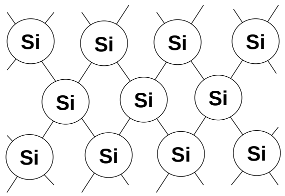
SEMICONDUCTORS: CHEMICAL STRUCTURE

Start with a silicon **substrate**.

Silicon has 4 valence electrons, and therefore a “lattice” structure:



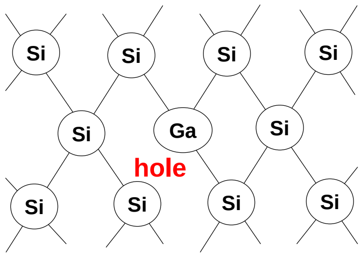
Each atom bonds with 4 neighbors.

No free electrons (poor conductor) unless you heat it up (semi conductor).

Other Group IV elements can be used for substrate, but they are harder to come by (carbon lattice for instance…)

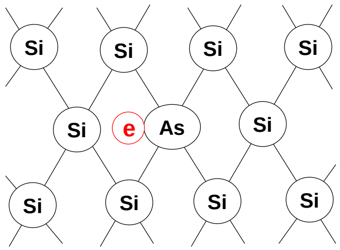
DOPING

Make silicon a better conductor by adding Group III or Group V elements: process called **doping**



Add Group III elements like gallium or indium to get **p-type material**

Note that the Ga atom has only 3 valence electrons with which to bond; missing bond is called a **hole**



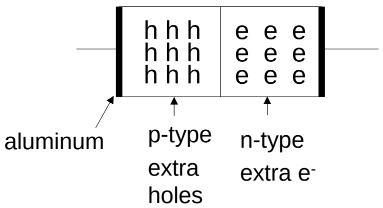
Add Group V elements like arsenic or phosphorus to get **n-type material**

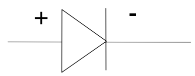
Note that the As atom has 5 valence electrons; it has an unbonded electron

Materials are electrically neutral! Equal number of protons and electrons!

P-N JUNCTION: THE BASIS FOR ELECTRONICS

Put p-type and n-type material together:





This is a diode.

Essential Property: Make current flow (or not flow) by applying electric field (voltage) to metal ends.

"Voltage Controlled Switch"

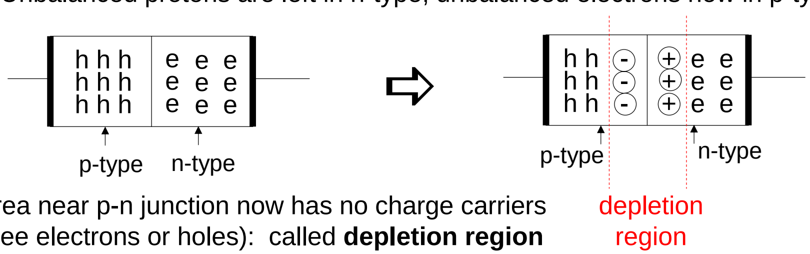
PHYSICS OF P-N JUNCTION

CASE: Open Circuit

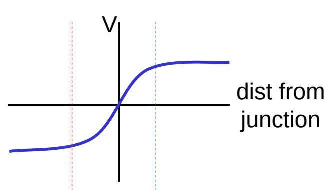
Free electrons from n-type are chemically attracted to holes in p-type.

Free electrons move across junction to fill holes: process called **diffusion**

Unbalanced protons are left in n-type, unbalanced electrons now in p-type.



Area near p-n junction now has no charge carriers (free electrons or holes): called **depletion region**



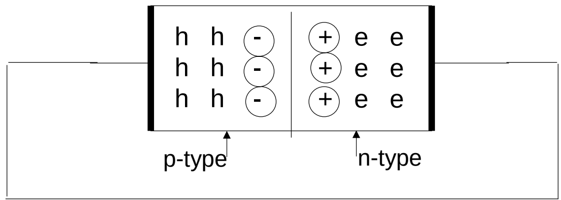
The charged atoms in the depletion region create an electric field, and thus a difference in electric potential.

When the potential drop becomes steep, the free electrons no longer cross: **drift** takes over

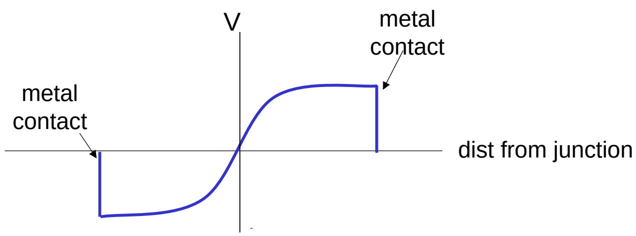
PHYSICS OF P-N JUNCTION

CASE: Short Circuit

Is there a current when I short a diode? Is KVL violated? NO.

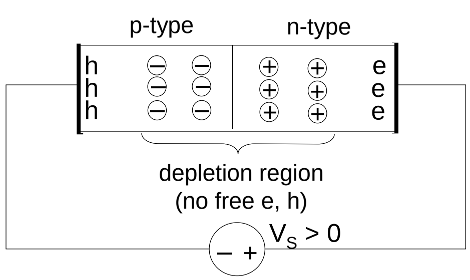


At metal-semiconductor junction, potential changes to balance device.
Electrons in metal can redistribute easily to do this.

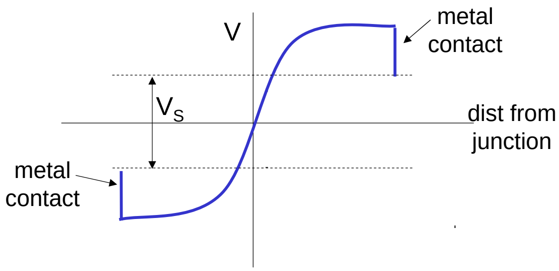


PHYSICS OF P-N JUNCTION

CASE 2: Reverse Bias



A diode is in **reverse bias** mode when the + (p-type) terminal is at a (moderately) lower potential than the – (n-type) terminal.

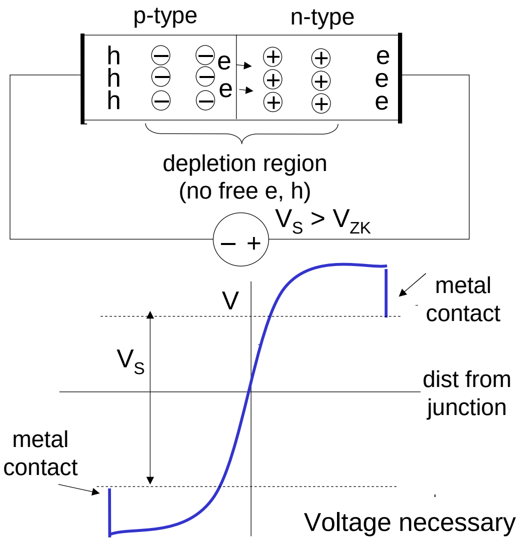


Electrons bunch up by positive metal contact, but few cross through wire because of potential drop between contacts.

A tiny "leakage current" flows due to these few stray electrons, but basically **zero current flow**.

PHYSICS OF P-N JUNCTION

CASE: Reverse Breakdown



When the diode + terminal is at a much lower potential than the - terminal, **reverse breakdown** occurs.

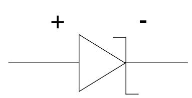
Reverse breakdown begins when the potential rise across the junction becomes so great that electrons from the p-type material travel across the rise.

The difference in potential has to be great enough to overcome the chemical bonds in the p-type lattice.

Voltage necessary for breakdown: V_{ZK} "Zener knee"

PHYSICS OF P-N JUNCTION

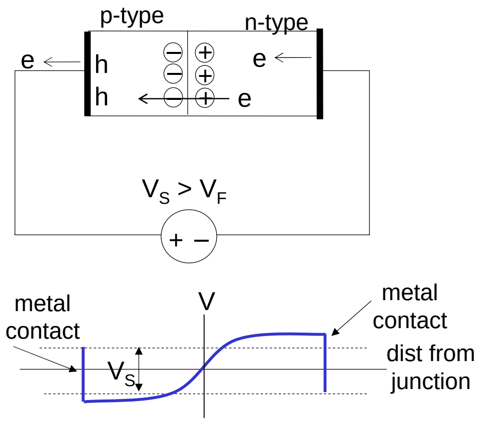
CASE: Reverse Breakdown



- There are diodes called Zener diodes that are designed to operate in reverse breakdown.
- The voltage across the diode in the reverse breakdown mode is about constant, as once the voltage gets past V_{ZK}, the depletion layer does not really increase—the current increases dramatically (also known as **avalanche current**).
- As the reverse voltage is increased, there will be a limit to the current flow: **reverse saturation current**
- A Zener diode is used to regulate voltage within a circuit, since it provides about the same voltage (V_{ZK}) for a whole range of reverse current conditions.
- Zener diodes can be obtained for a variety of V_{ZK} values, anywhere from 0.5 V to 200 V.

PHYSICS OF P-N JUNCTION

CASE: Forward Bias



The difference in potential created by the voltage source makes the drop across the junction less steep.

If V_S is large enough, greater than the diode forward voltage V_F, electron diffusion (movement to fill holes) overcomes electron drift (movement due to electric field).

Electrons flow across junction and combine with holes.

The need to redistribute charge at metal ends ensures continuous supply of electrons and holes.

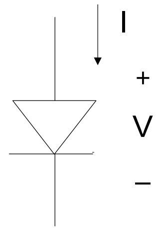
Current flows from + terminal to – terminal

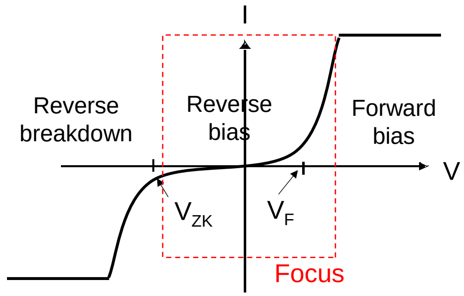
PHYSICS OF P-N JUNCTION

CASE: Forward Bias

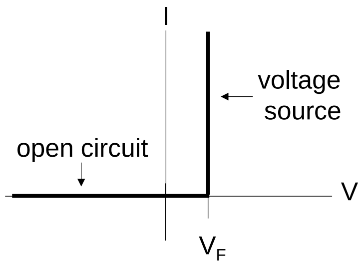
- When the voltage across the forward-biased diode is increased past V_F, the current increases dramatically.
- As the forward voltage is increased, there will be a limit to the current flow: **saturation current**
- When operating in forward-bias mode in a circuit, diode voltage is nearly constant (equal to V_F). A voltage around V_F occurs for a whole range of forward current conditions.
- Many diodes have a V_F of 0.6 to 0.7 V, but light emitting diodes (LED's) often have higher V_F values. An LED emits light when it is forward biased.

SUMMARY

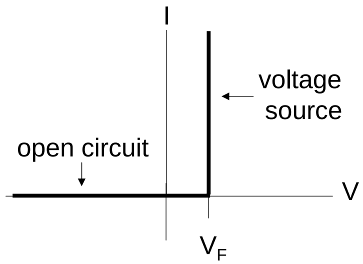




- Forward Bias
  $V > V_F$ $I > 0$
- Reverse Bias
  $V < V_F$ $I = 0$



IMPLICATIONS



We now have a voltage-controlled switch.

Voltages (1's and 0's) can perform switching, to turn other voltages on and off (create other 1's and 0's).

This is the basis of electronic computation.