Semiconductors, Diodes, and Transistors

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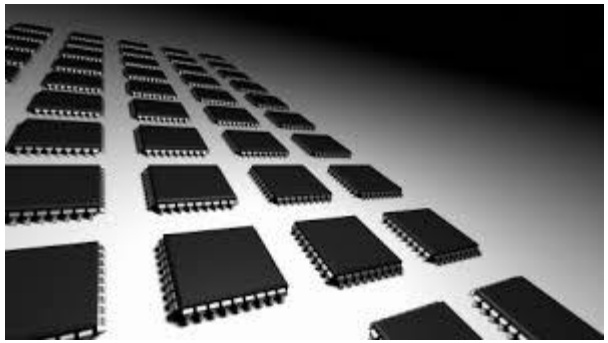
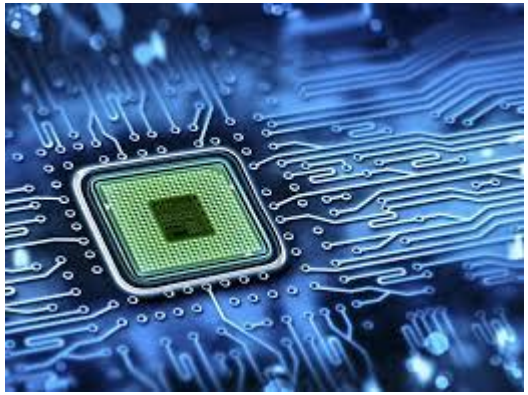
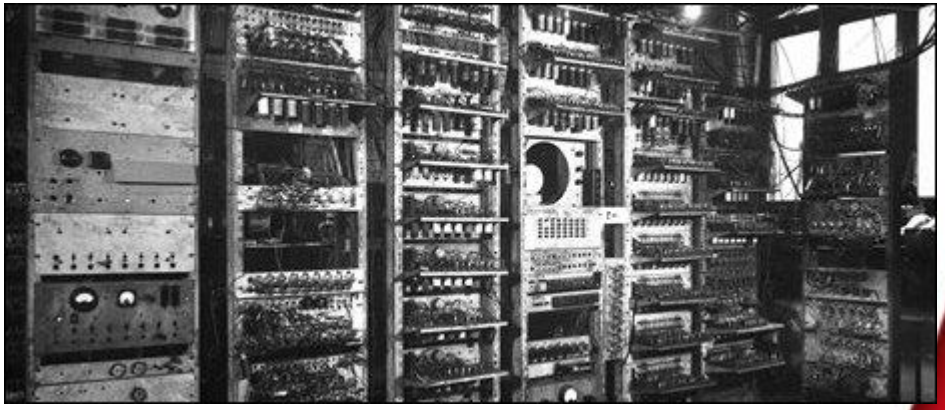
Science By The Slice

UNIVERSITY OF NEBRASKA–LINCOLN

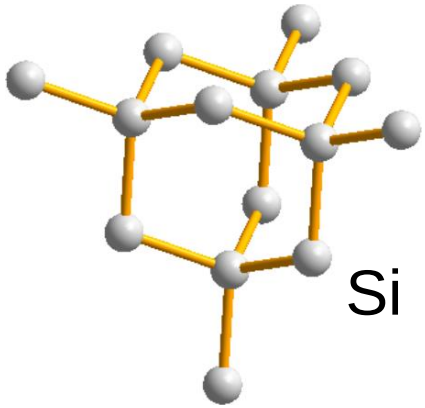
Semiconductors

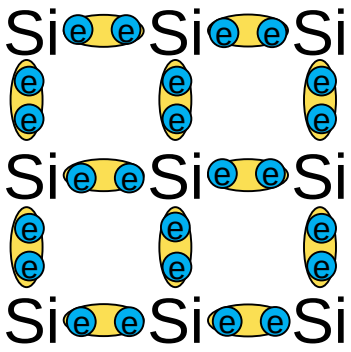




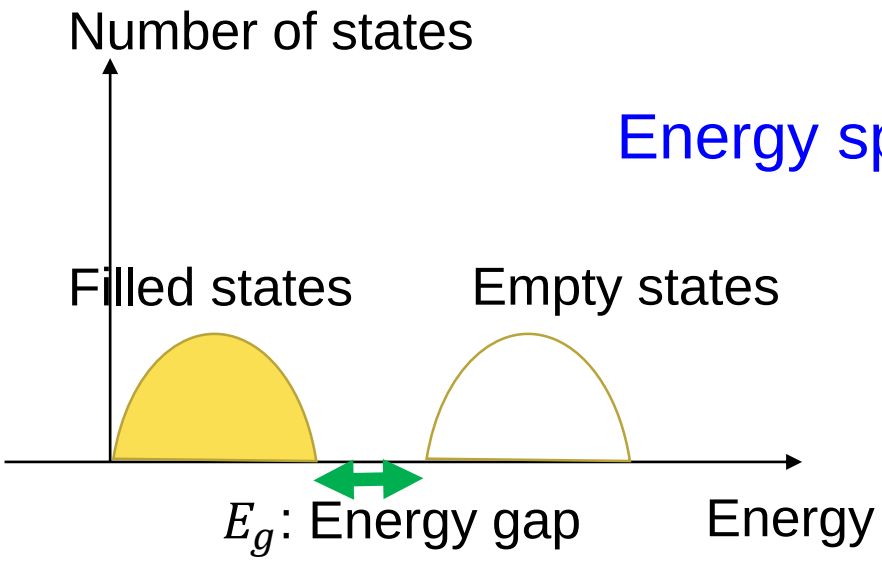


Semiconductors



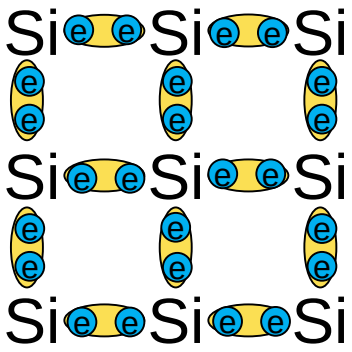


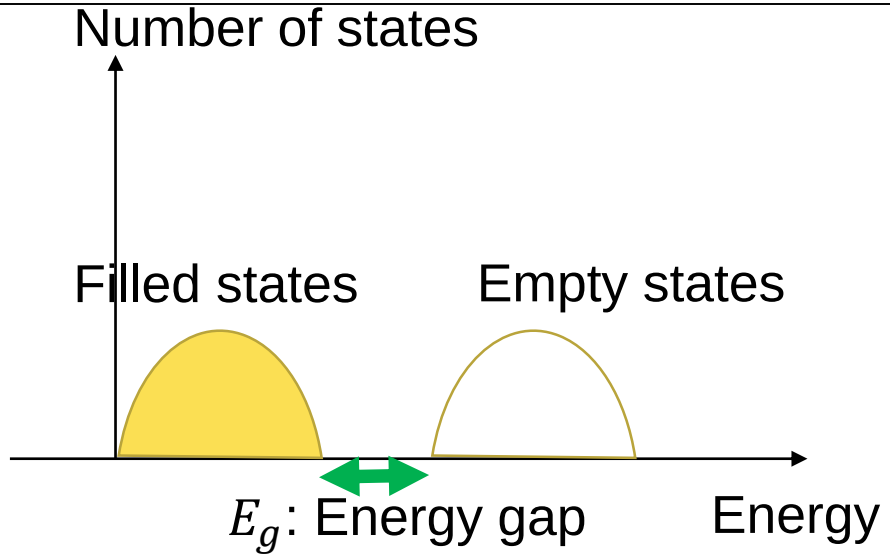
Real space view

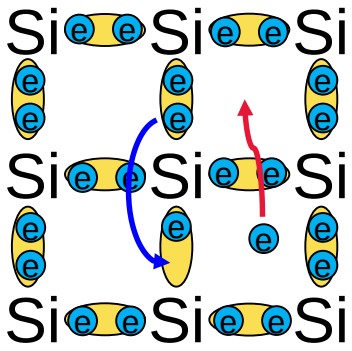


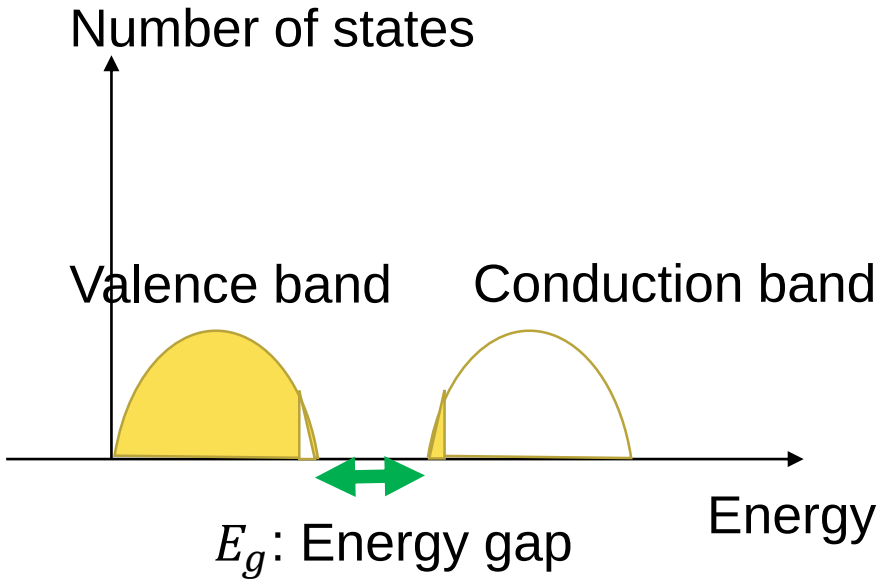
Energy space view

Intrinsic semiconductors

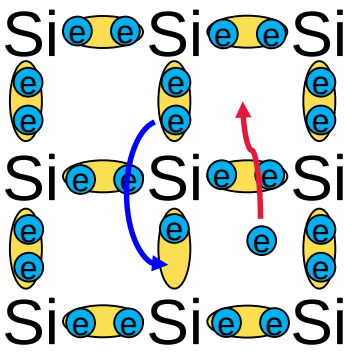






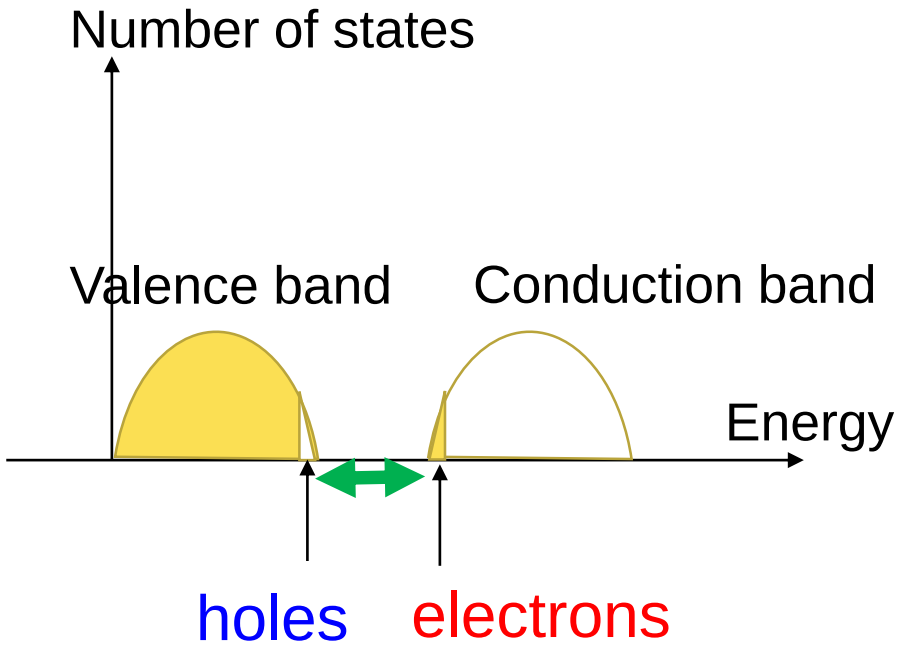


Two types of conduction channels in semiconductors

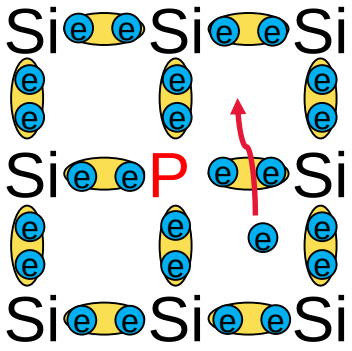


Electron conduction: (free) electrons move between non-bonding states.

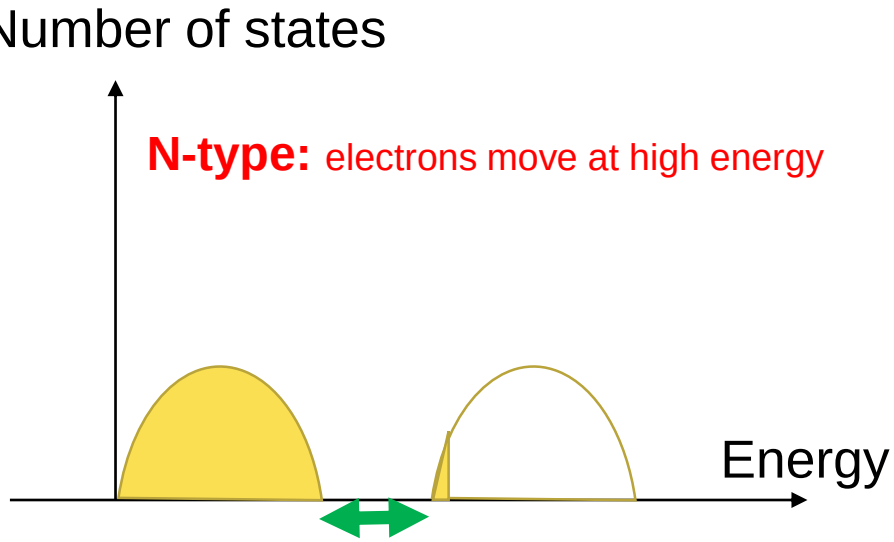
Hole conduction: (bonded) electrons move between bonding states.

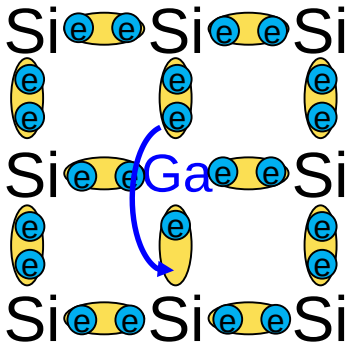


p-type and n-type (doped) semiconductors

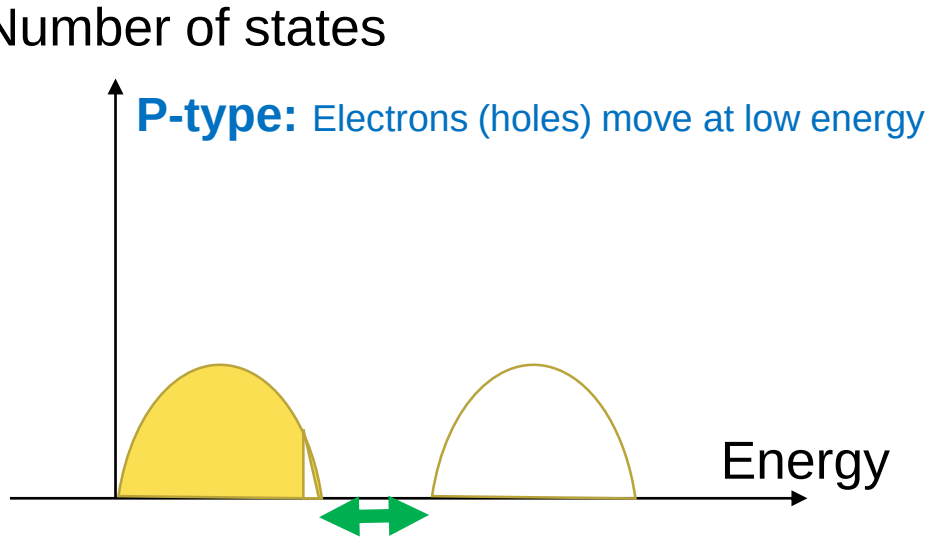


electron conduction



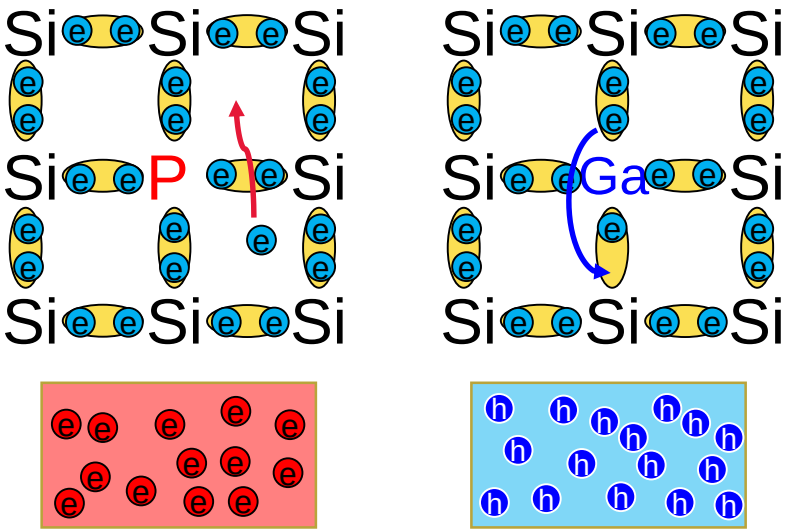


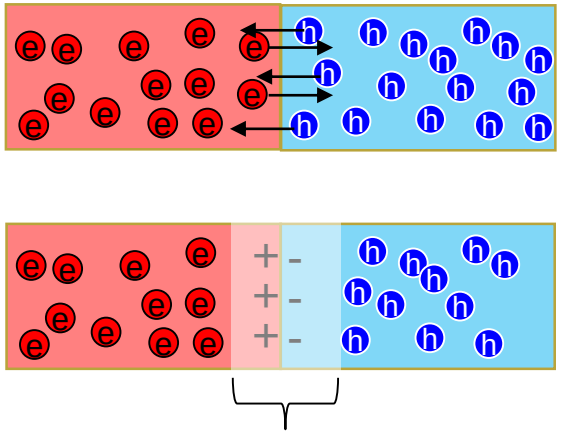
hole conduction

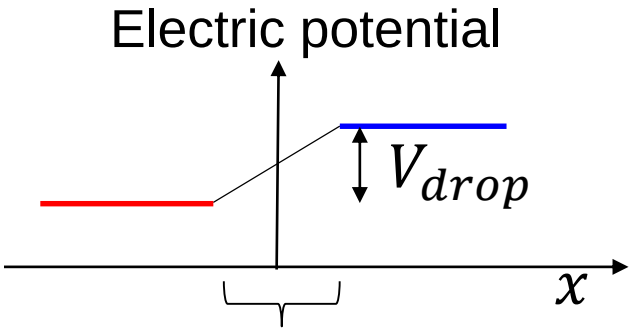


Diode and p-n junctions

p-n junctions



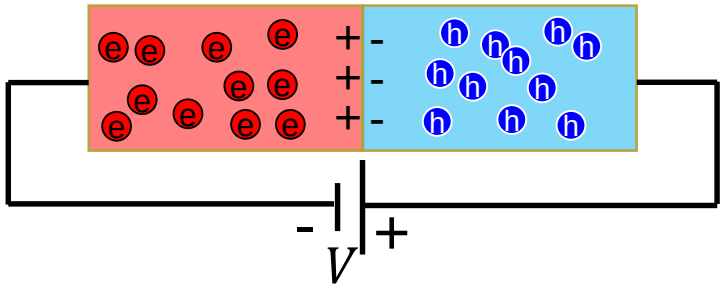


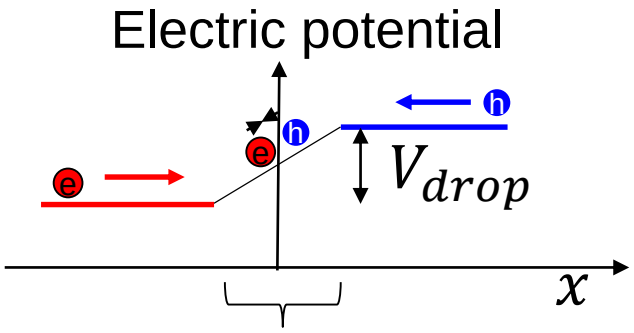


1) Electrons will move from the n-type to fill the holes in the p-type.
2) Both p-type and n-type will become (charged), building up an internal field.
3) The internal field will prevent more electrons to move into p-type to fill the holes and reach an equilibrium
4) The p-type still has holes and n-type still has extra electrons.

Resistance of a p-n junction

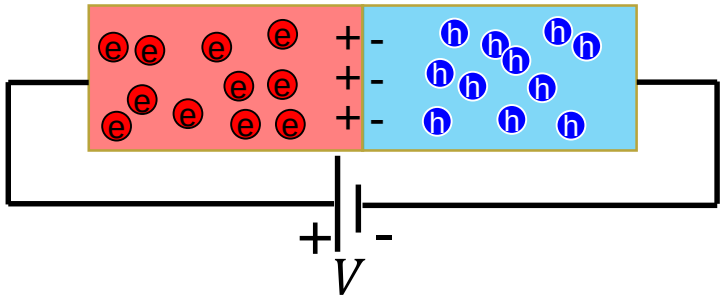
Forward bias

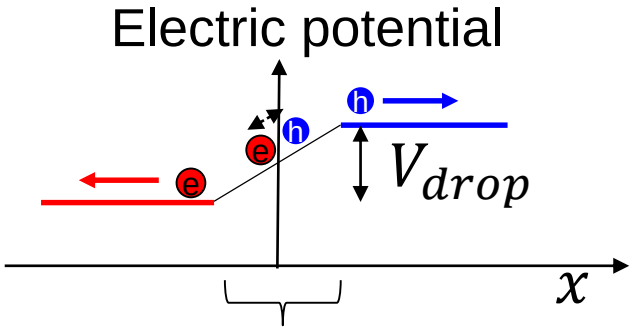




Resistance is small when $V > V_{drop}$

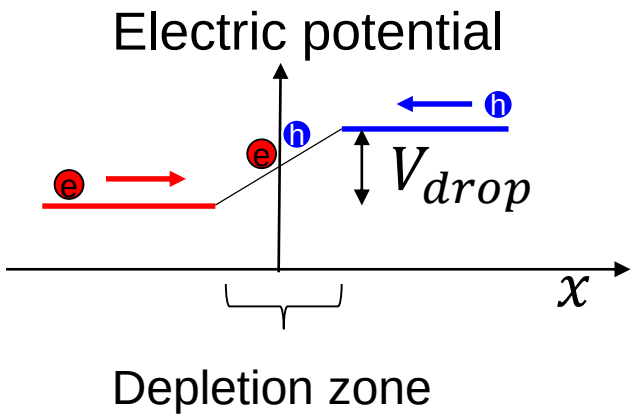
Reverse bias





The resistance is large since there is no source of electrons and holes.

Two charge transport mechanism in a p-n junction

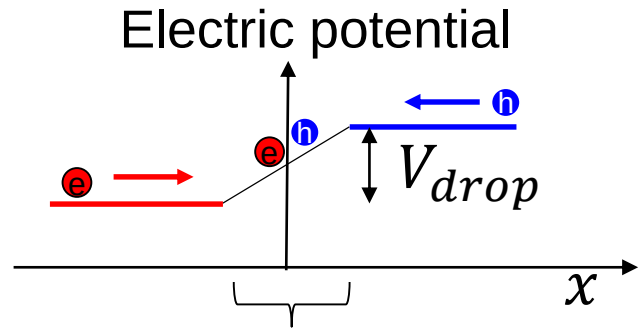


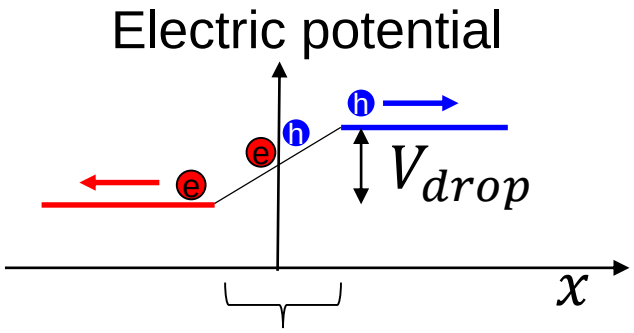
Mechanism 1: electron conduction and hole **conduction**

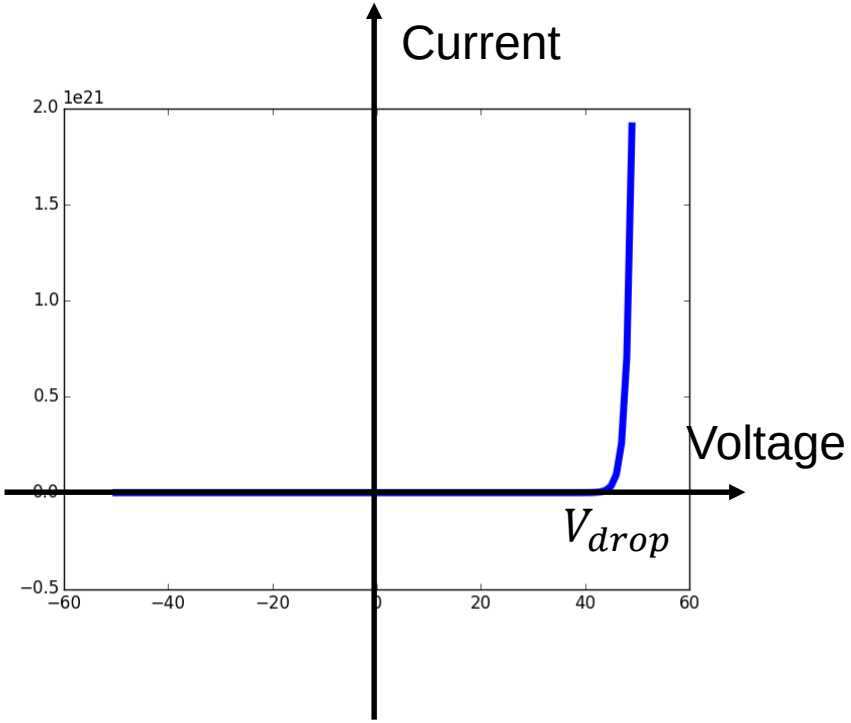
Mechanism 2: electron-hold **recombination** (annihilation)

The **recombination** is much slower (about 100 times) than the electron and hole **conduction**.

Diode: a non-liner electric component from p-n junction







The current-voltage relation does not obey Ohm' law.

Diodes (non-linear electric components)

For a diode: the resistance is a function of voltage, making it a non-linear electric component.

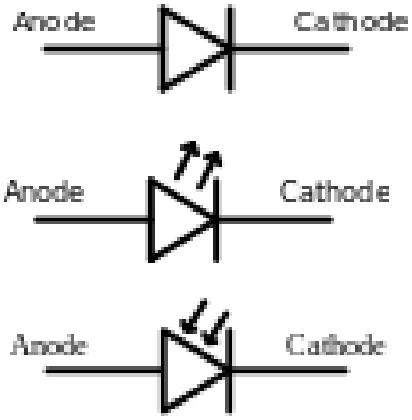
Applications

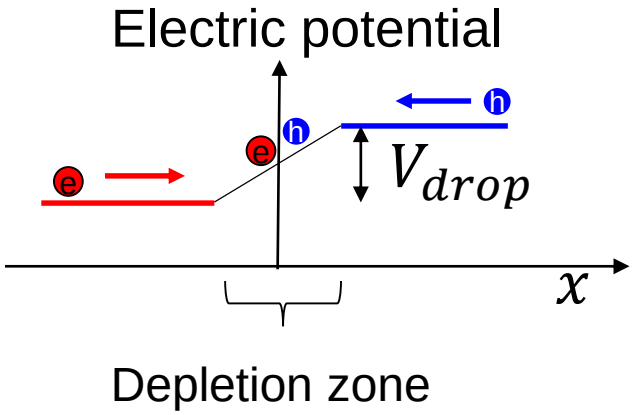
Single component:

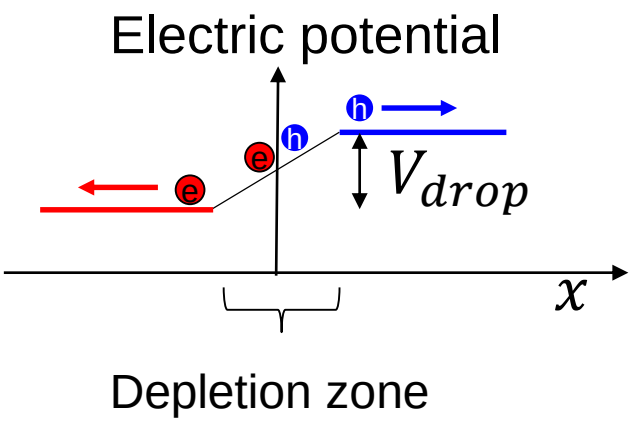
- light emitting diode (LED)
- photo detector (sensor)
- photo voltaic (energy harvest)

Multi components:

- rectifier

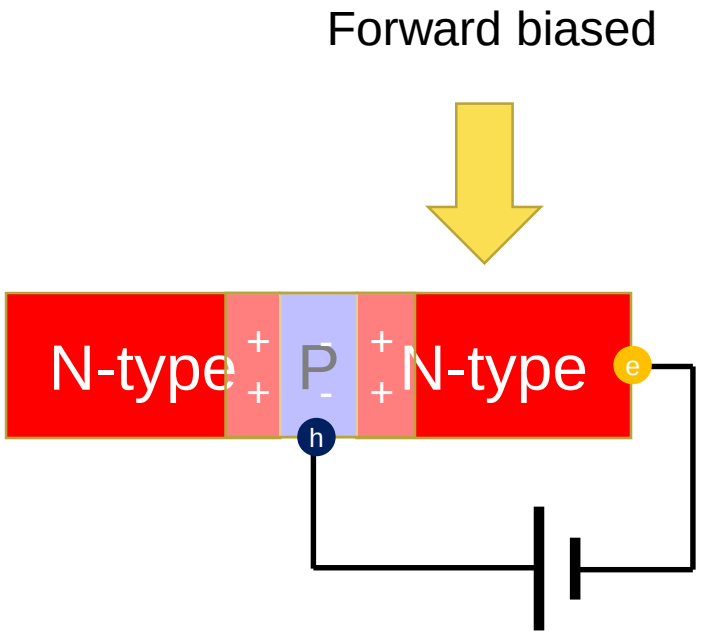


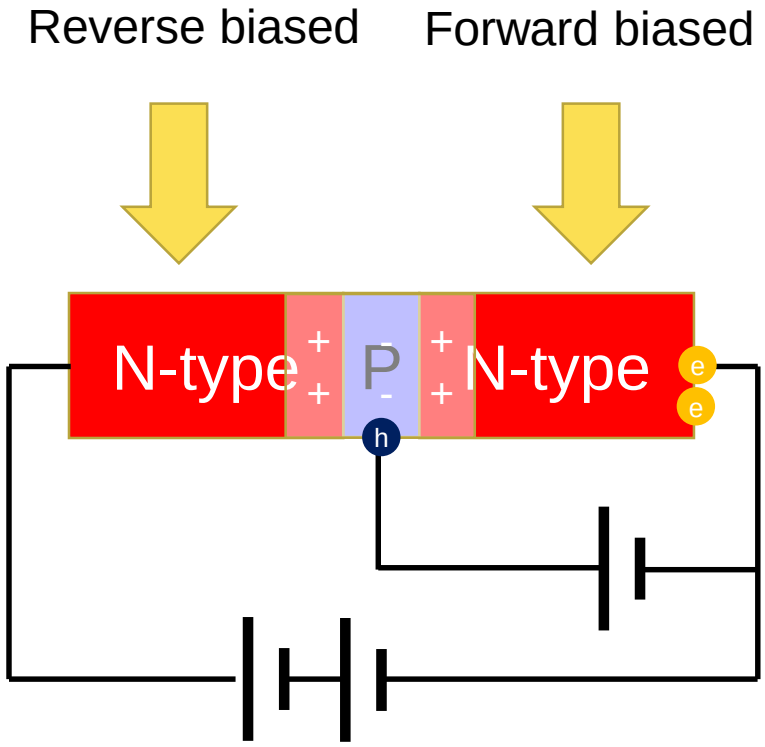




Transistors

Bipolar-junction transistor: n-p-n type

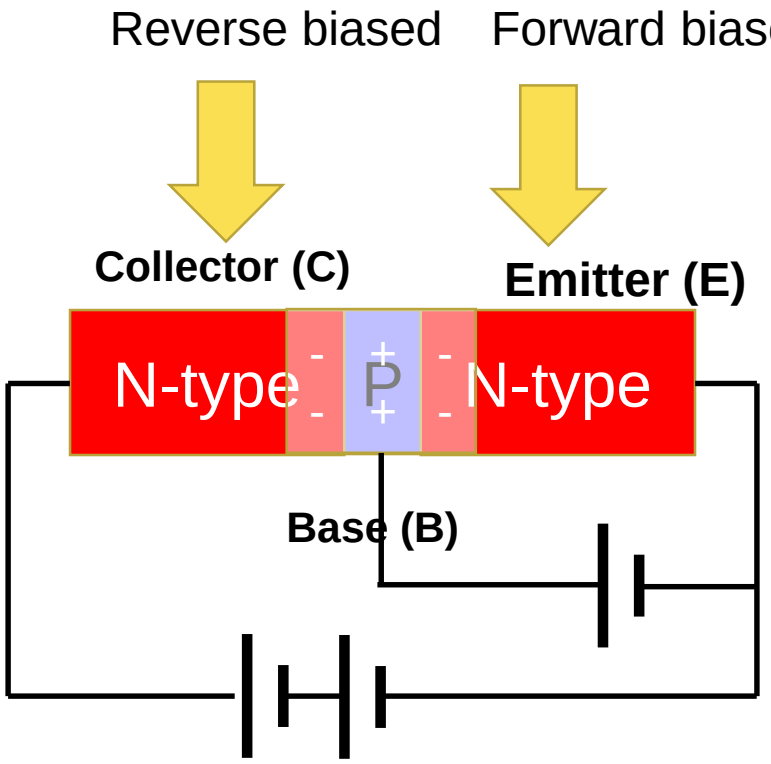


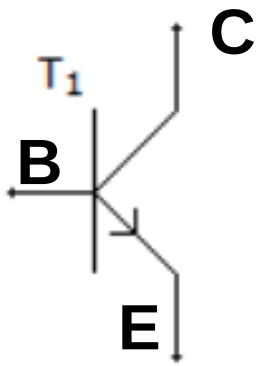


For the forward biased p-n junction, there will be significant current coming from the **recombination**.

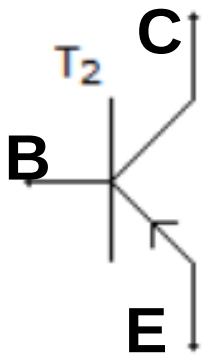
For the reversed biased p-n junction, there will be even more current because the electron conduction is 100 times faster than **recombination**.

Bipolar-junction transistor





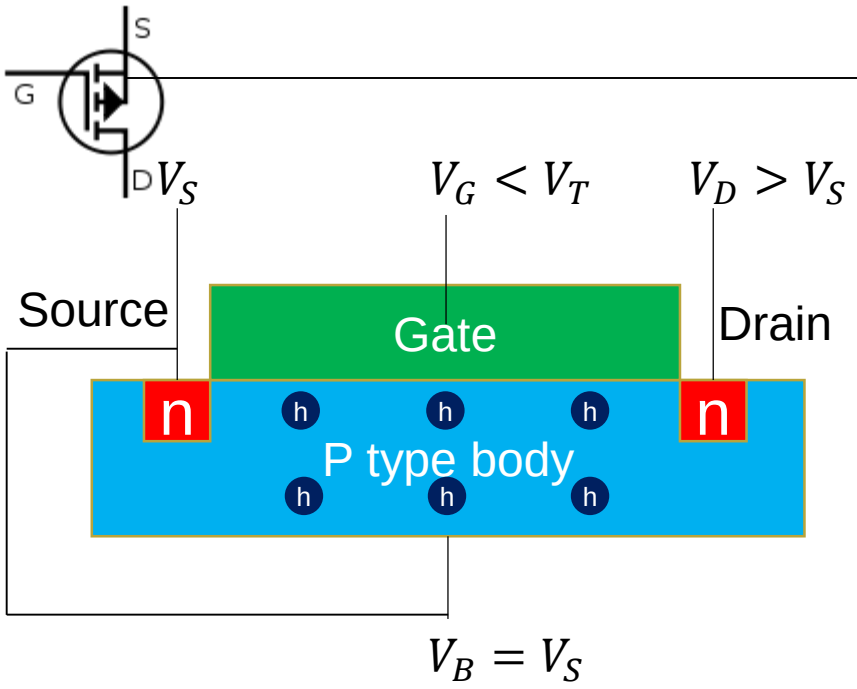
NPN



PNP

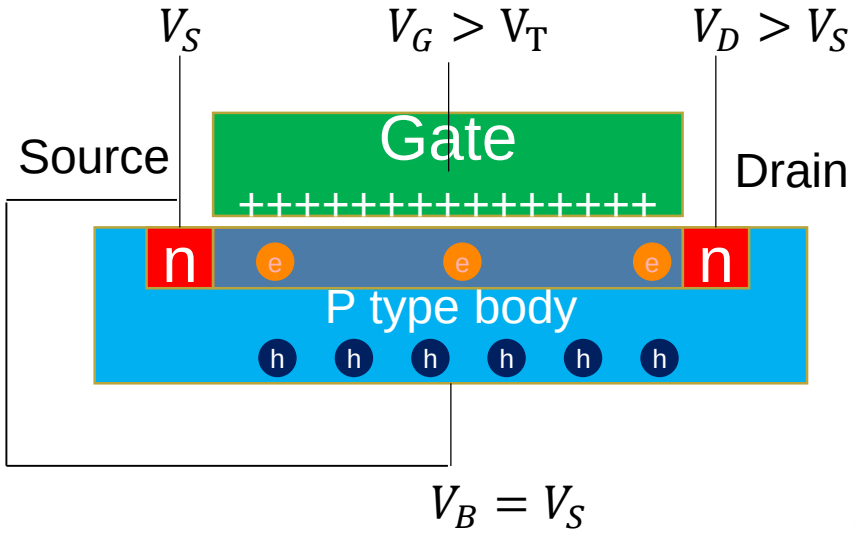
Because transport is 100 times faster than recombination, $I_C = \beta I_B,\ \beta \approx 100$.

Field-effect transistor: MOSFET (metal oxide semiconductor FET)



When the gate voltage $V_G - V_S < V_T$,, it is a PNP junction between source and drain, which normally does not conduct.

This is high resistance state.

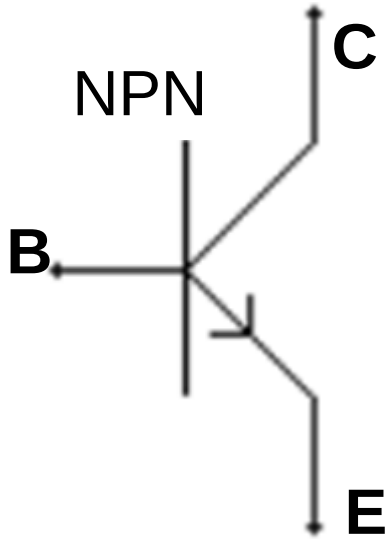


When the gate voltage $V_G - V_S > V_T$, electrons are attracted to the channel between source and drain. The part of the ***p*** type body close to the Gate is effectively ***n*** type now, which connects the two "***n***" electrodes and conductor.

This is the low resistance state.

From transistors to computers

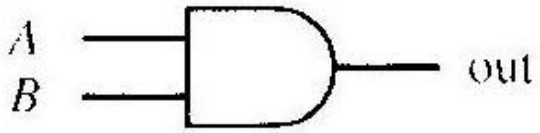
Transistor as a switch



When BE voltage is high, CE resistance is low.
So the BE voltage can be used to switch the CE circuit “ON” and “OFF”.

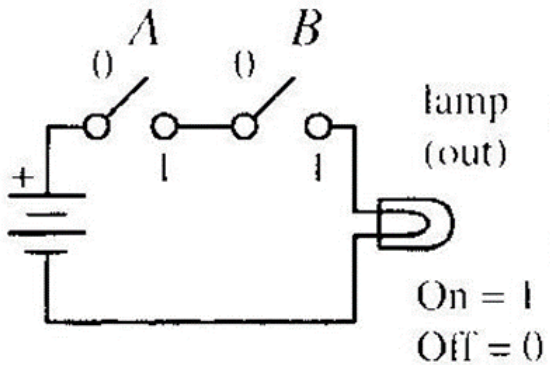
Logic AND Gate

"AND" Logic Symbol

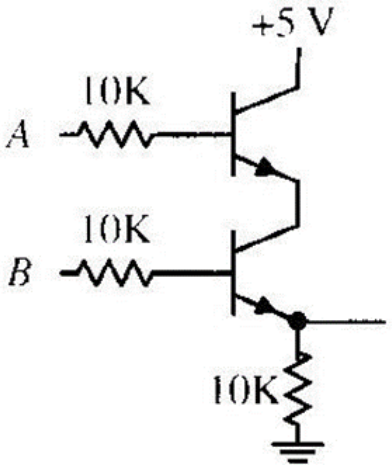


Truth Table

A	B	out
0	0	0
0	1	0
1	0	0
1	1	1



Switch Analogy

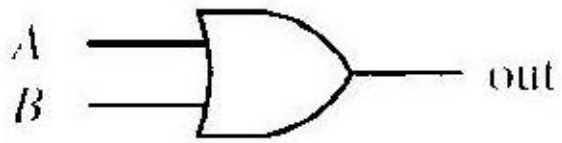


Transistor Circuit Analogy

The ouput of an AND gate is HIGH only when both inputs are HIGH.

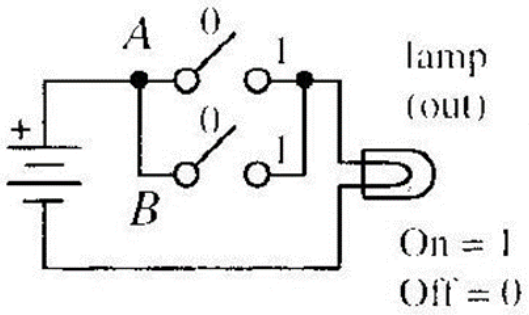
Logic OR Gate

"OR" Logic Symbol

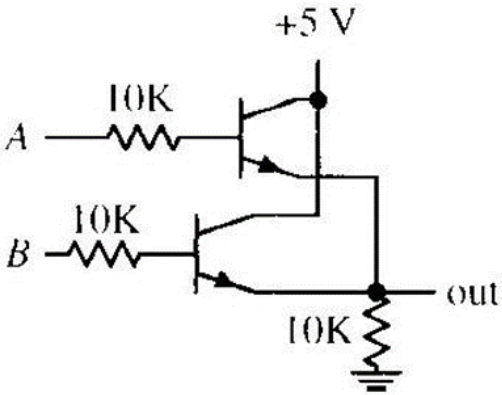


Truth Table

A	B	out
0	0	0
0	1	1
1	0	1
1	1	1



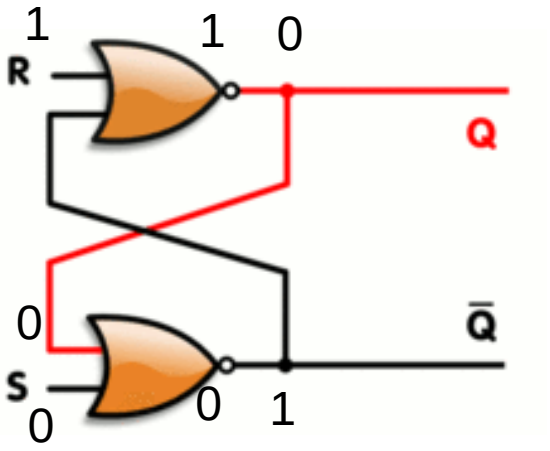
Switch Analogy



Transistor Circuit Analogy

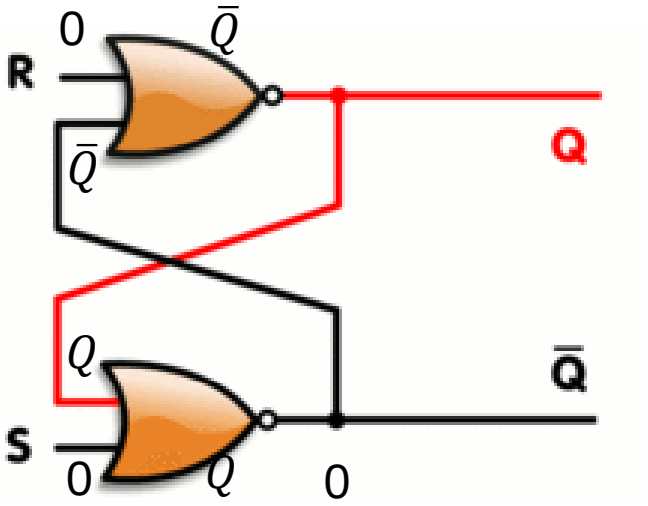
The output of an OR gate will go HIGH if one or both inputs goes HIGH. The output only goes LOW when both inputs are LOW.

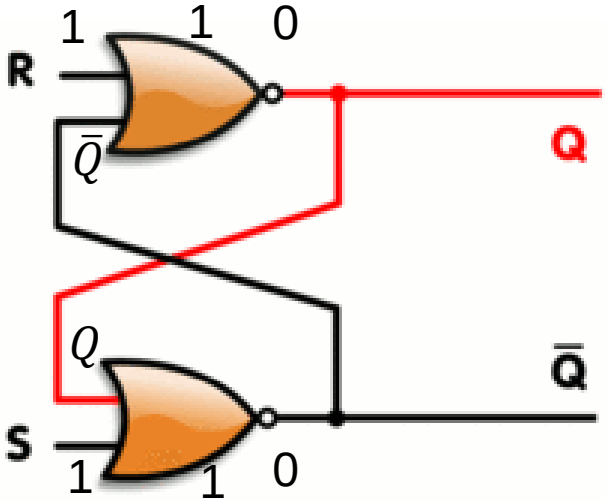
Flip-flop as memories



S	R	Q	$\bar{Q}$	
1	0	1	0	Set
0	1	0	1	Reset
0	0	Q_{t-1}	Q_{t-1}	No change
1	1	?	?	unstable

How about $S = 1, R = 0$?





Picture from https://en.wikipedia.org/wiki/Flip-flop_(electronics)

Thank you for your attention!

University of Nebraska Lincoln