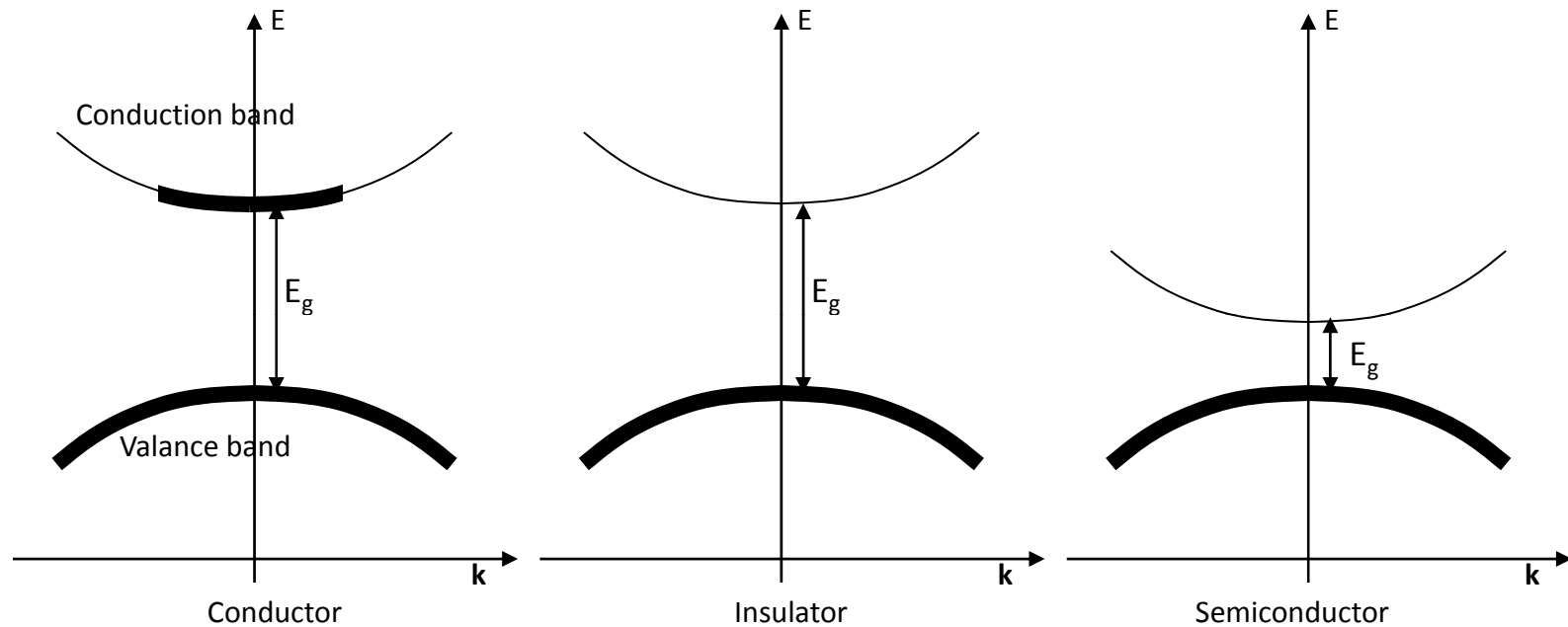


Insulator, semiconductor, and conductor



Semiconductor is an insulator with a energy small gap. It conducts slightly at high temperatures because thermal excitations create electrons in the conduction bands, and holes in the valance band.

Example

Two common types of semiconductors found in electronic components:

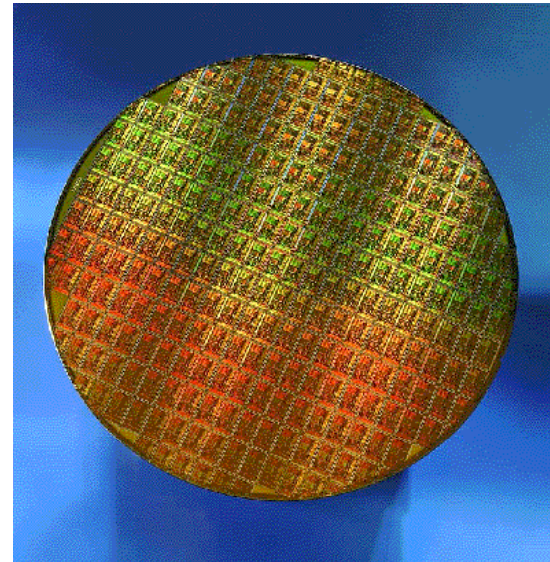
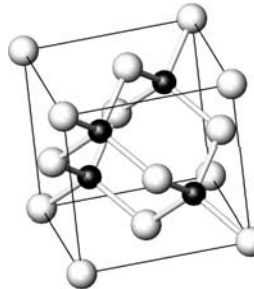
Ge with $E_g = 0.66 \text{ eV}$



Si with $E_g = 1.11 \text{ eV}$

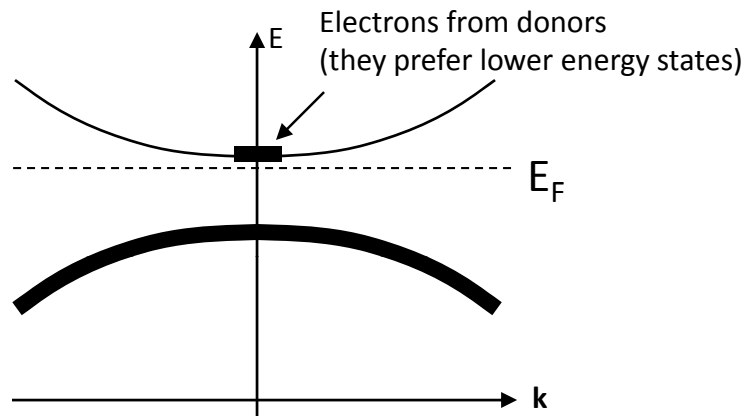


GaAs with $E_g = 1.43 \text{ eV}$



Doped semiconductors

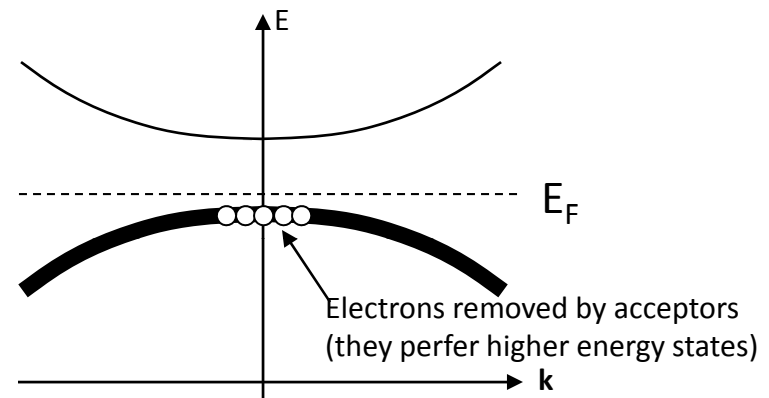
Two types of doped semiconductors:



n-type

Carrier: electrons in conduction band.

Carrier charge: negative



p-type

Carrier: vacancies in valence band (holes).

Carrier charge: positive

In the same electric field, n-type and p-type carriers move in opposite directions, but they carry current in the same direction!

Example

Si is in group IV.

If it is doped with B (group III element), B will accept electrons from Si and make Si becomes a p-type semiconductor.

If it is doped with P (group V element), P will donate electrons to Si and make Si becomes an n-type semiconductor.

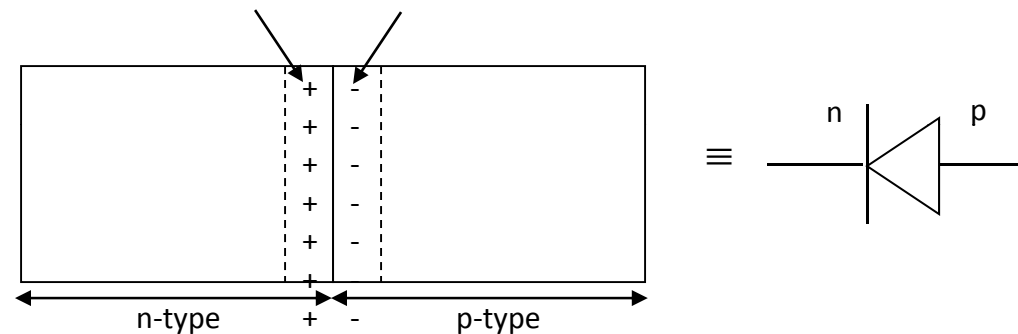
Periodic Table of the Elements

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
I	II	III A	IV A	V A	VIA	VII A	VIII			IB	IIB	IIIB	IVB	VB	VIB	VII B	0
1 H Hydrogen	Non-metals Metals																2 He Helium
3 Li Lithium	4 Be Beryllium											5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon
11 Na Sodium	12 Mg Magnesium											13 Al Aluminum	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon
55 Cs Cesium	56 Ba Barium	57~71 lan Lanthanides	72 Hf Hafnium	73 Ta Tantalum	74 W Tungsten	75 Re Rhenium	76 Os Osmium	77 Ir Iridium	78 Pt Platinum	79 Au Gold	80 Hg Mercury	81 Tl Thallium	82 Pb Lead	83 Bi Bismuth	84 Po Polonium	85 At Astatine	86 Rn Radon
87 Fr Francium	88 Ra Radium	89~103 act Actinides	104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium									
Halogens Noble gases																	

Joining n- and p- type semiconductors together – Diode I

Positive charges formed by:
(i) positive donors left by electrons migrated to p-side.
(ii) holes migrated from the p-side.

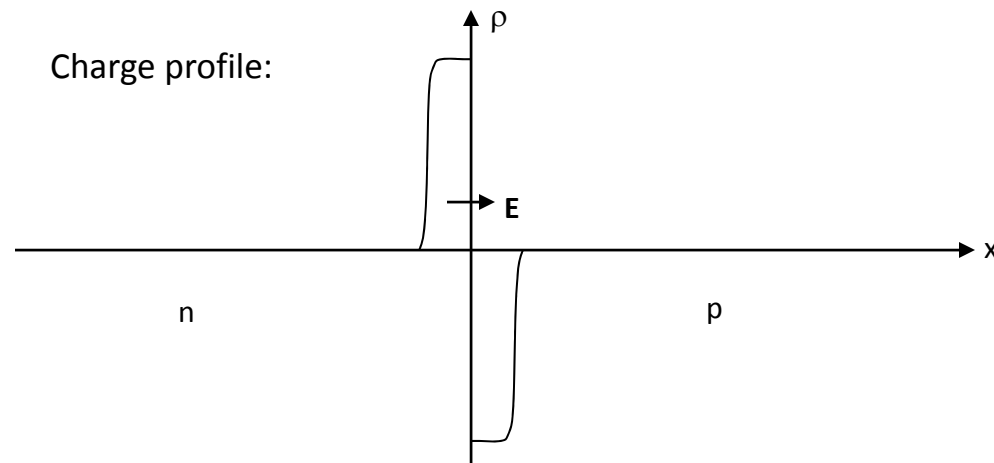
Negative charges formed by:
(i) negative acceptors left by electrons migrated to p-side.
(ii) electrons migrated from the n-side.



Notes:

1. Carriers of opposite sign do not recombine easily because they live in two different bands.
2. Carriers cannot migrate further because of Coulomb attraction and a depletion layer is formed at the interface.

Charge profile:



Example

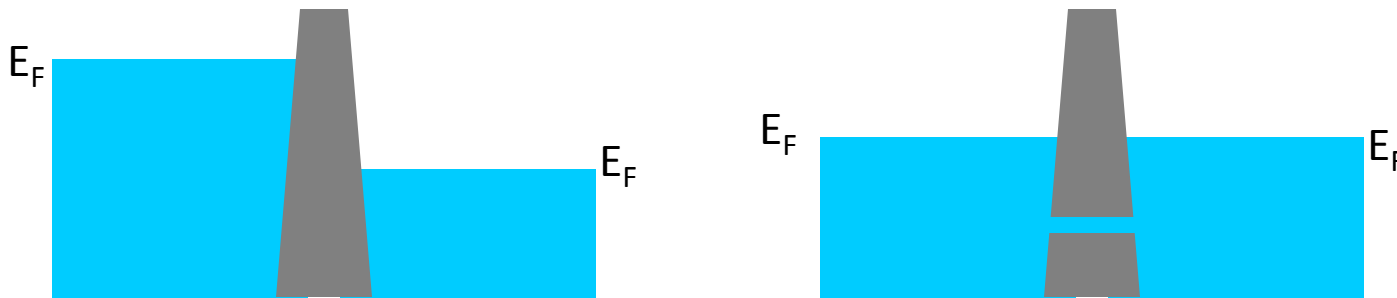
When will the migration stop?

The Fermi level of an n-type semiconductor is closer to the conduction band. The Fermi level of a p-type semiconductor is closer to the valance band.

When the n-type semiconductor touch the p-type semiconductor, the Fermi levels at the two sides are not aligned and the charge carrier will flow from one side to the other. As this happens, the Fermi level at the n-side will fall and the Fermi level at the p-side will rise.

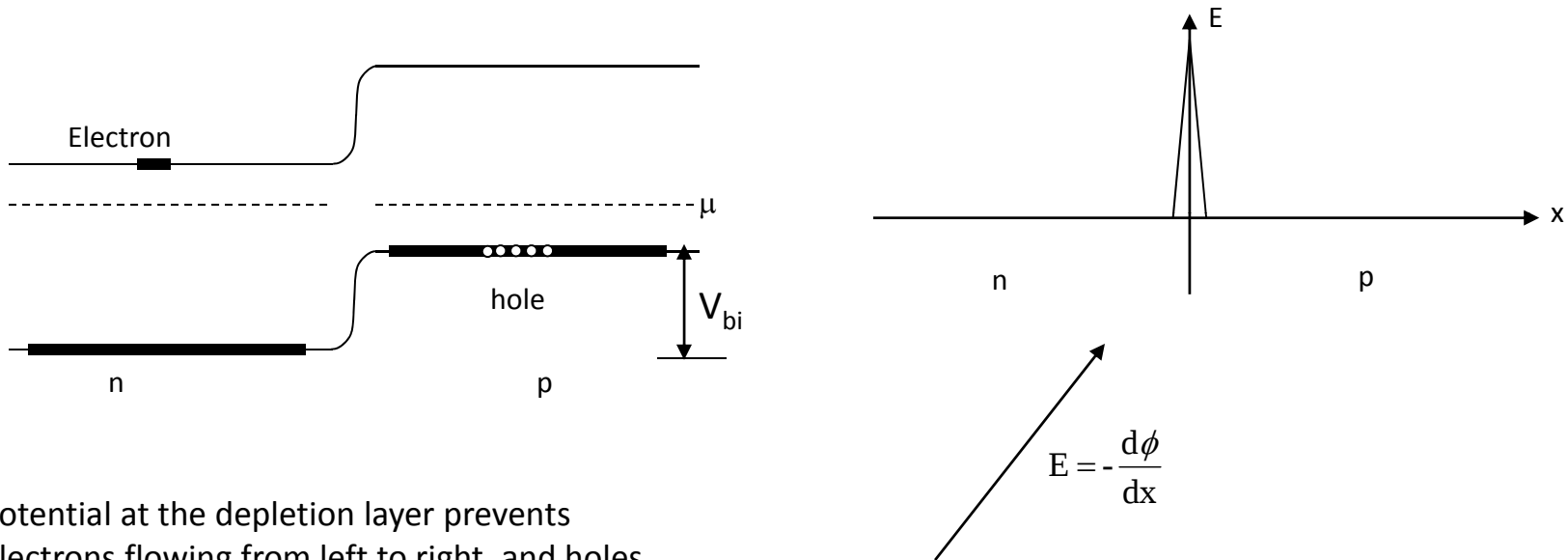
When the Fermi levels at the two sides are aligned, the carrier flow will become equilibrium and the migration will stop.

Think of water flow:

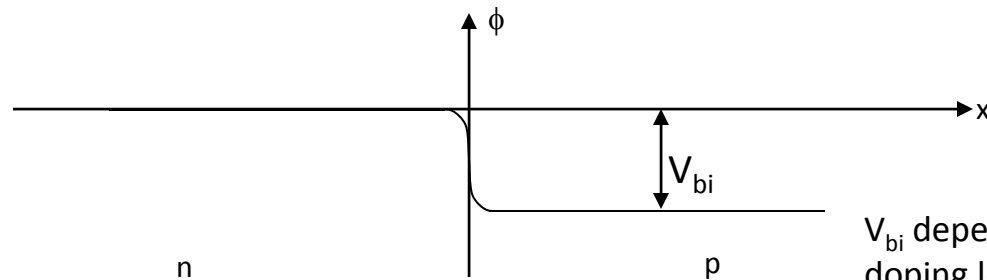


Joining n- and p- type semiconductors together – Diode II

What happen when the energy bands:



Potential at the depletion layer prevents
electrons flowing from left to right, and holes
from right to left:



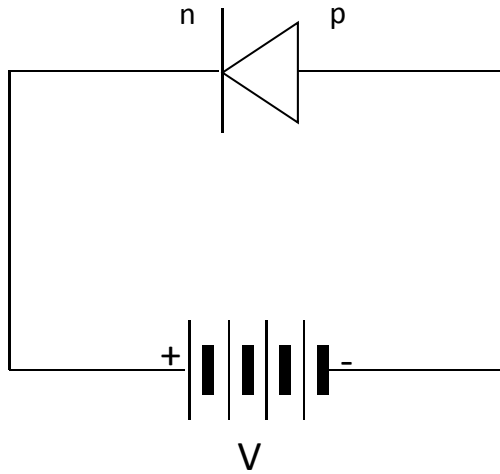
V_{bi} depends on the gap E_g , and
doping levels of the semi
conductor.

Example (important)

V_{bi} for most diodes equal to 0.6 eV.

Reverse bias

Reverse bias is the condition when you connect a positive potential to the n-side and negative potential to the p-side of a diode:

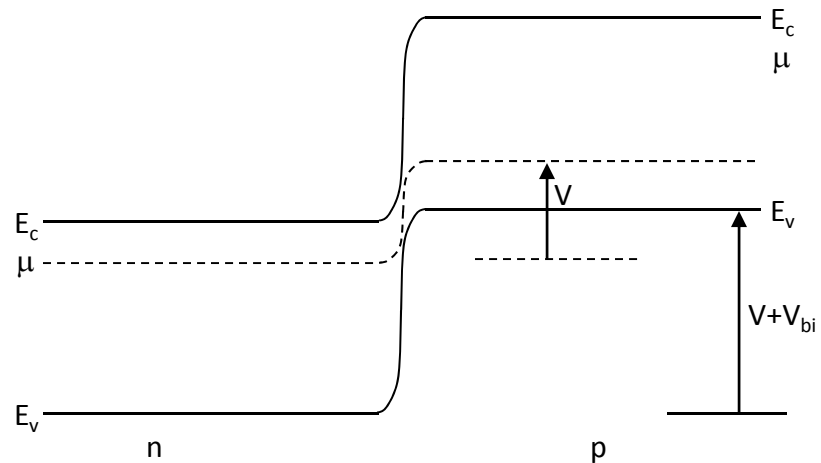


There is no current flowing through the junctions when the diode is reverse biased. Note that most of the external voltage V is “consumed” across the depletion layer, but not at other parts of the diode.

Charge density: The external voltage will push electrons towards right and holes towards left. More recombination occurs and more static charges are resulted. The depletion layer will grow thicker.

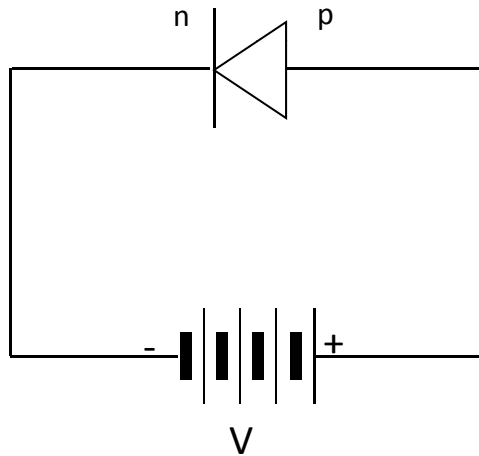
Electric potential: the potential step across the depletion layer will increase from V_{bi} to $V + V_{bi}$.

The external potential add an electric field in the *same* direction of the intrinsic field inside the depletion layer. Hence the electric field in the depletion layer will become stronger, further preventing electrons and holes traveling to the opposite side.



Forward bias

Forward bias is the condition when you connect a positive potential to the p-side and negative potential to the n-side of a diode:

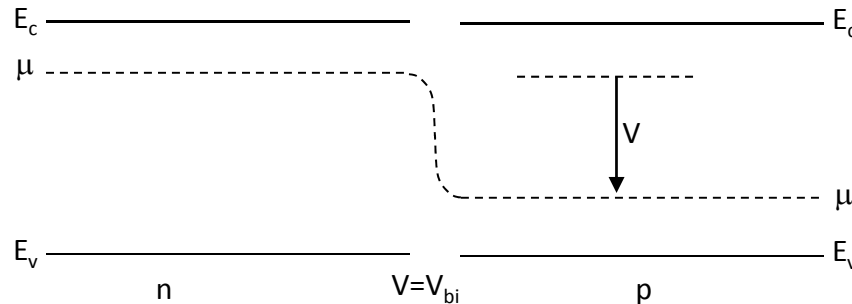


There is no current flowing through the junctions when the diode is reverse biased. Note that most of the external voltage V is “consumed” across the depletion layer, but not at other parts of the diode.

Charge density: The external voltage will remove electrons and holes from the depletion layer. The depletion layer will become thinner.

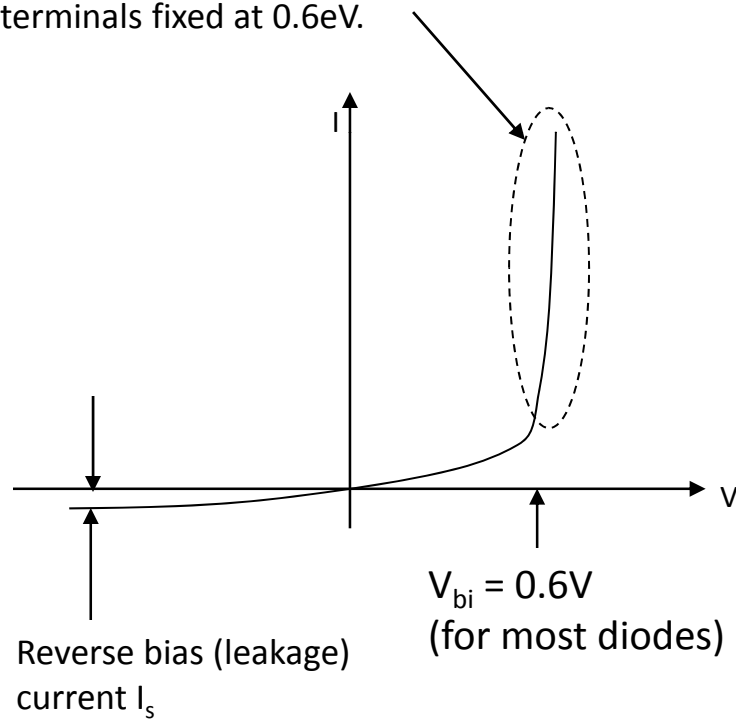
Electric potential: the potential step across the depletion layer will decrease from V_{bi} to $V - V_{bi}$. *When V is larger than V_{bi} , the barrier is removed and electrons and holes can move freely across the junction.*

The external potential add an electric field in the *same* direction of the intrinsic field inside the depletion layer. Hence the electric field in the depletion layer will become stronger, further preventing electrons and holes traveling to the opposite side.



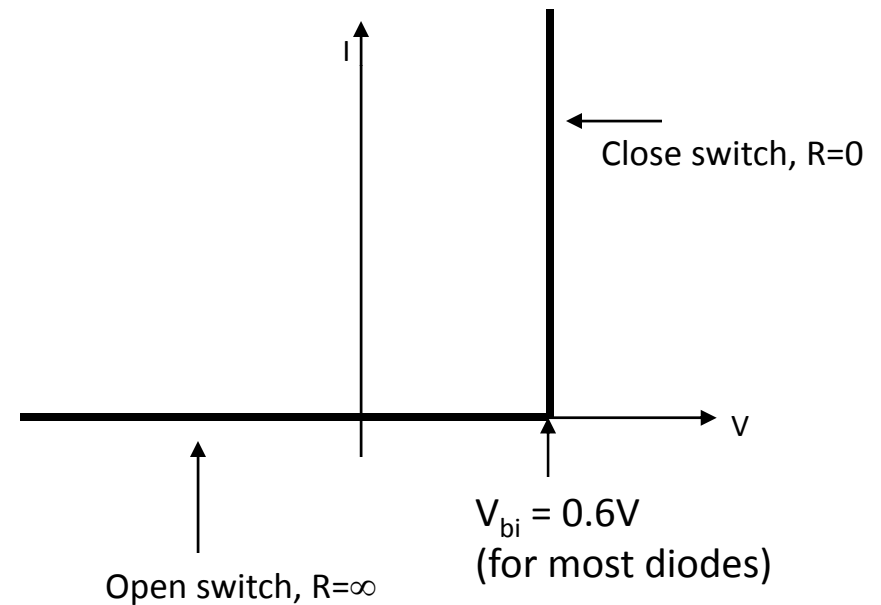
Characteristics of a diode

Operating region of a diode. In this region, it acts like a constant voltage source with the voltage across its two terminals fixed at 0.6eV.



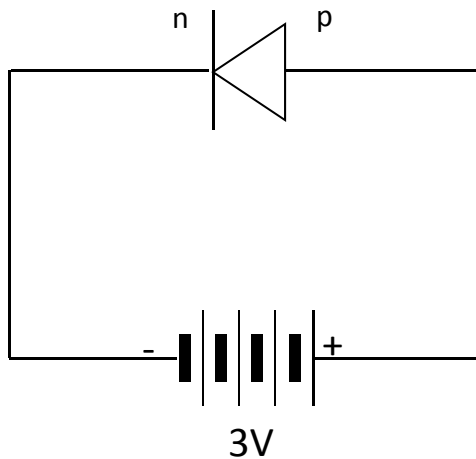
$$I = I_s \left[e^{eV/k_B T} - 1 \right]$$

Idealization:

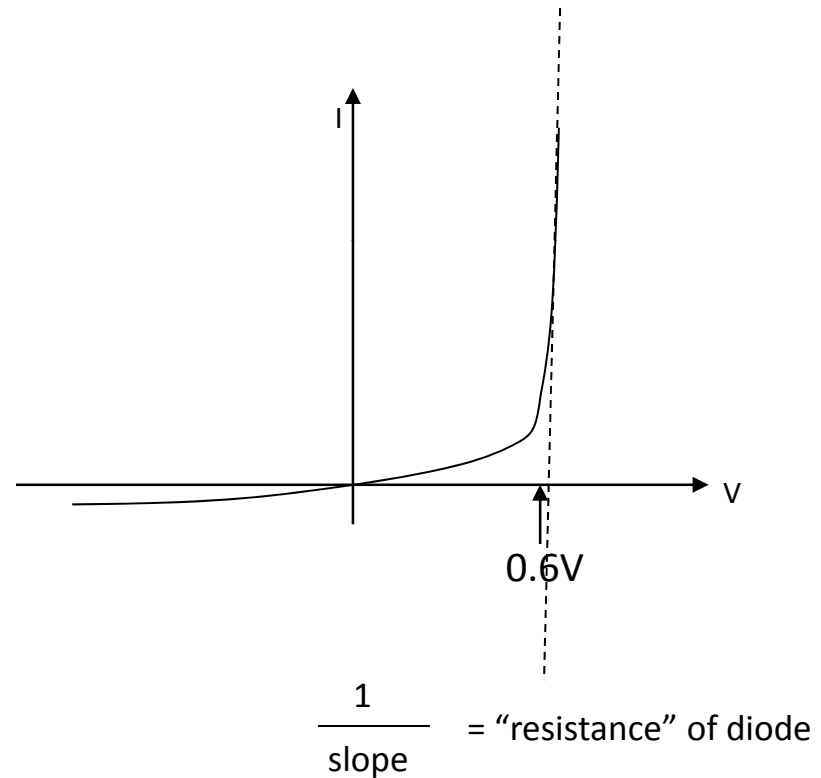


Example (important)

If you do this,

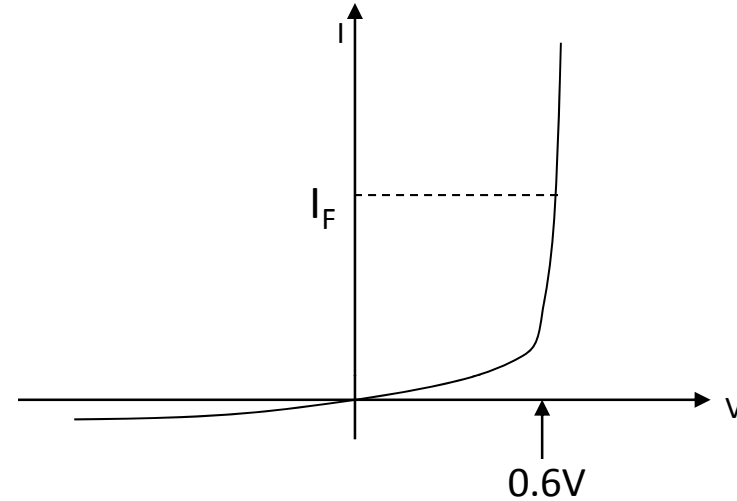
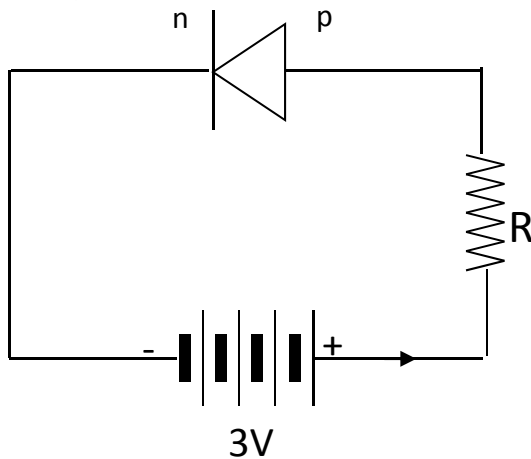


you will burn out the diode easily because $3V \gg 0.6V$. If the diode survives, it is because the power supply has a large output impedance.



Example (important)

Proper way to do it:



1. Look up the forward bias current from manual of the diode, say, 10mA for this example. This is the current I you want to maintain in the circuit loop.
2. Apply Ohm's Law (or Kirchhoff's voltage rule), *assuming a voltage drop of 0.6V across the diode*:

$$3 = 0.6 + (10 \times 10^{-3})R \Rightarrow (10 \times 10^{-3})R = 2.4$$

$$\Rightarrow R = 240\Omega$$

If I_F is not given, you can make a guess from quantities like maximum forward current etc.