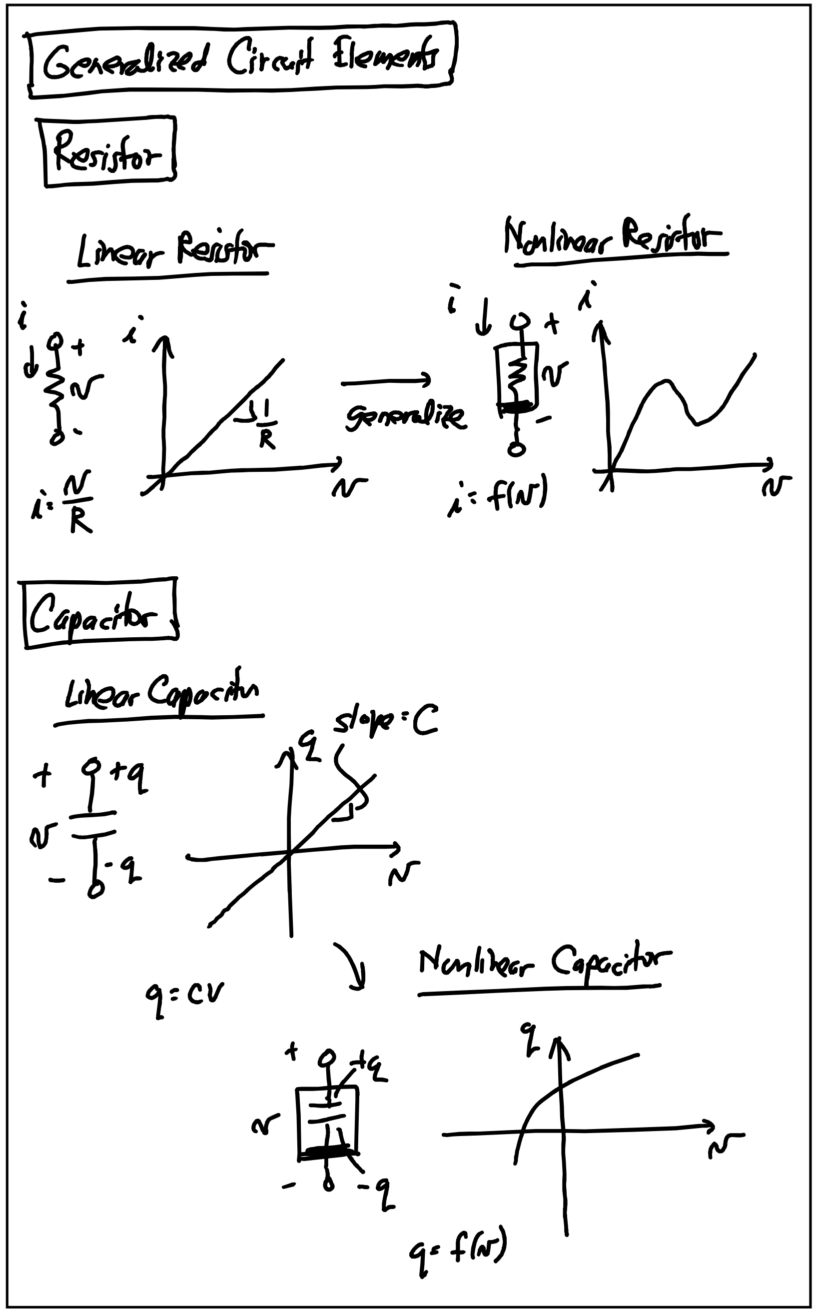
Lecture 10: Semiconductors

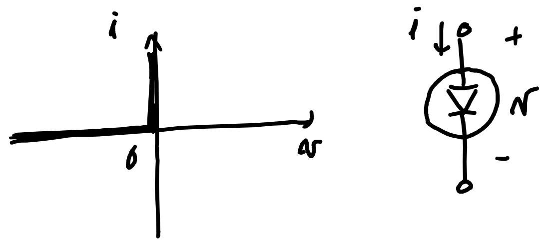
- Announcements:
- HW#4 online and due Friday via Gradescope
- Lab#2 continues into next week
  - Prelab is due at the beginning of lab
- Lab#3 will post on website soon
- ------------------------------------
- Lecture Topics:
  - Generalized Circuit Elements
  - Conductors
  - Insulators
  - Semiconductors
  - Doping
  - Semiconductor Currents
- ------------------------------------
- Last Time:
- Started generalized circuit elements
- Now, continue with this …



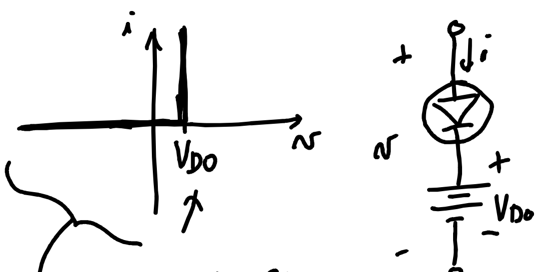
⇒ there are also nonlinear inductors → generally, not seen in low to mid frequency integrated circuits

Example. Diode → several models, all of which represent nonlinear resistors

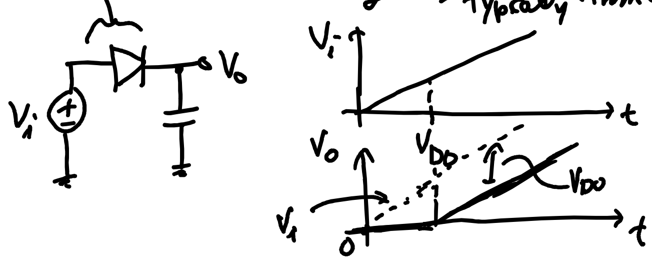
A. Ideal-



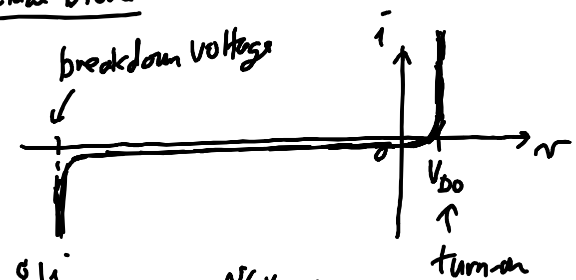
B. Constant V-



"diode on" voltage → typically from 0.5V to 0.7V



C. Actual Diode -



$i = I_S(e^{v/nV_T} - 1)$

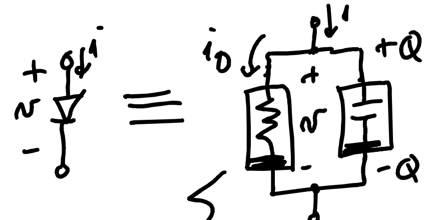
$I_S \triangleq$ saturation current

V_T = thermal voltage = 25mV

n = 1 or 2 ← discrete diode
↑
IC diode

Diode → not only a nonlinear resistor
↳ also includes nonlinear capacitance

a more exact model:



$i_D = f'(v) = I_S(e^{v/nV_T} - 1)$

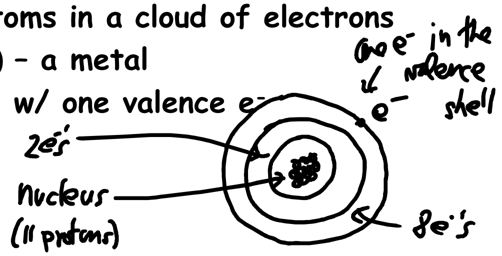
$Q = f''(v) = q\left(\frac{N_A N_D}{N_A + N_D}\right) A W_{d0} \sqrt{1 + \frac{V_R}{\phi_j}}$

$[V_R = -v]$

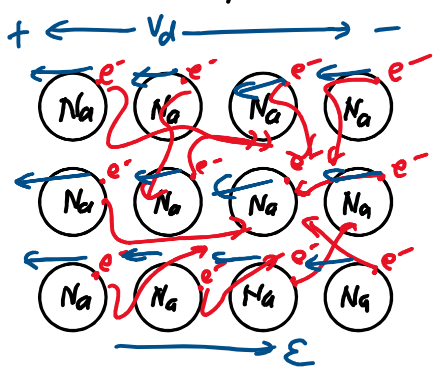
- **Semiconductors**:
- To better understand the physical operation of diodes (and later, transistors), need to understand semiconductors
- Best to describe them in the context of other materials, like conductors and insulators
- **Materials**:
  - ↳ Made up of atoms
  - ↳ In solids, the atoms often bond together in a regular lattice
  - ↳ The atoms in the lattice happiest in a lowest energy state, i.e., with filled orbitals
  - ↳ Go to periodic table supplement

1. **Conductors**:

- Close-packed atoms in a cloud of electrons
- Ex. Na (sodium) – a metal
  - ↳ Alkali metal w/ one valence e^-

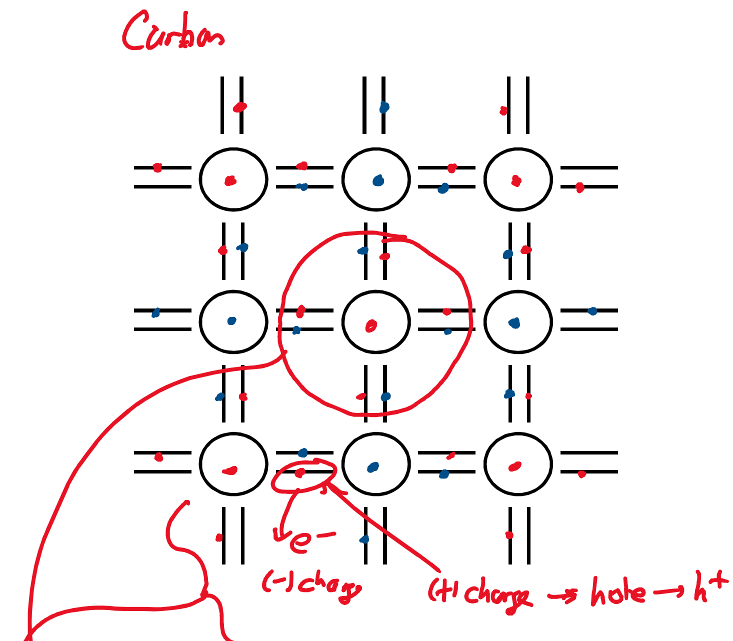


  - ↳ Orbital below valence shell already filled, so e^- can leave and be shared by all atoms in the solid



2. **Insulators**:

- Held together very strongly in a regular lattice by strong covalent bonds
- Lowest energy state when the valence shells of each atom are filled



  - Atom happy w/ an effectively filled valence band, so e^-'s not free to move about
  - An increase in energy can allow an e^- to break free into a higher energy free state in which an electric field can move the e^-
  - For example, high enough temperature generates a free e^- and h^+ pair, each of which is free to move under an applied electric field

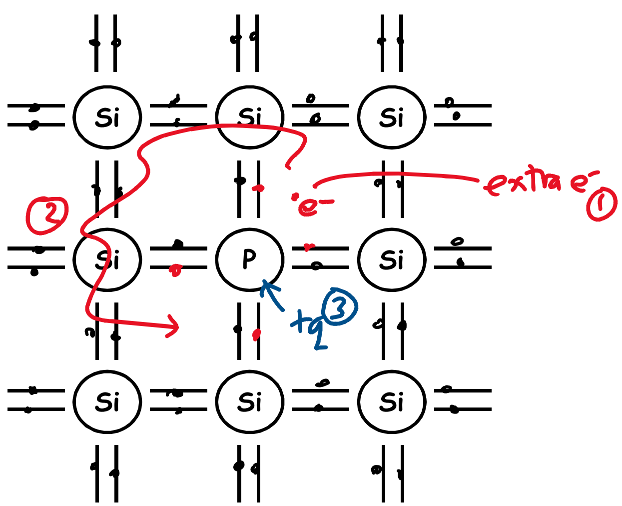
3. Semiconductors:

- Basically the same as insulators, except they require smaller temperatures to free e-s
- For most purposes, they are just like insulators … until they are doped, at which point they become like metals

- Doping:
- A semiconductor converts to a conductor when one adds certain impurities that substitute for Si atoms
- Type types of substitutional impurities
  - Donors
  - Acceptors

1. Donors:

- Elements with 5 valence e^-'s, e.g., phosphorous (P) and Arsenic (As)



1 – 4 e^-'s from P contribute to covalent bonds, leaving one extra e^-

2 – extra e^- can now move around

3 – When e^- moves away from the donor atom (in this case, P), the donor atom effectively represents a (+) static charge

- The larger the concentration of donors N_D, the greater the number of e^-'s available to generate the e^- cloud, i.e., the better the conductor

$n = \#$ of free e^-'s $\sim N_D$ $[cm^{-3}]$

2. Acceptors:

- Elements w/ 3 valence e^-'s, e.g., Boron (B)