Qualitative Picture of the Ideal Diode

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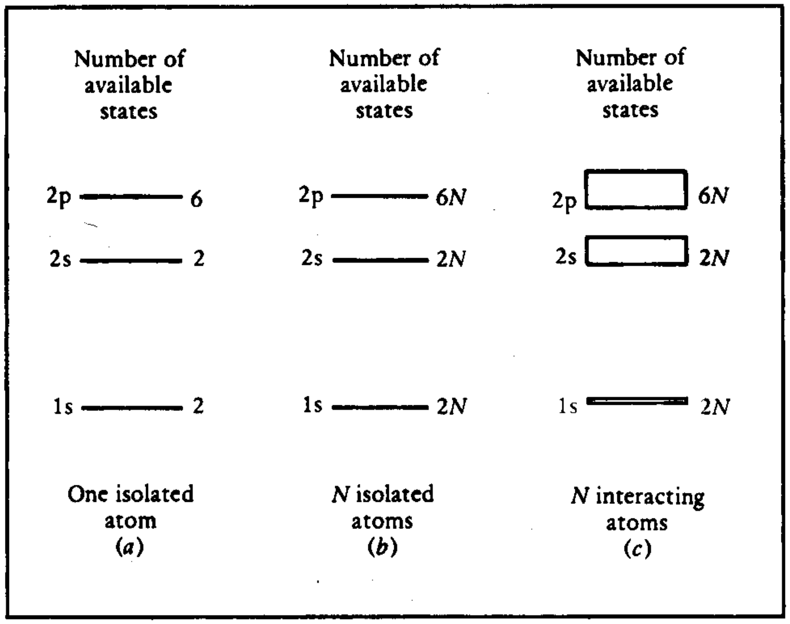
UC San Diego MAE 119

Lecture Notes

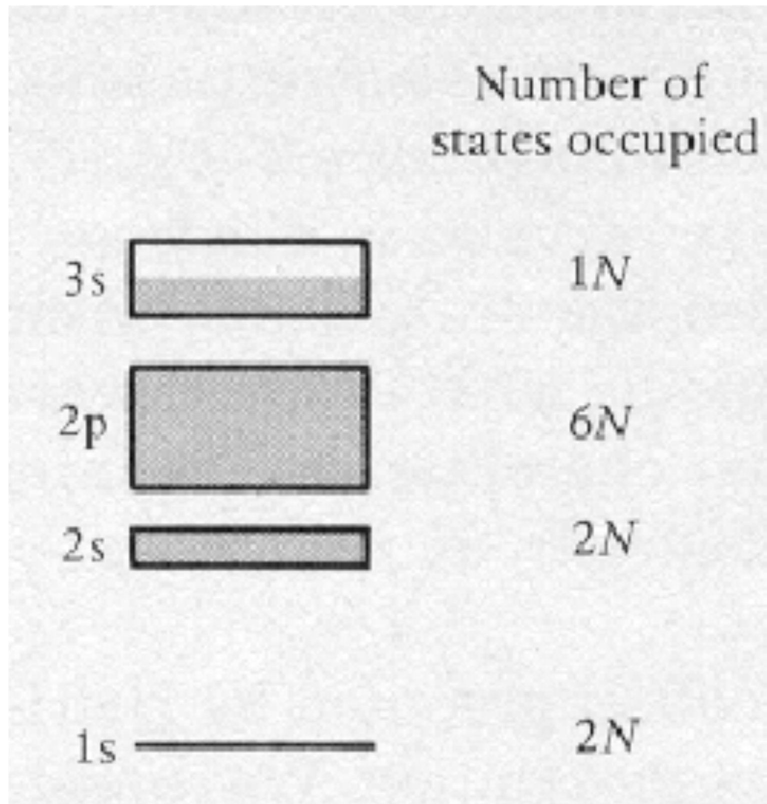
Band Theory of Solids: From Single Attoms…to Solid Crystals



- Isolated Li atom (conducting metal)
  - Has well-defined, isolated allowable electron energy levels
- N isolated atoms
  - N x isolated atom levels
- Strongly interacting Li atoms
  - Interaction shifts (or splits) individual **energy bands** into isolated regions separated by **forbidden bands**

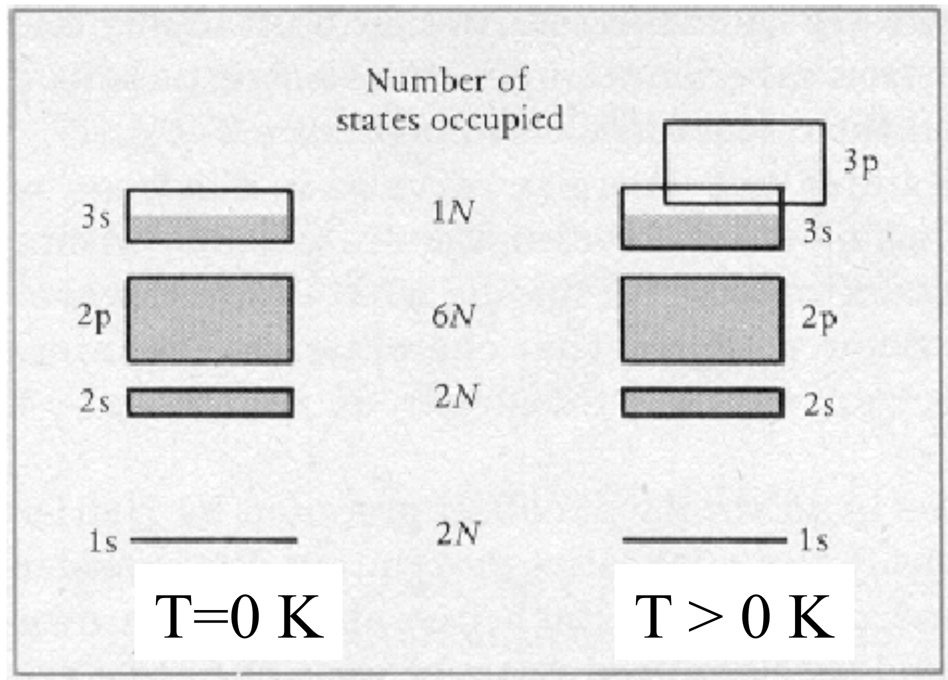
Band Theory of Solids: Conductors

- Next, consider N interacting sodium atoms at 0 deg K
  - Electrons in config $1s^2 2s^2 2p^6 3s^1$
  - Shells filled to 3s, which has 1 electron

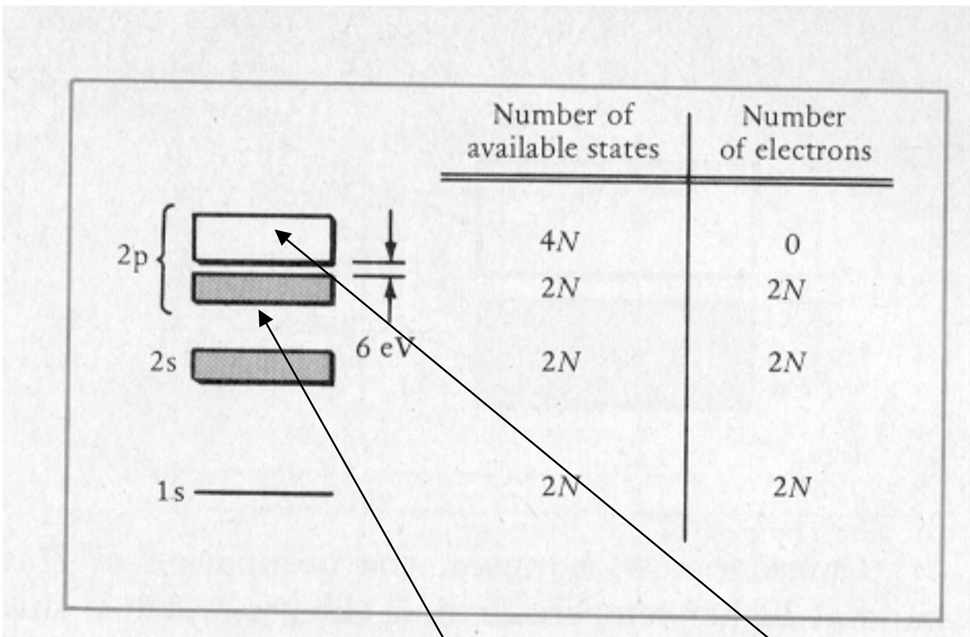


Band Theory of Solids: Conductors

- Next, consider N interacting sodium atoms w/ T>0
  - Electrons in config $1s^2 2s^2 2p^6 3s^1$
  - Shells filled to 3s, which has 1 electron
  - This Valence electron is weakly bound =>> if T High enough can move to mobile state ➔ conductor!



Band Theory of Solids: Insulators



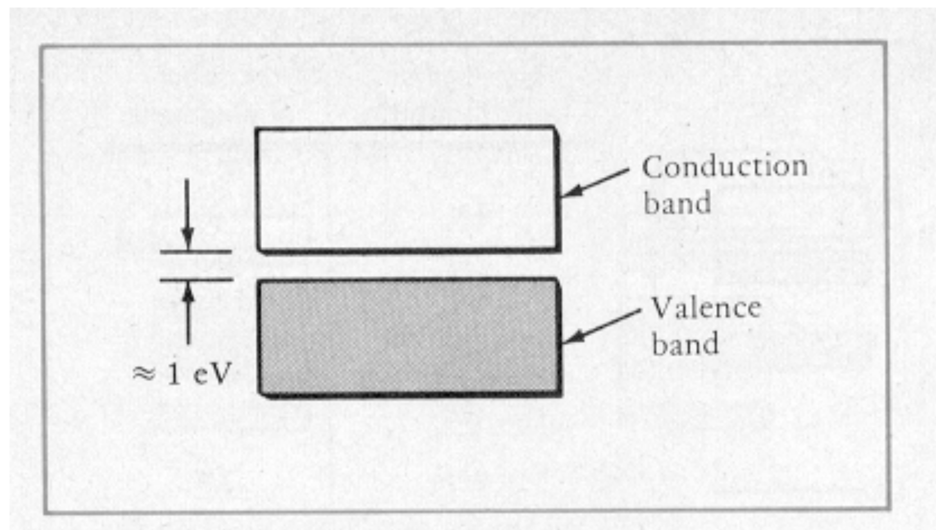
Lower levels: VALENCE BAND
Upper levels: CONDUCTION BAND

- Carbon in Diamond Form
  - Electrons in $1s^2 2s^2 2p^2$ State
  - 2p band has 2N electrons, but 6N states
  - BUT… crystal structure splits 2p into two distinct bands
  - ***BAND GAP is ~6 eV >> Temperature (~0.02-0.1 eV)***

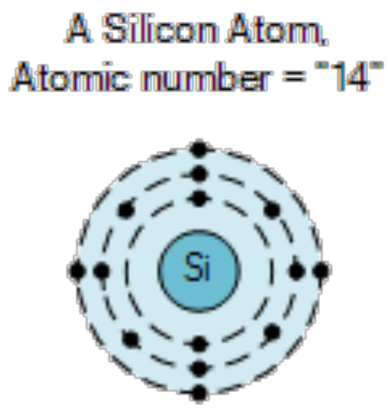
Thus…Diamond is An Insulator

Band Theory of Solids: Semiconductors

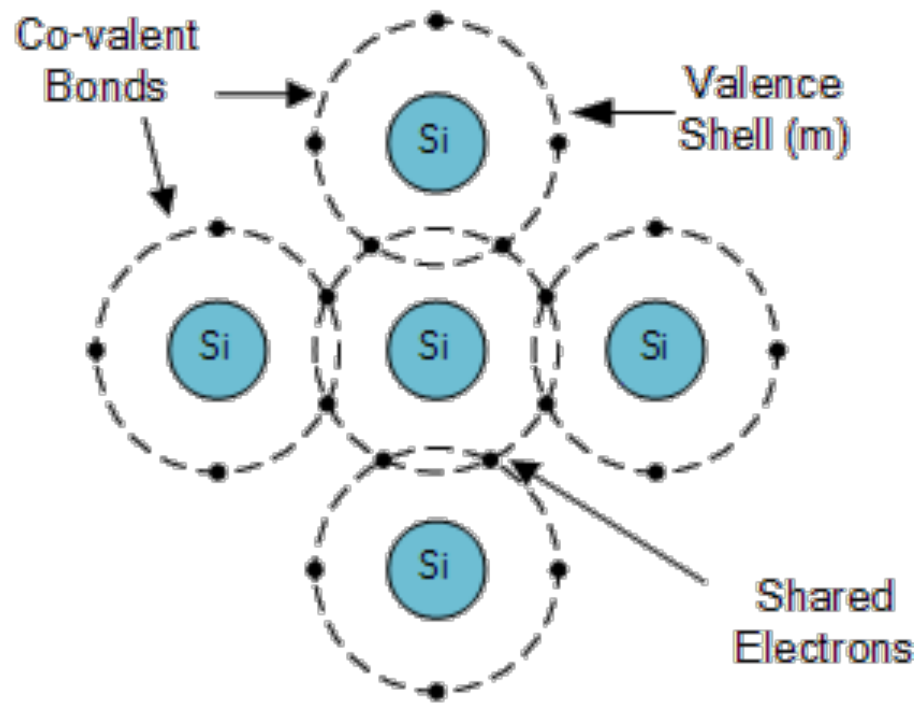
- ***Some crystalline materials have smaller band-gap energy***
- At low temperatures behave like insulators
  - E_{bg}~1eV >> Temperature
- With an electric field
  - Electrons gain energy
  - Can move into upper (conduction) band



Si as a Semiconductor Material



Silicon atom showing 4 electrons in its outer valence shell (m)



Silicon Crystal Lattice

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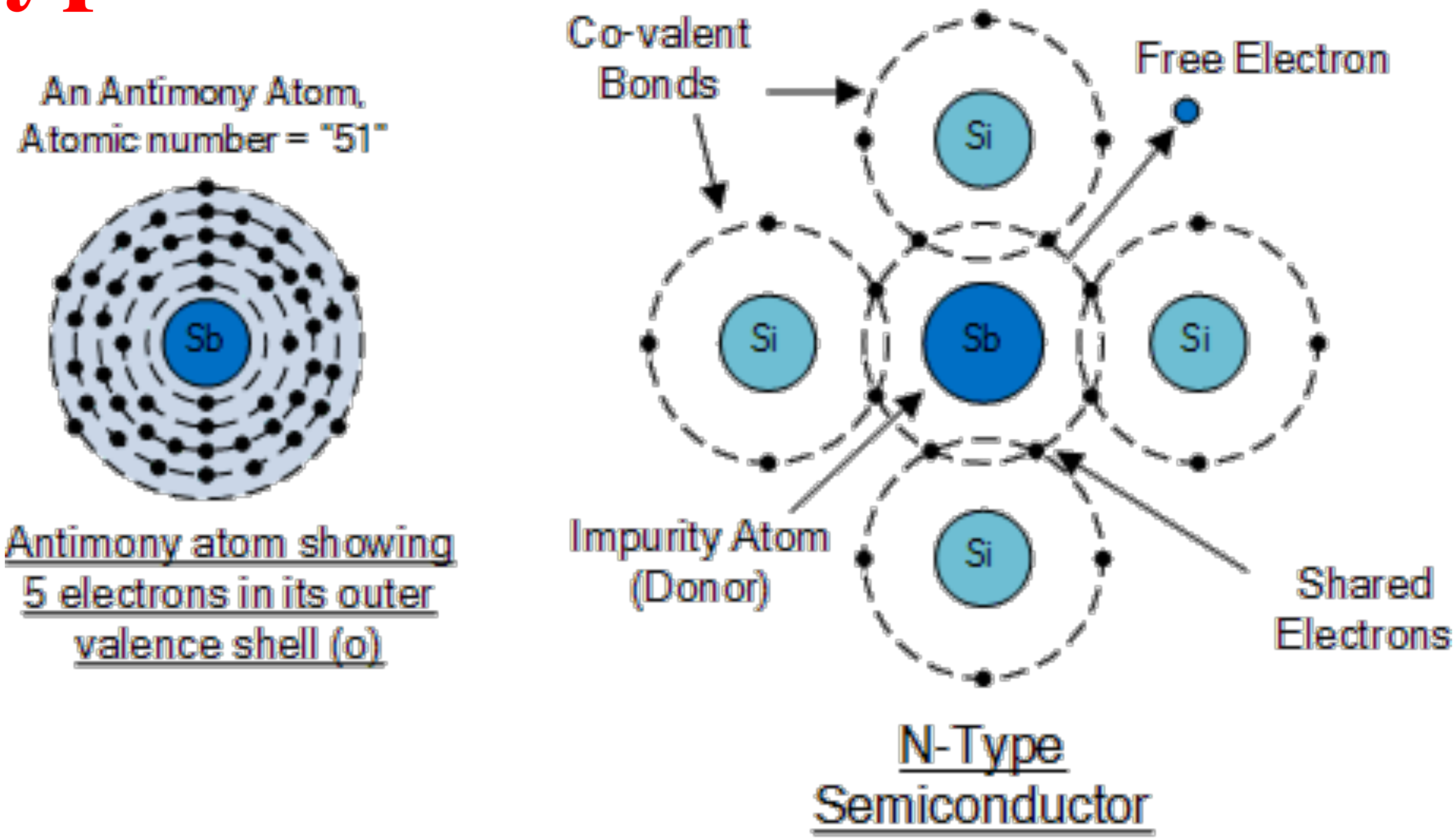
N-type Semiconductor Materials



N-type Si has an extra electron for each dopant atom,
This electron is mobile

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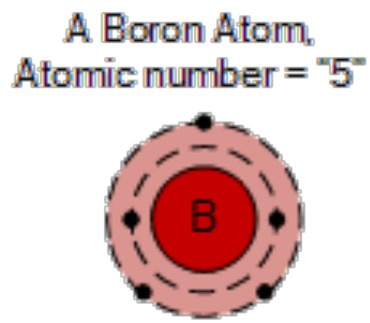
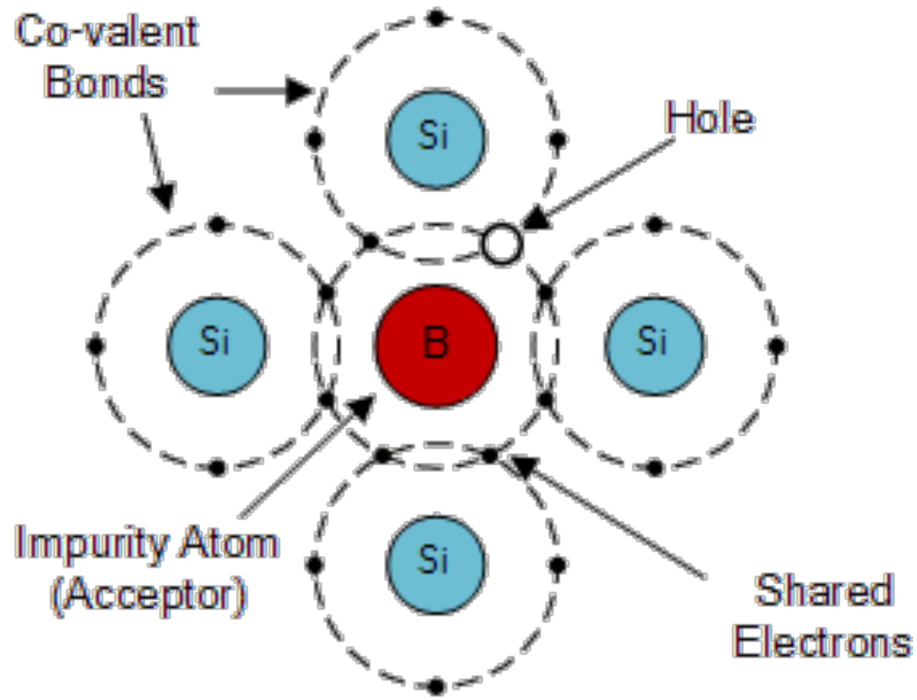
P-type Semiconductor Materials



Boron atom showing
3 electrons in its outer
valence shell (L)



P-Type
Semiconductor

P-type Si has a "hole" (i.e a missing electron) that acts like
A mobile positive charge

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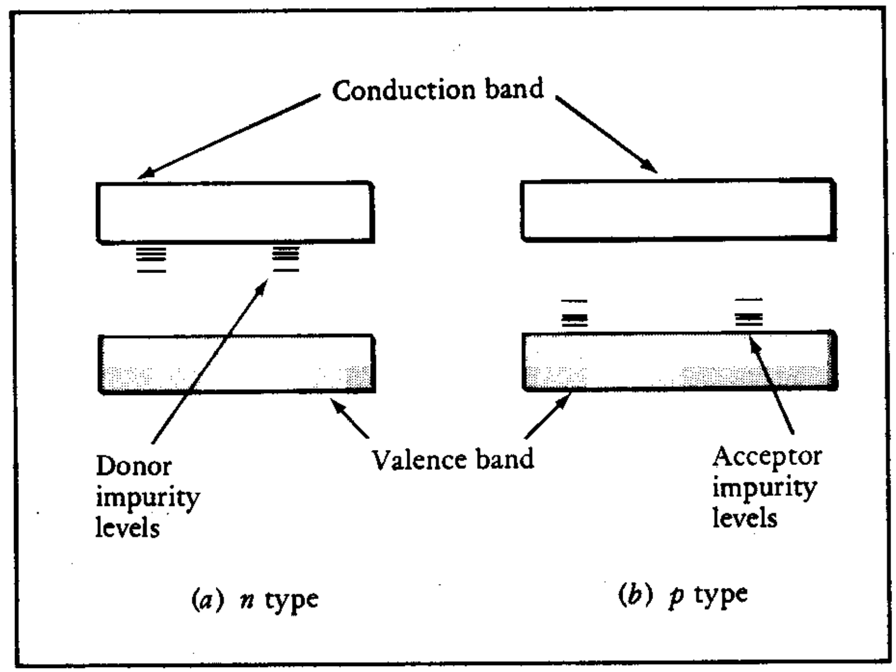
Dopants create allowed energy states between the pure material valence and conduction bands

- Pure semiconductor matl's conduction and valence bands separated by E_{gap}
- In pure materials this gap has no allowed states -> no particles in these energy ranges
- IF ADD donor or acceptor impurities then this creates allowed states between the pure-material conduction & valence bands



Basics of Solar PV Cells

- Key Concepts
  - Un-illuminated p-n junction diode
  - Photon Energy Spectrum
  - Charge Carrier Generation Via Photon Absorption
  - Charge Carrier Loss Mechanisms
  - Illuminated p-n junction diode: The Solar PV Cell
  - Solar PV Cell's as an Electricity Source

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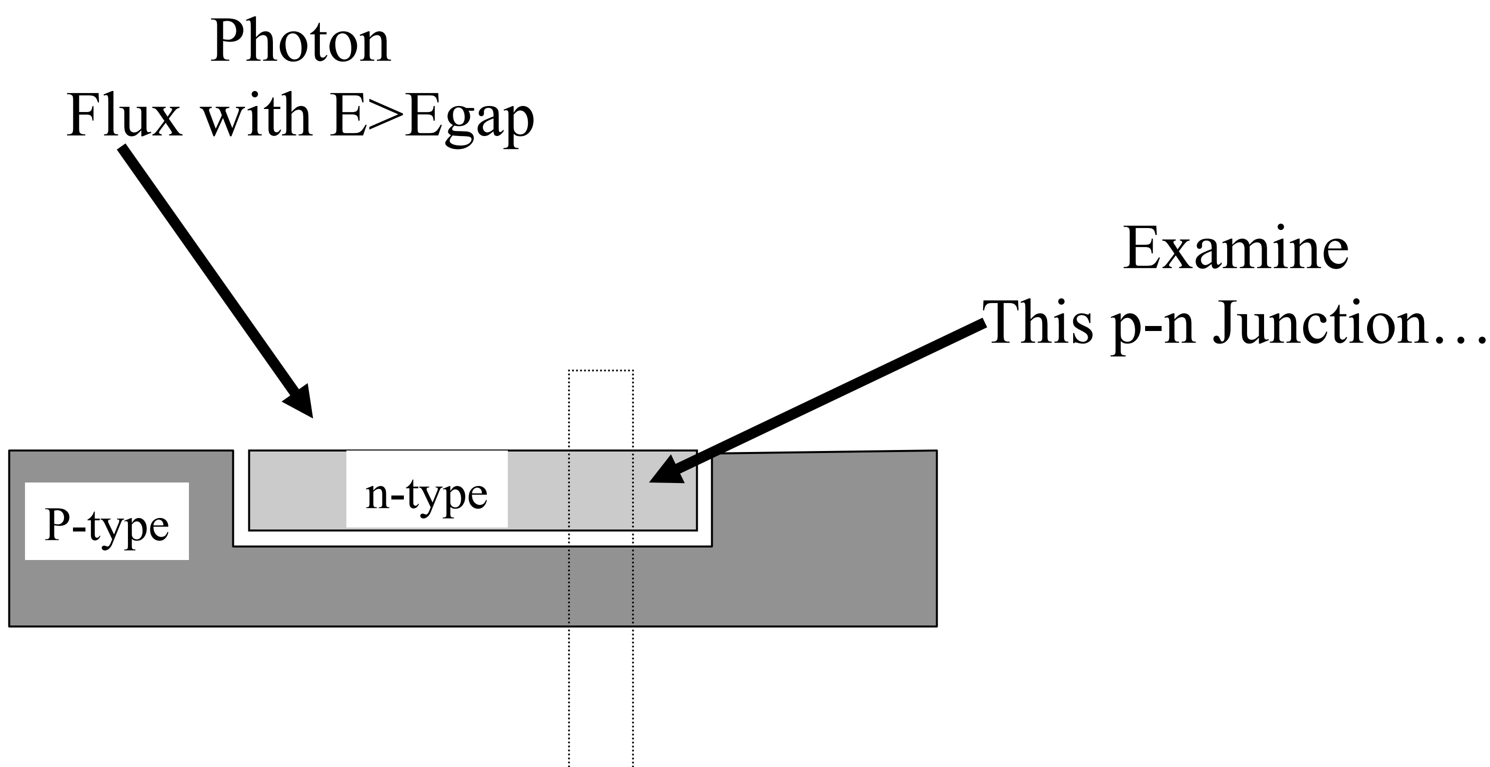
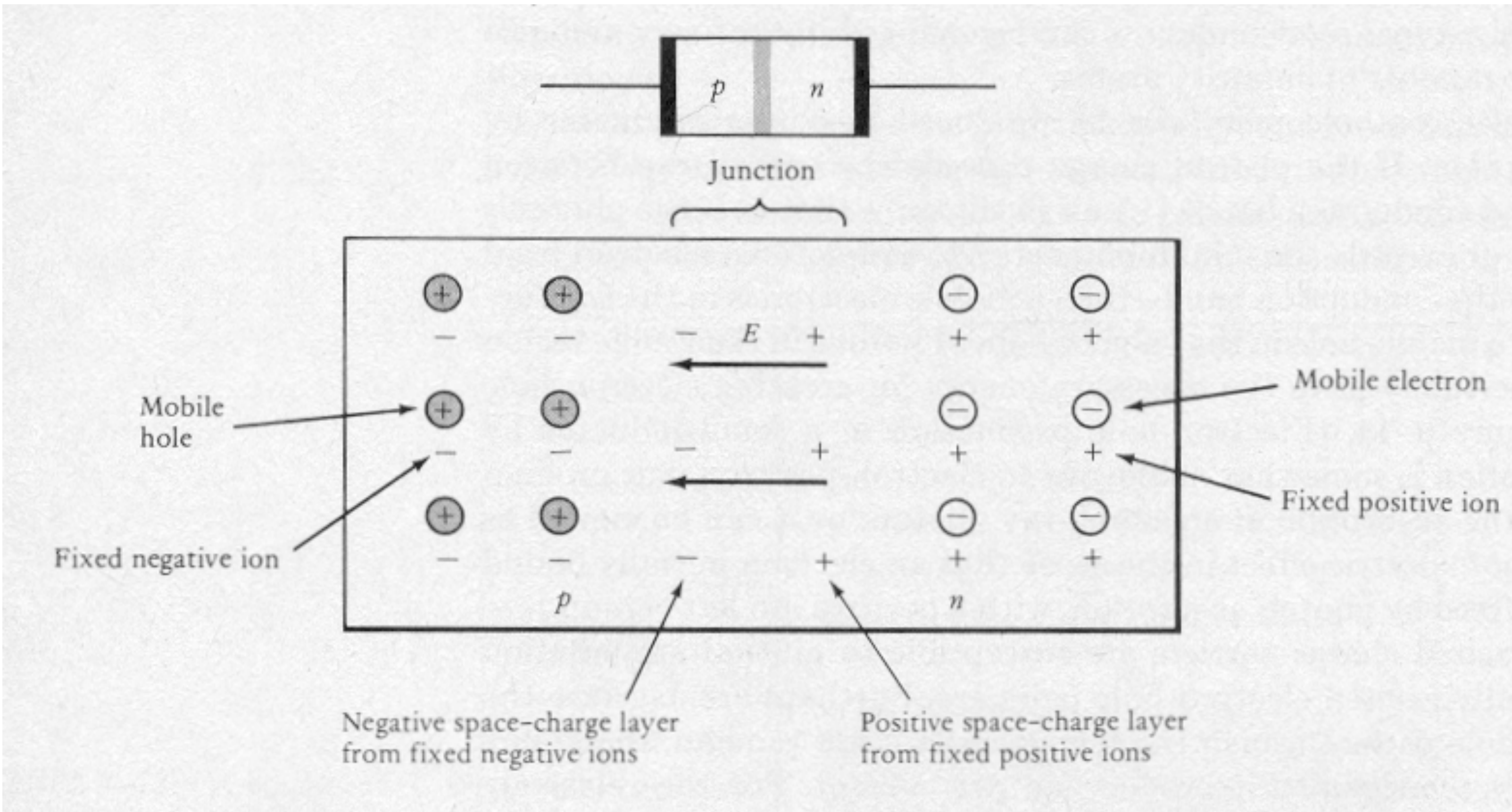
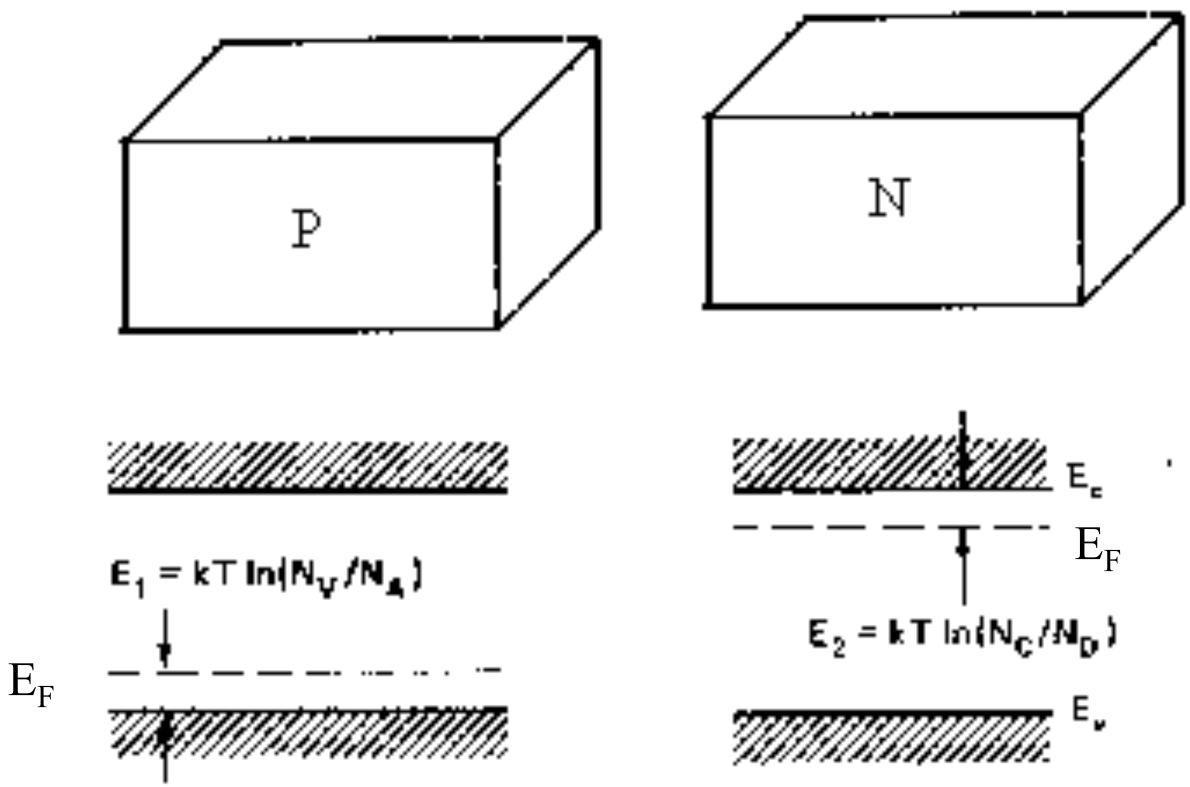
A Solar PV Cell is just a p-n junction ("diode") illuminated by light….



Simplified Model of PV Cell: No Light



Conduction Band & Valence Band Energy Levels in ***SEPARATE*** p-type and n-type materials



Conduction Band & Valence Band Energy Levels in ***p-n junction***

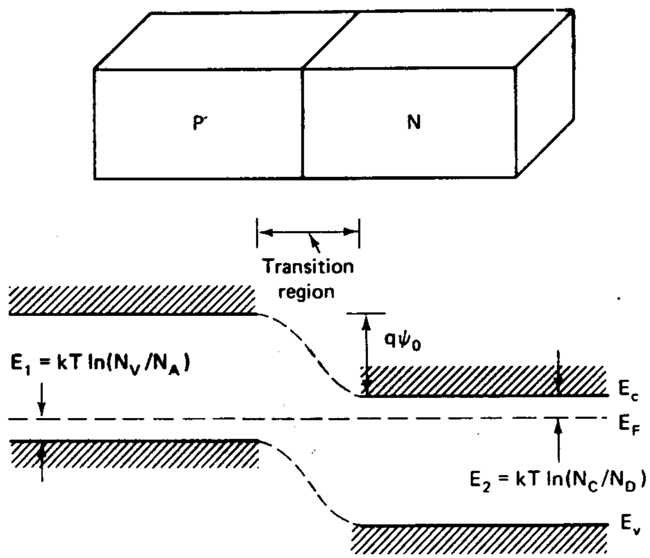
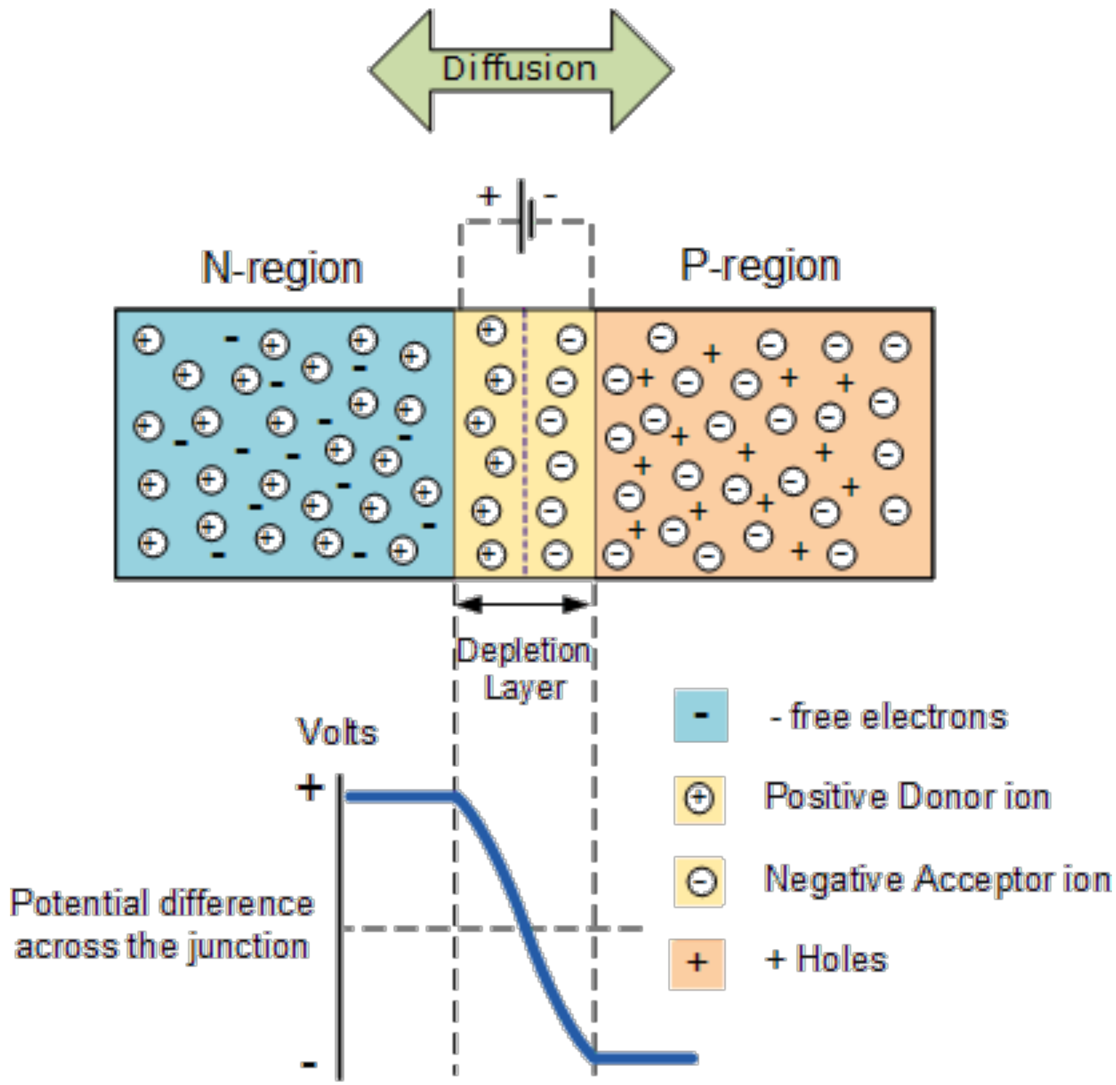


Figure 4.3. A p-n junction formed by bringing the isolated p-type and n-type regions together. Also shown is the corresponding energy-band diagram at thermal equilibrium.

- THERE CAN ONLY BE ONE FERMI ENERGY IN A SYSTEM AT EQUIL (!)
- Result:

$$\psi_0 = \frac{kT}{q} \ln\left(\frac{N_A N_D}{n_i^2}\right)$$

P-N Junction formed by joining p & n type materials



- Concentration gradient of n and p densities leads to diffusion of mobile electrons into the p-region, and mobile holes into the n-type region.
- This leaves behind immobile positive donor ions in n-region (N_{D+}) and negative acceptor (N_{A-}) ions in p-region
- Process stops when sufficiently large potential gradient develops

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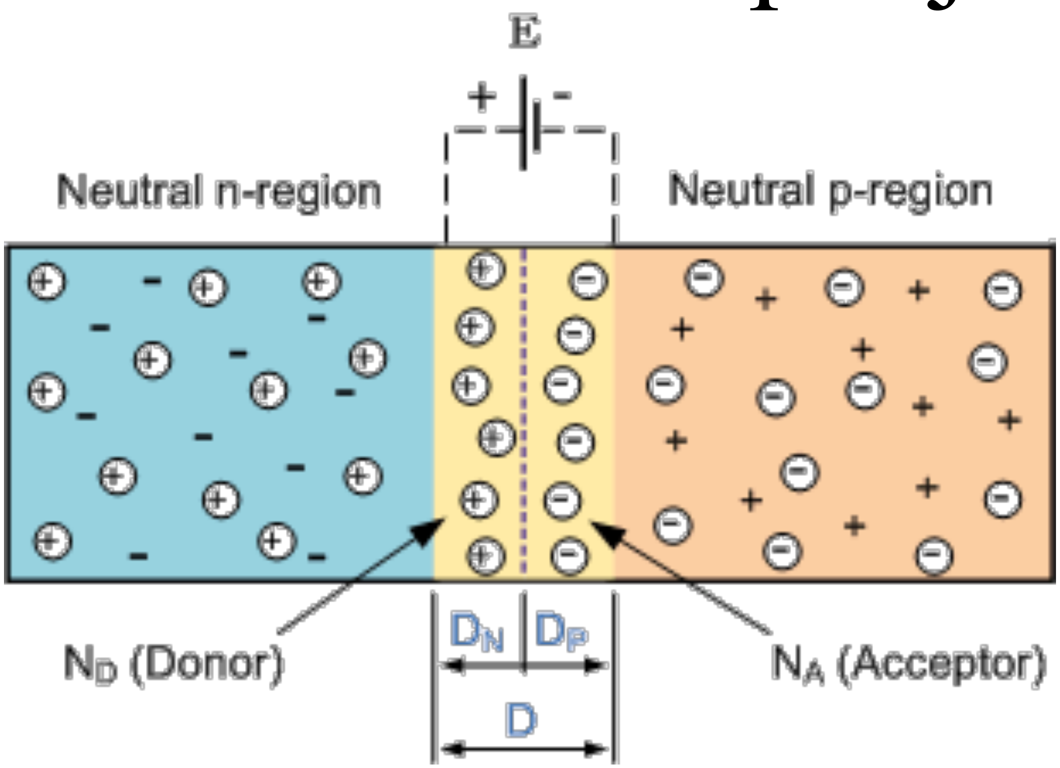
Equilbrium potential develops across the p-n junction



Get an electric field naturally occuring across junction

$$E_o = V_T \ln\left(\frac{N_D . N_A}{n_i^2}\right)$$

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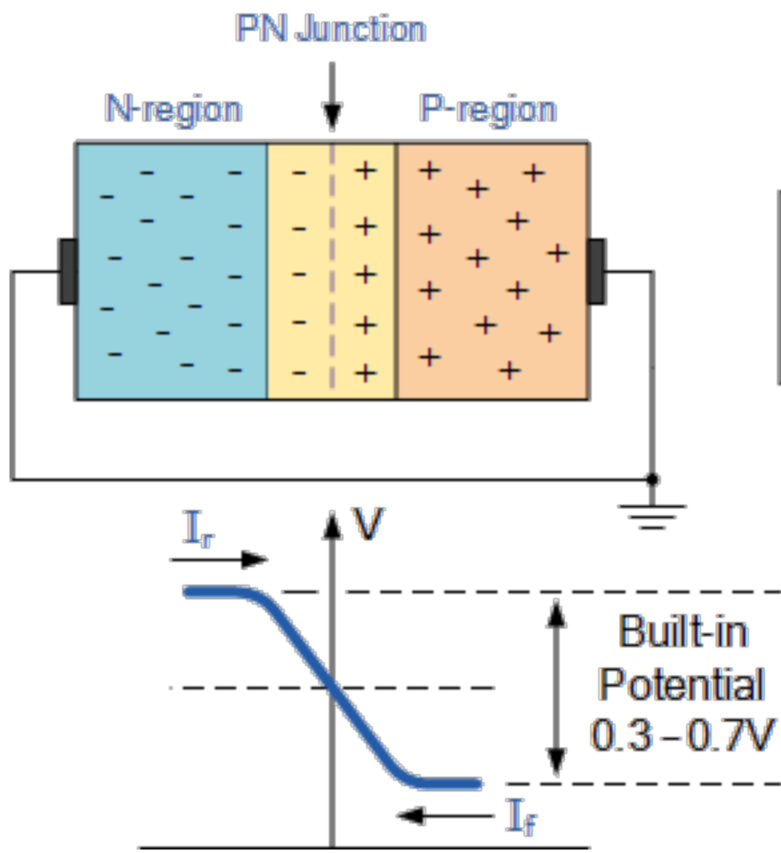
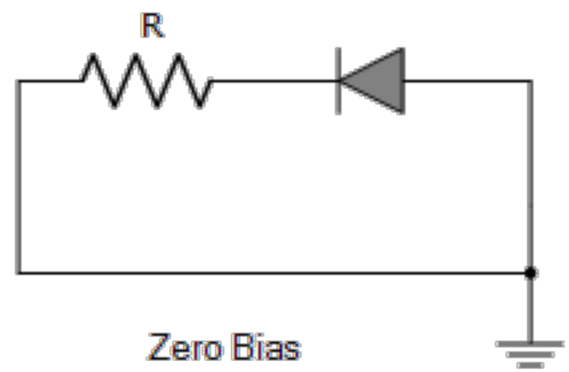
Now connect p and n regions via external circuit





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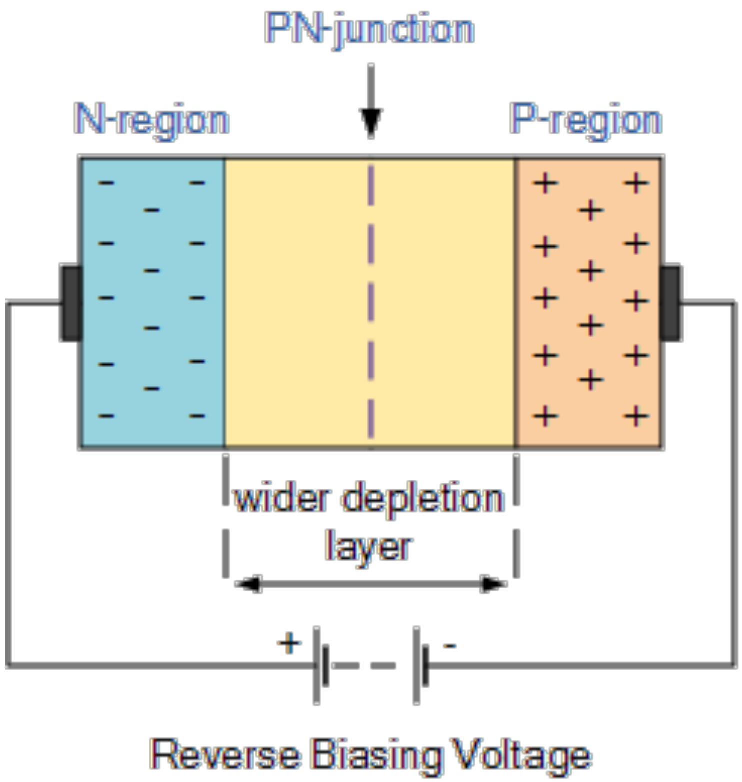
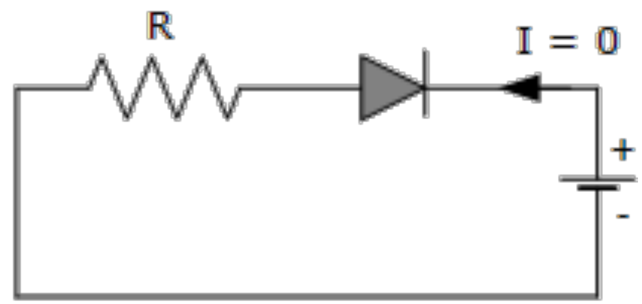
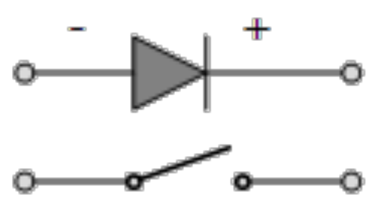
Connecting w/ext. circuit and adding an external bias that ***ADDS*** to natural bias (***"Reverse"*** bias) widens depletion zone







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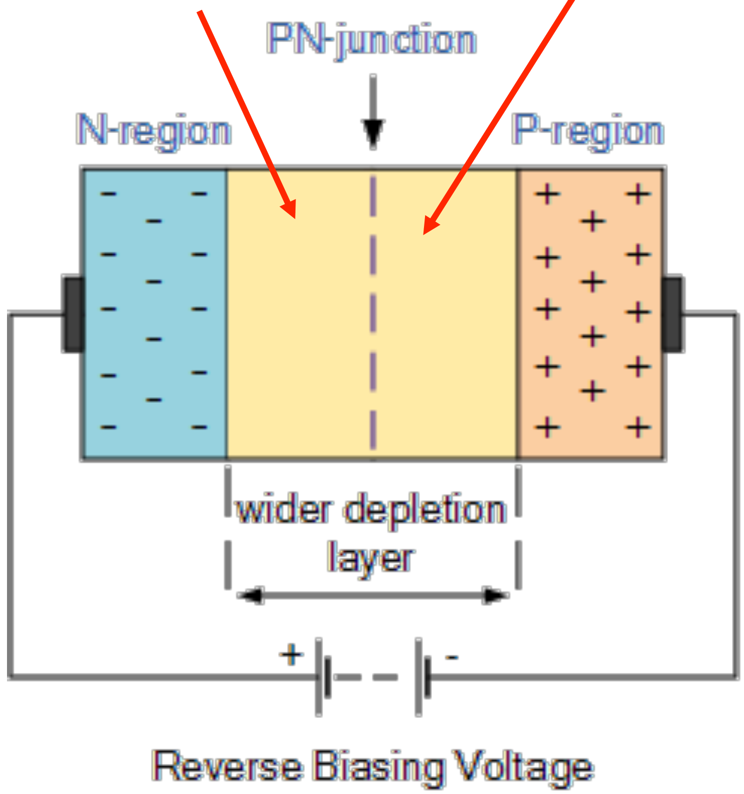
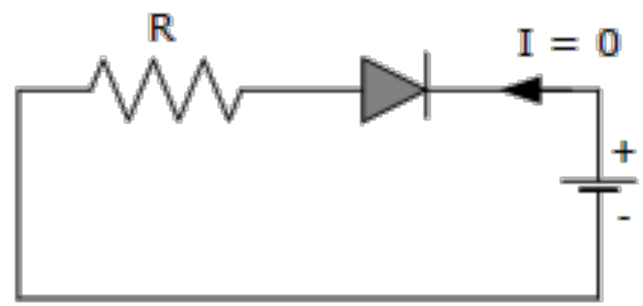
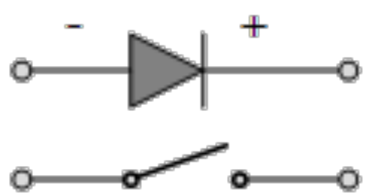
Connecting w/ext. circuit and adding an external bias that ***ADDS*** to natural bias (***"Reverse"*** bias) widens depletion zone

Uncover more un-neutralized N_{D+} ions

Uncover more un-neutralized N_{A-} ions







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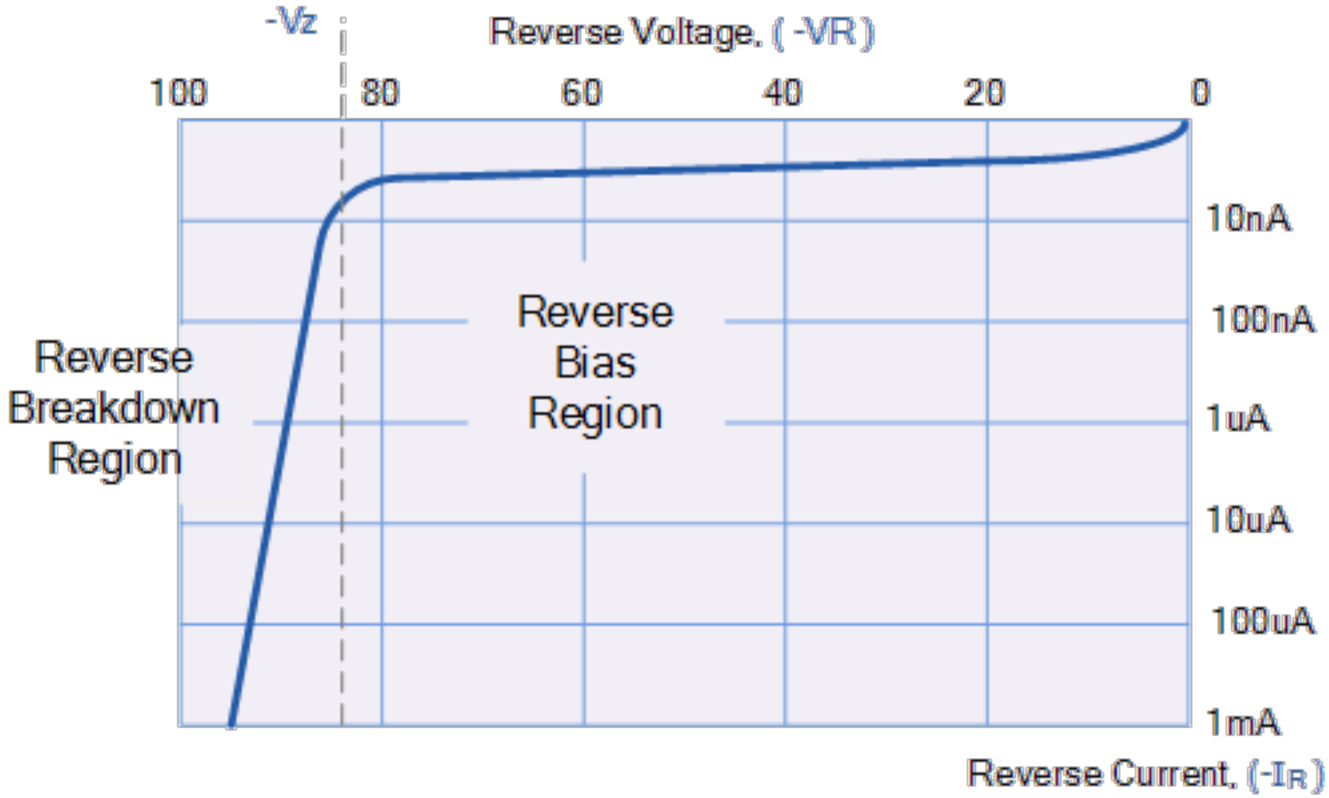
Current-voltage response for reverse bias



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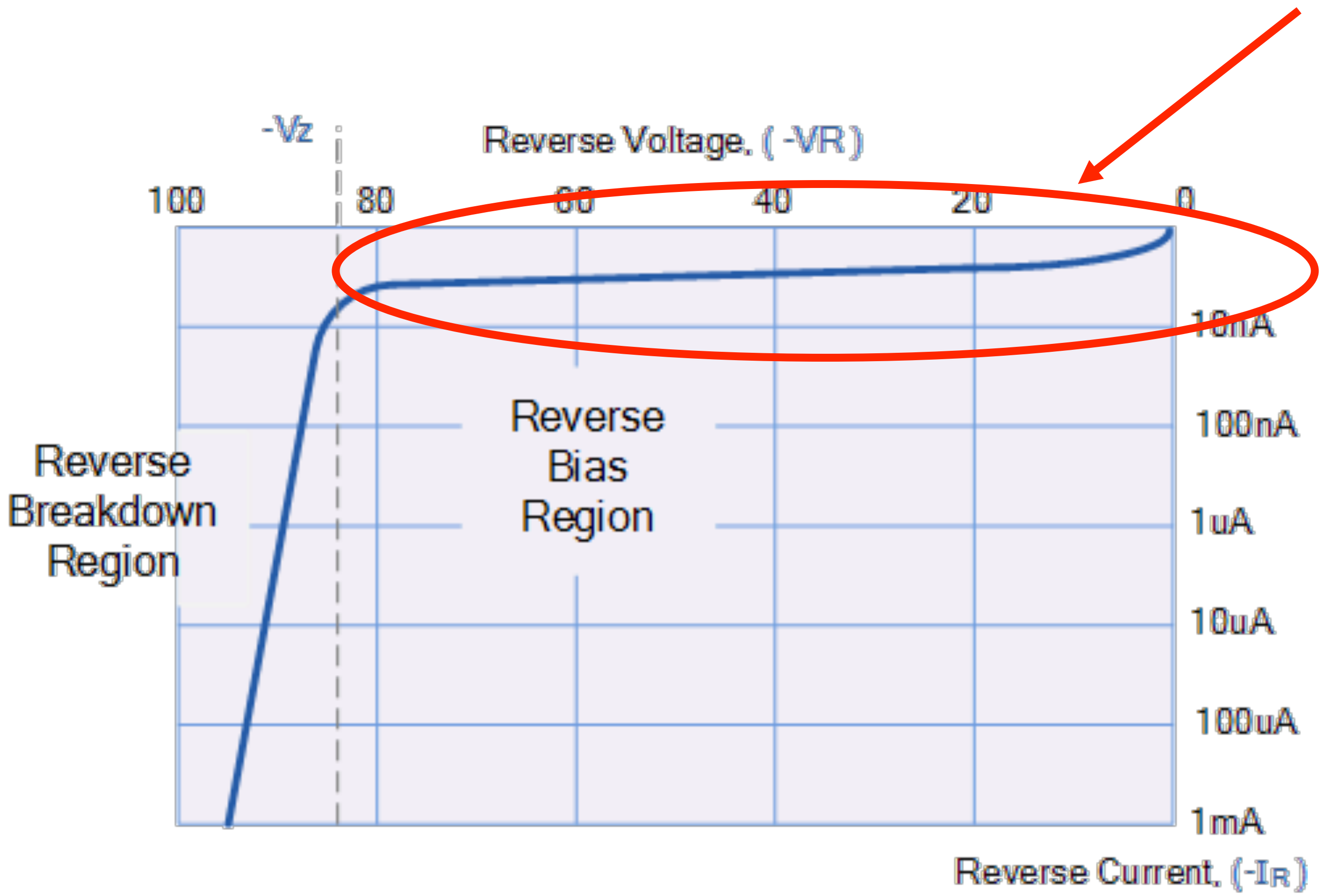
Current-voltage response for reverse bias

Hard for current to flow…



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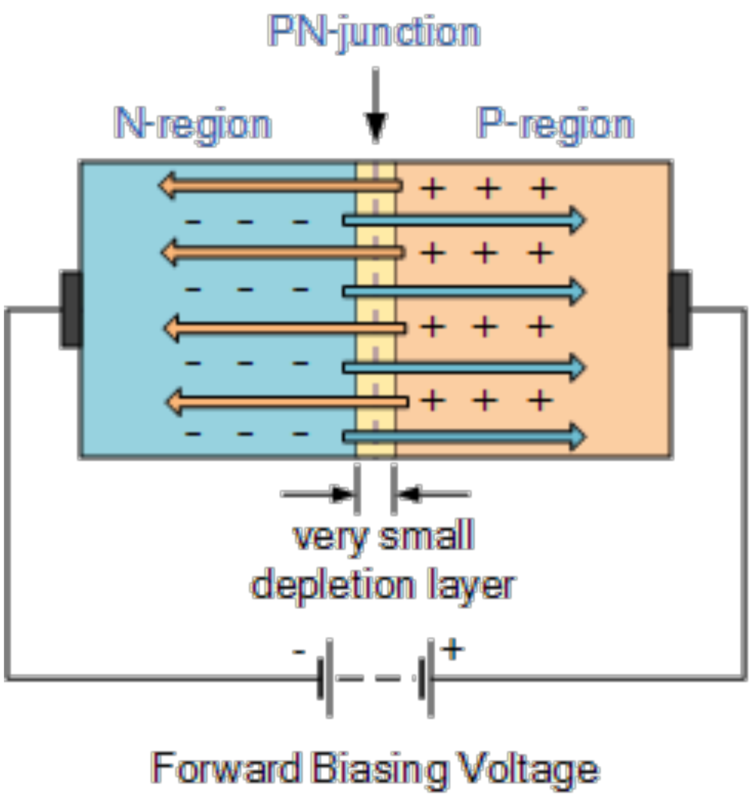
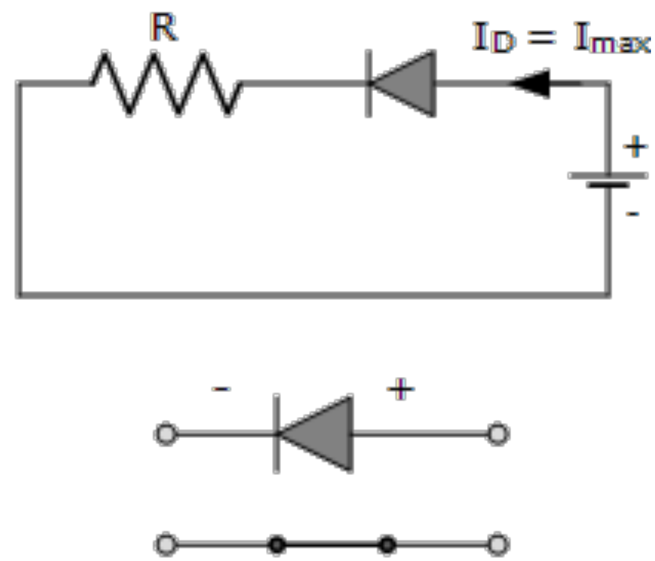
Canceling out natural bias (i.e. "Forward Bias") Causes current to flow!





Forward bias reduces width of depletion zone & "injects" minority carriers (i.e. holes in N-region, Electrons in P-region) which can then diffuse thru that zone

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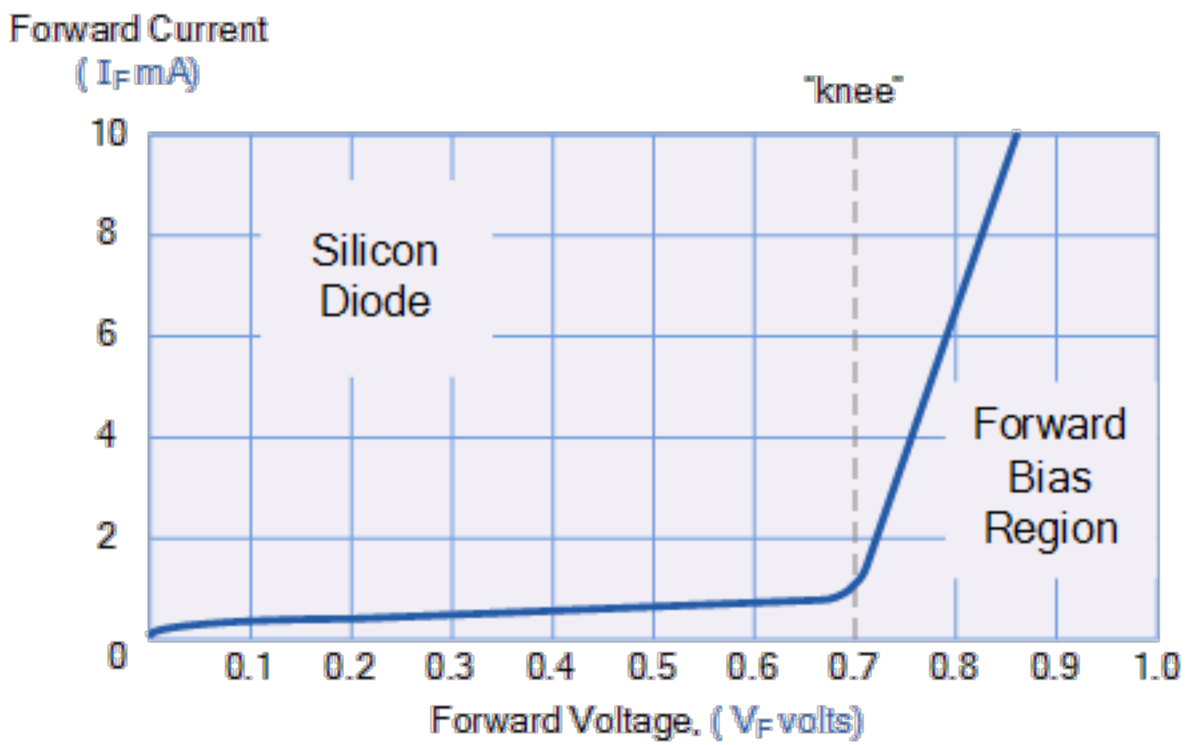
Current-voltage response forward bias



When forward bias voltage reaches or exceeds the Natural bias of the p-n junction, large current can Begin to flow

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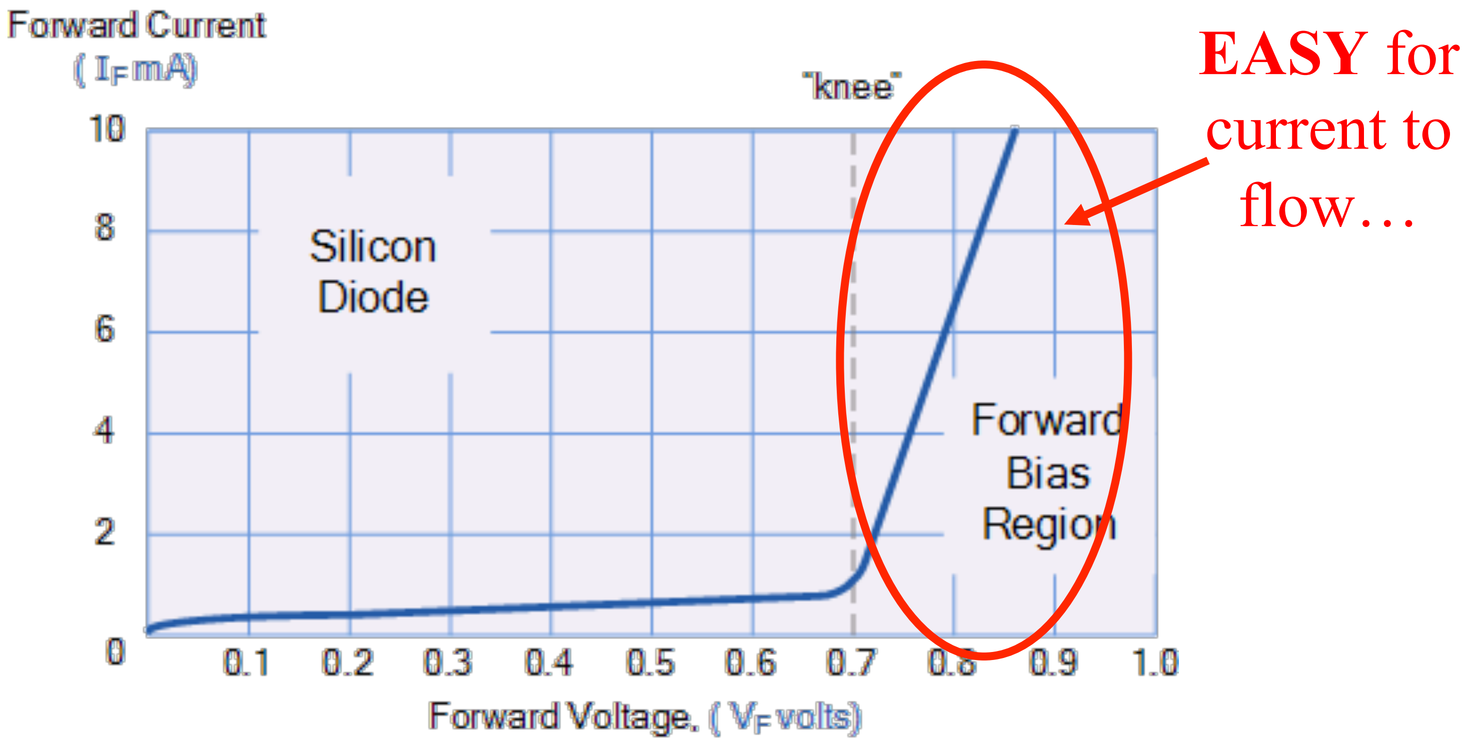
Current-voltage response forward bias



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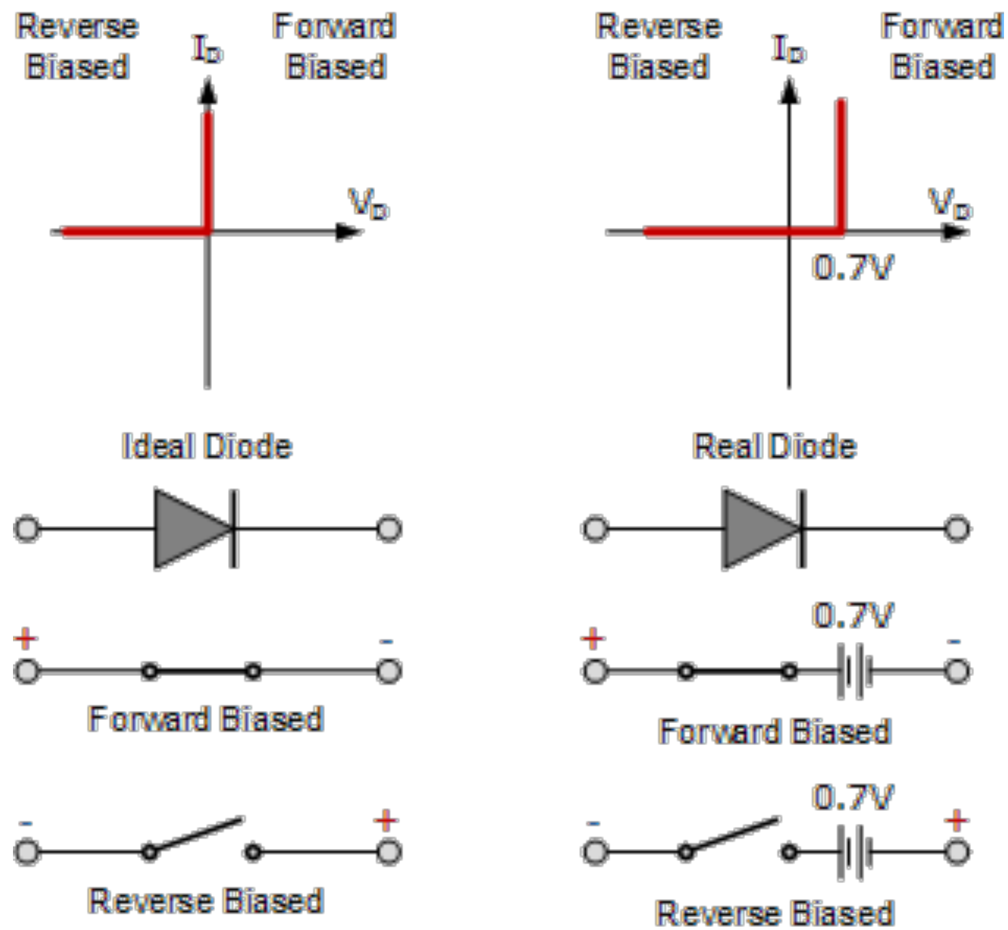
Diode current-voltage characteristics



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