MALVINO & BATES

Electronic
PRINCIPLES

SEVENTH EDITION

Chapter 2

Semiconductors

Topics Covered in Chapter 2

- Conductors
- Semiconductors
- Silicon crystals
- Intrinsic semiconductors
- Two types of flow
- Doping a semiconductor
- Two types of extrinsic semiconductors
- The unbiased diode

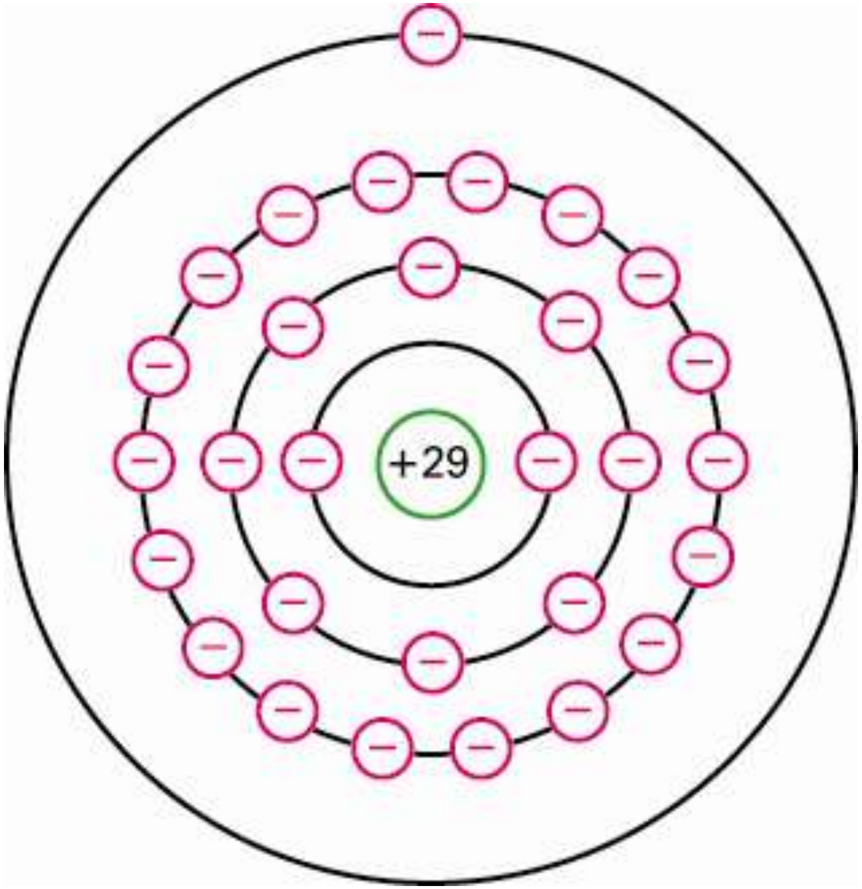
Topics Covered in Chapter 2 (Continued)

- **Forward bias**
- **Reverse bias**
- **Breakdown**
- **Energy levels**
- **The energy hill**
- **Barrier potential and temperature**
- **Reverse-biased diode**

Conductor

- A material that allows current to flow
- Examples: copper, silver, gold
- The best conductors have one valence electron

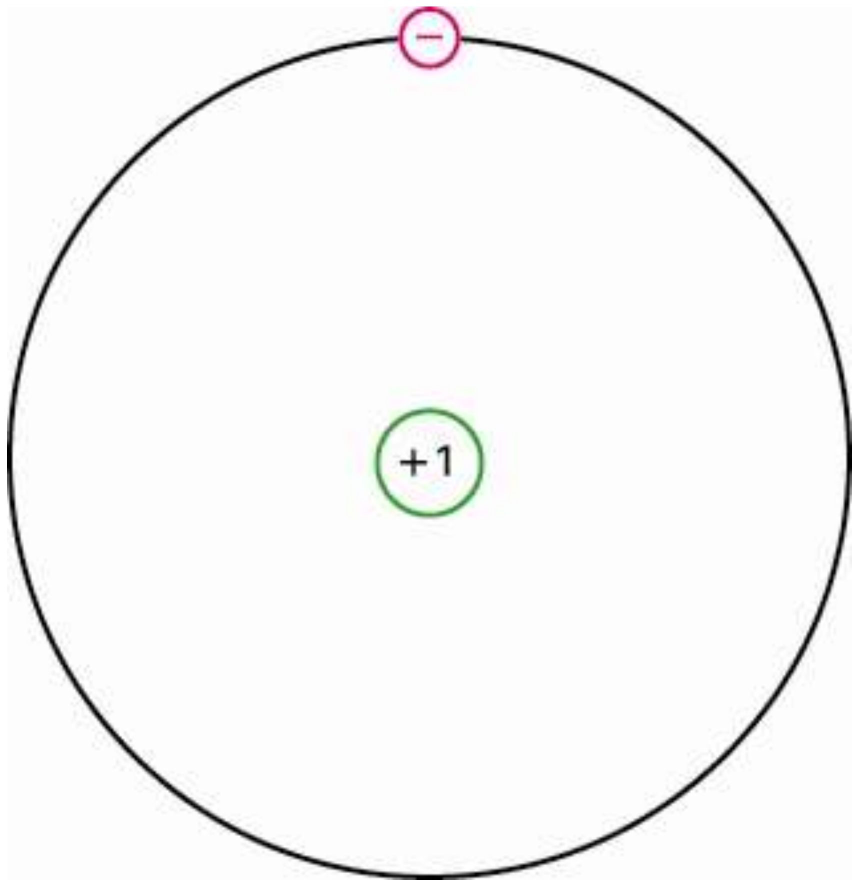
Atomic Structure of Copper



Core

- Nucleus and inner orbits
- Valence or outer orbit controls electrical properties
- Core of copper atom has net charge of + 1

Core of Copper



Free Electron

- The attraction between core and valence electron is weak
- An outside force easily dislodges a free electron from an atom

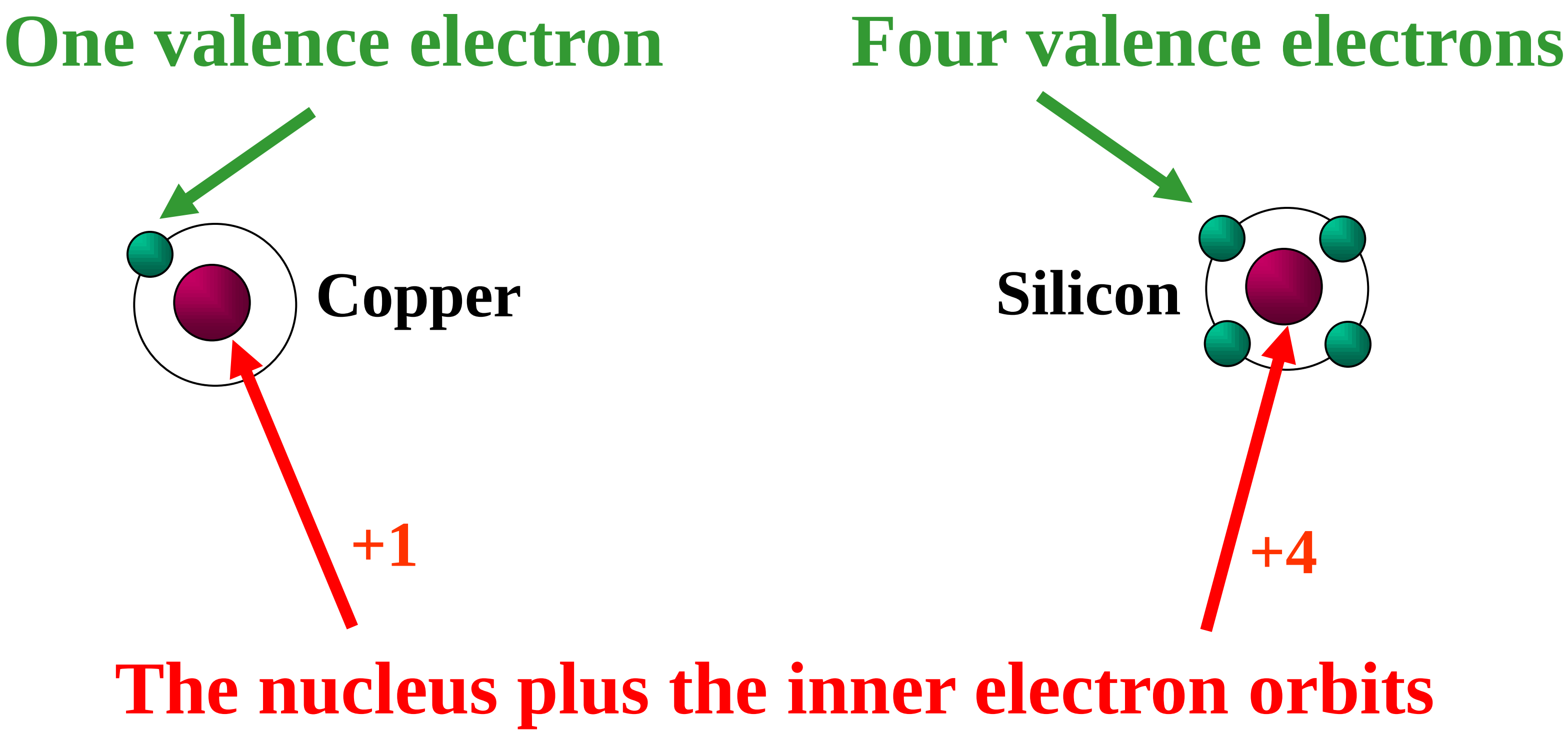
Semiconductor

An element with electrical properties between those of a conductor and those of an insulator.

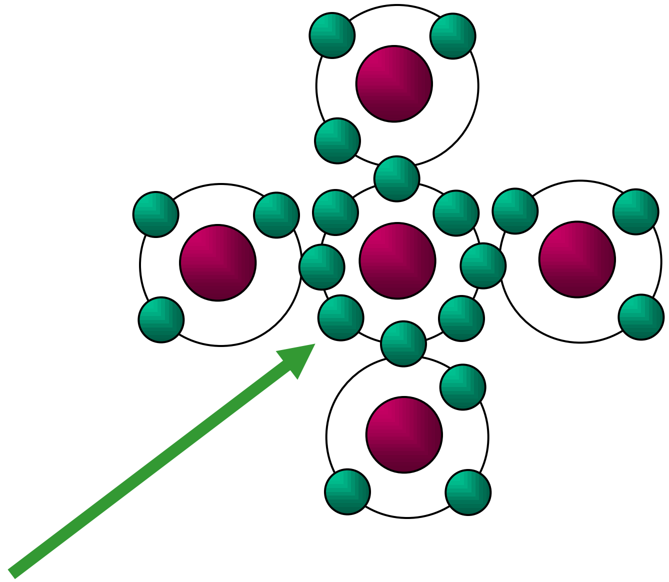
Semiconductor Examples

- Semiconductors typically have 4 valence electrons
- Germanium
- Silicon

Core diagrams for copper and silicon:



Silicon atoms in a crystal share electrons.



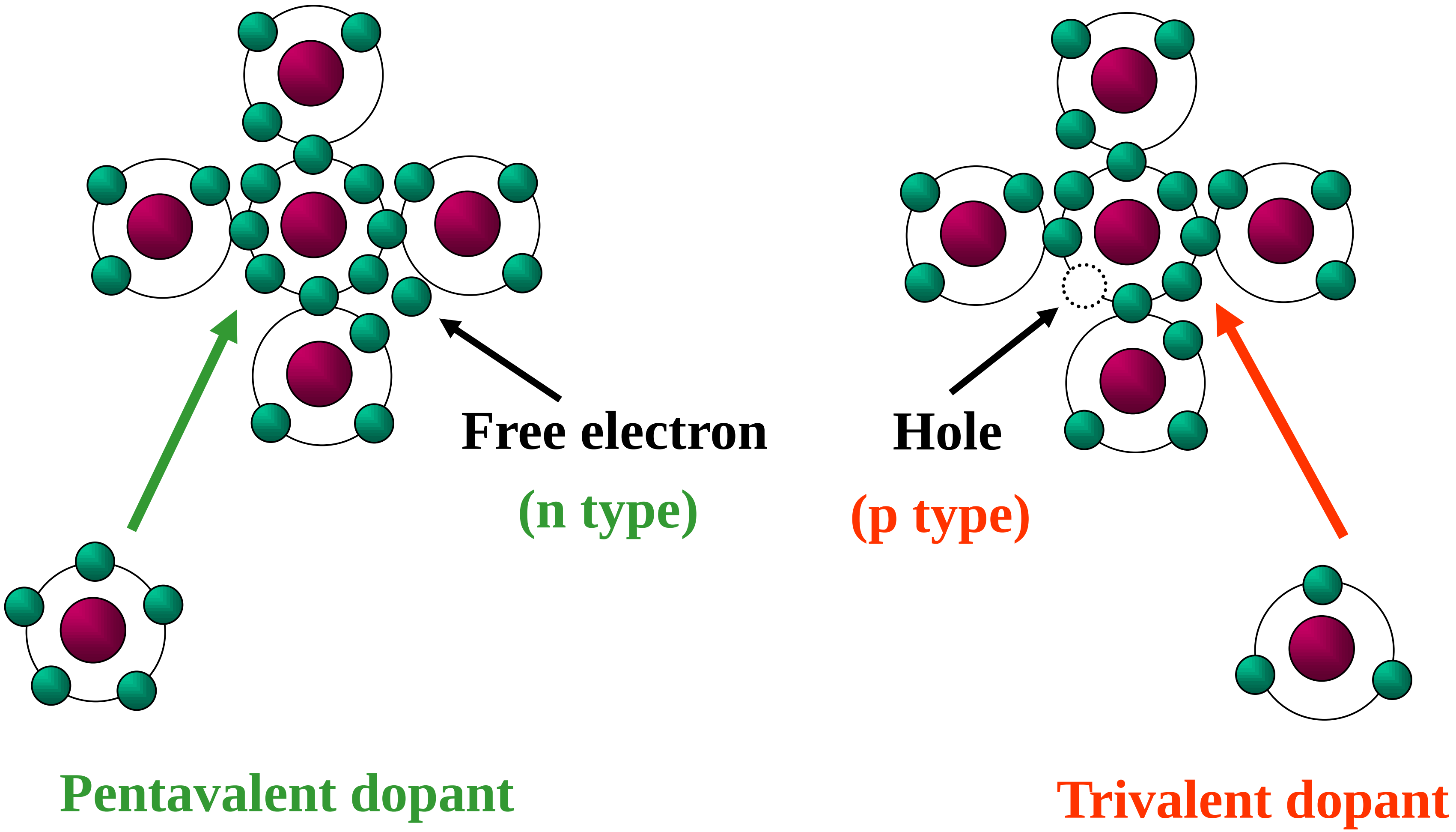
Valence saturation: n = 8

Because the valence electrons are bound, a silicon crystal at room temperature is almost a perfect insulator.

Inside a silicon crystal

- Some free electrons and holes are created by thermal energy.
- Other free electrons and holes are recombining.
- Recombination varies from a few nanoseconds to several microseconds.
- The time between creation and recombination of a free electron and a hole is called the life time.

Silicon crystals are doped to provide permanent carriers.



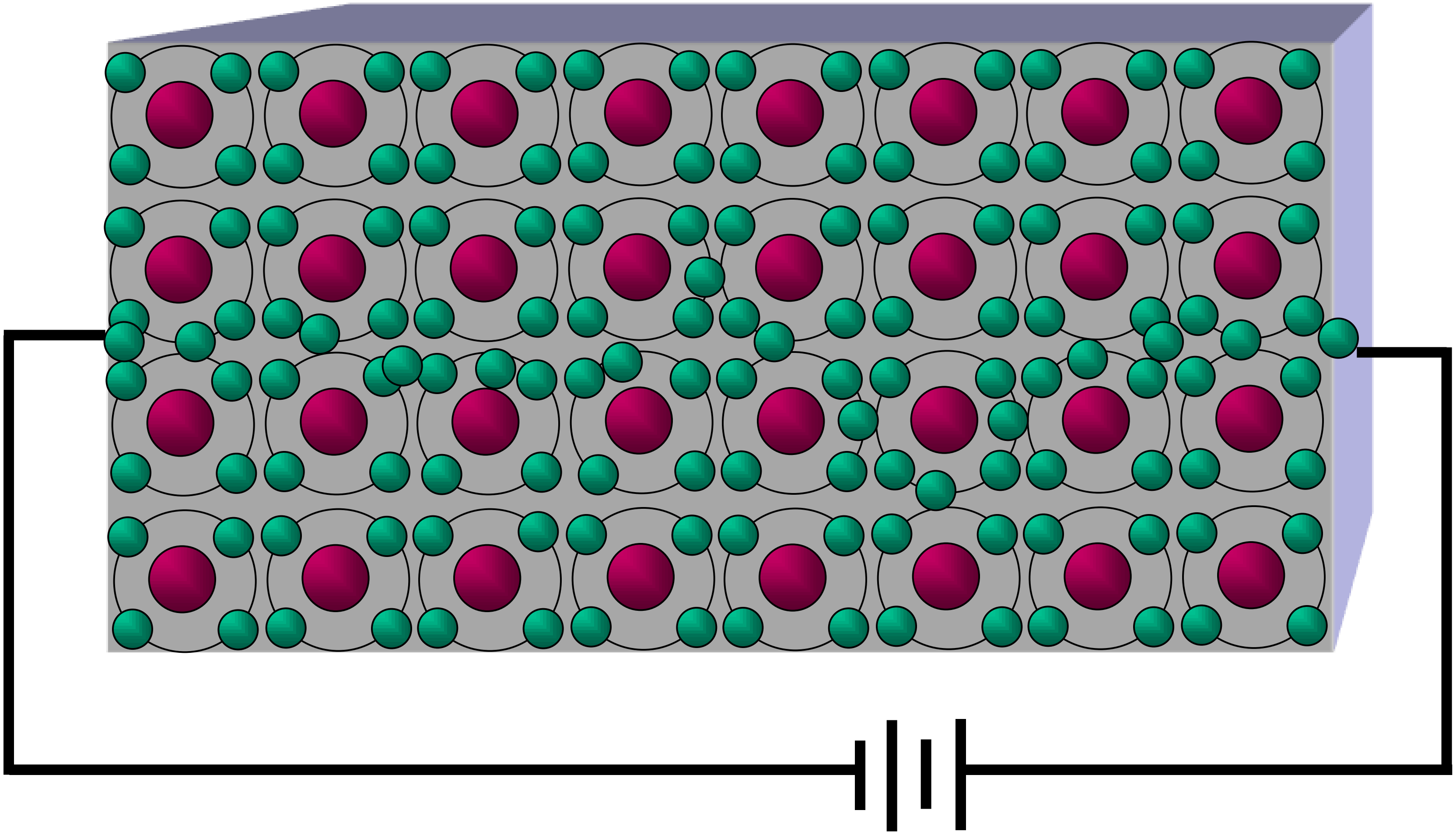
Intrinsic Semiconductor

- A pure semiconductor
- A silicon crystal is intrinsic if every atom in the crystal is a silicon atom
- Two types of current flow: electrons and holes

Doping

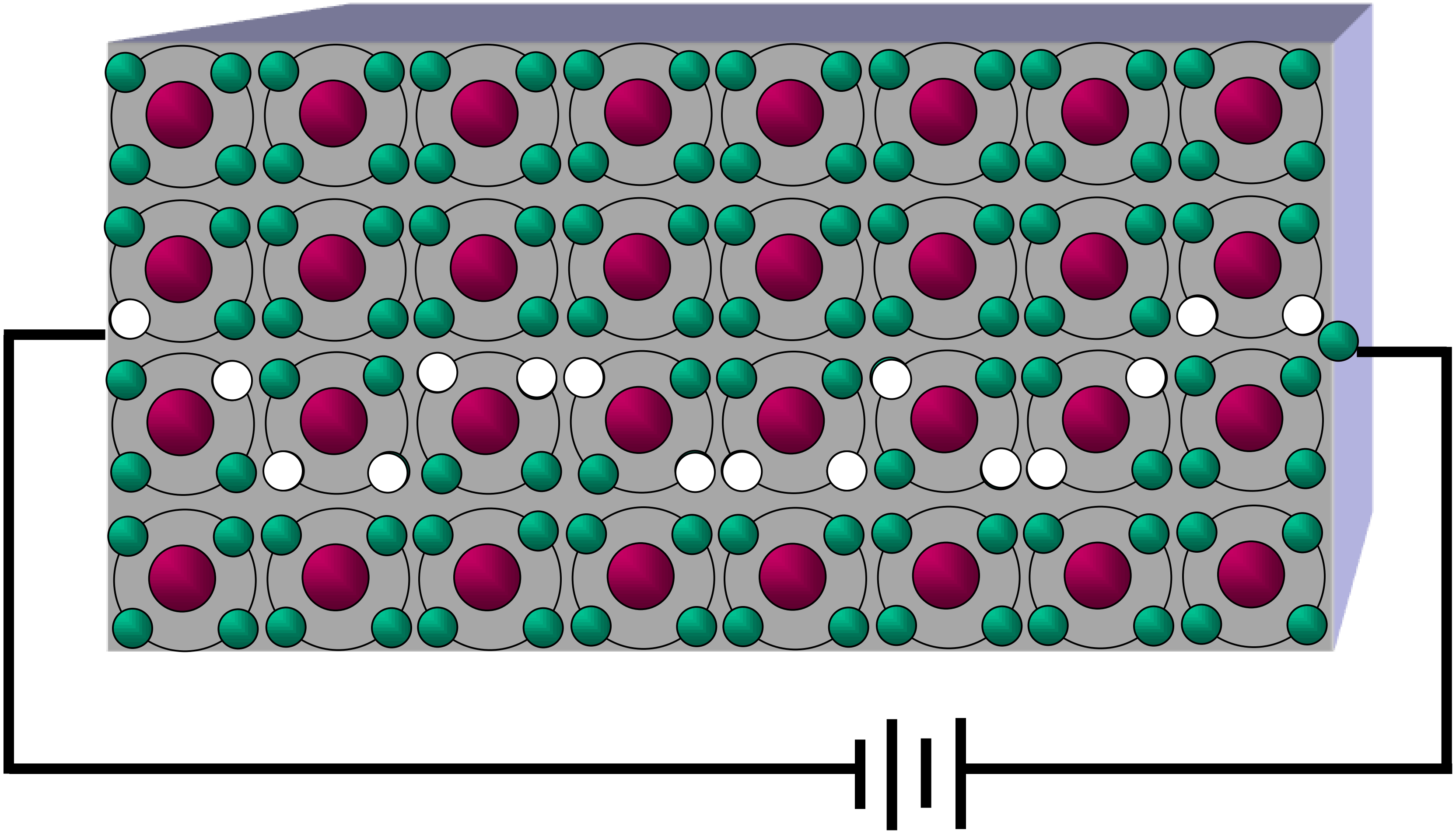
- Adding impurity atoms to an intrinsic crystal to alter its electrical conductivity
- A doped semiconductor is called an extrinsic semiconductor

This crystal has been doped with a pentavalent impurity.



The free electrons in n type silicon support the flow of current.

This crystal has been doped with a trivalent impurity.



The holes in p type silicon support the flow of current.

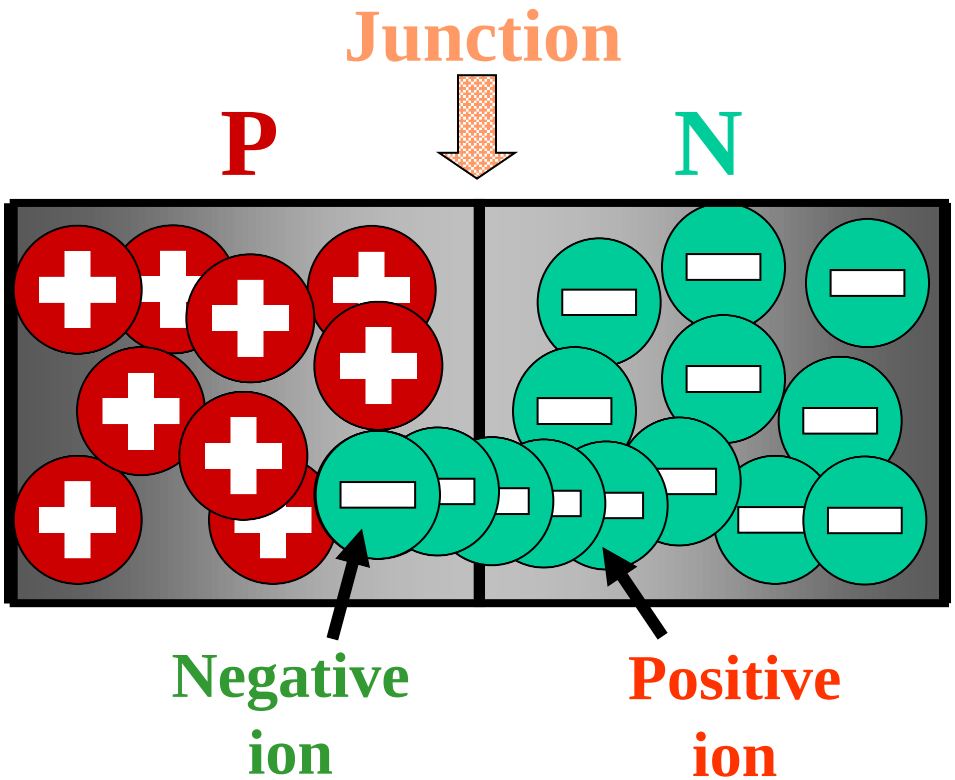
Note that hole current is opposite in direction to electron current.

Semiconductors in Summary

- **The most popular material is silicon.**
- **Pure crystals are intrinsic semiconductors.**
- **Doped crystals are extrinsic semiconductors.**
- **Crystals are doped to be n type or p type.**
- **An n type semiconductor will have a few *minority* carriers (*holes*).**
- **A p type semiconductor will have a few *minority* carriers (*electrons*).**

- **A semiconductor can be doped to have an excess of free electrons or holes**
- **The two types of doped semiconductors are n type and p type**

Doping a crystal with both types of impurities forms a pn junction diode.



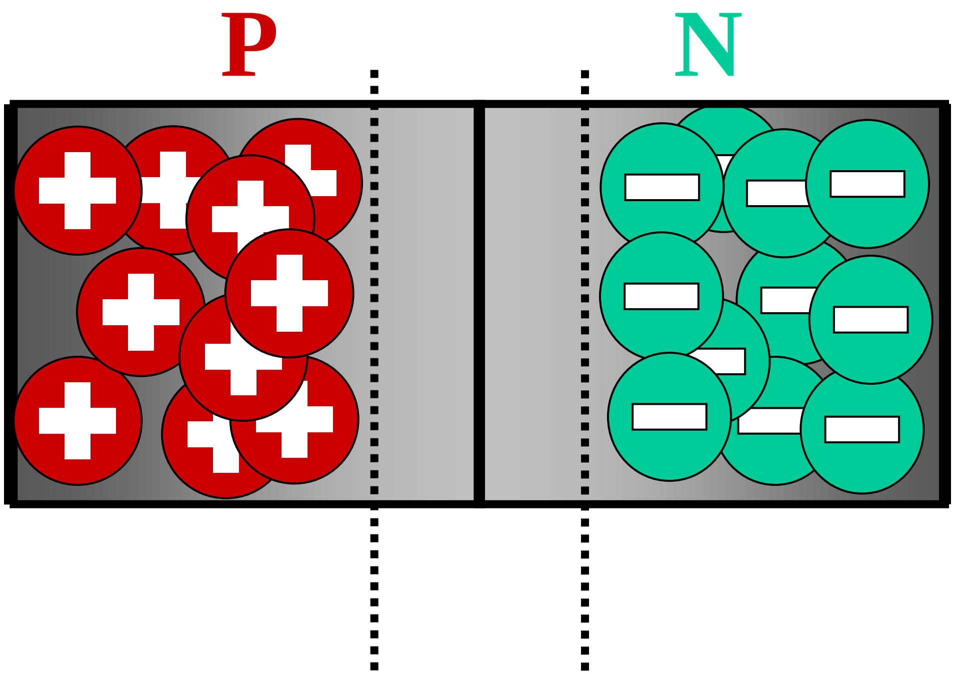
Some electrons will cross the junction and fill holes. A pair of ions is created each time this happens.

As this ion charge builds up, it prevents further charge migration across the junction.

The pn barrier potential

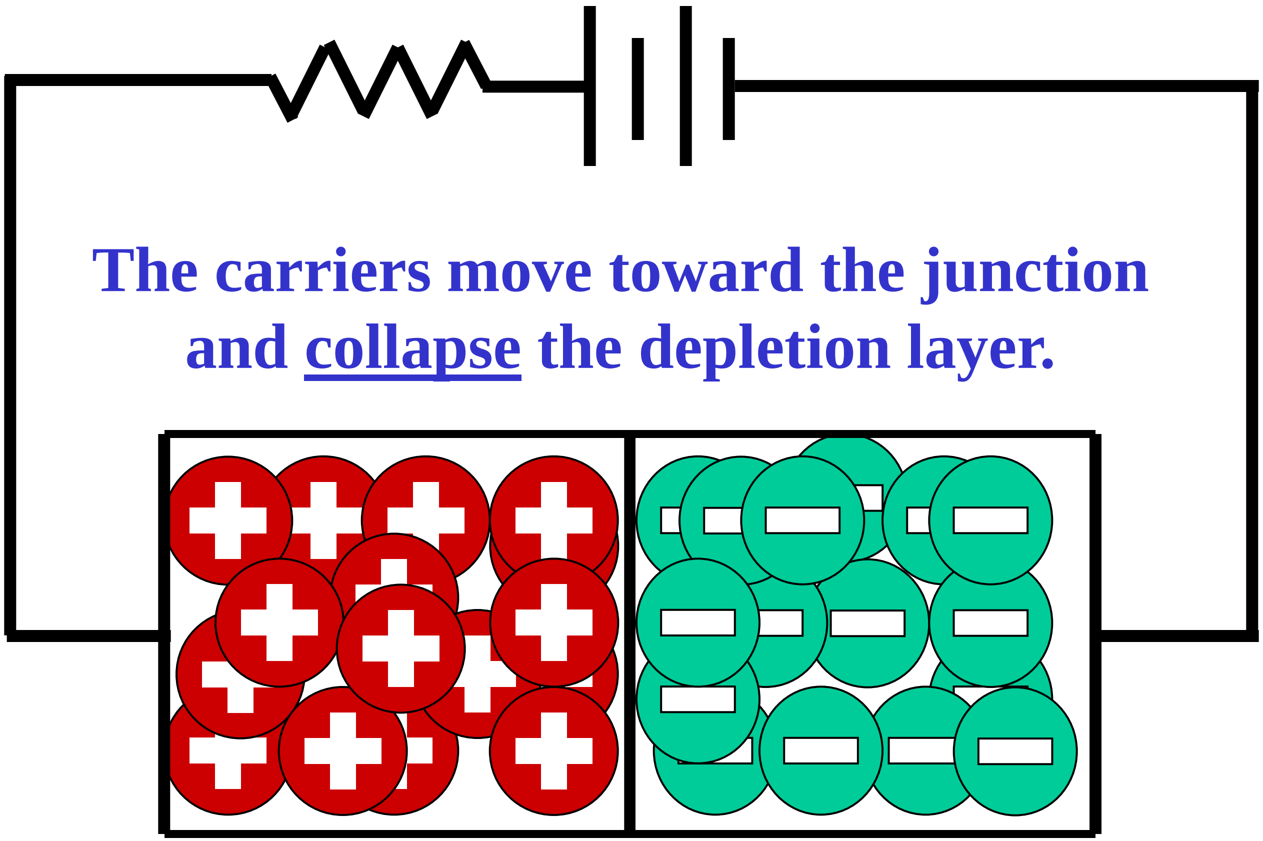
- Electron diffusion creates ion pairs called **dipoles**.
- Each dipole has an associated **electric field**.
- The junction goes into **equilibrium** when the barrier potential prevents further diffusion.
- At 25 degrees C, the **barrier potential** for a silicon pn junction is about **0.7** volts.

Each electron that migrates across the junction and fills a hole effectively eliminates both as current carriers.



This results in a region at the junction that is <u>depleted</u> of carriers and acts as an insulator.

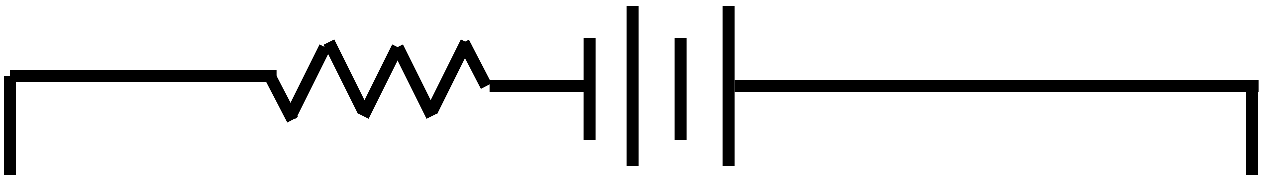
Forward bias



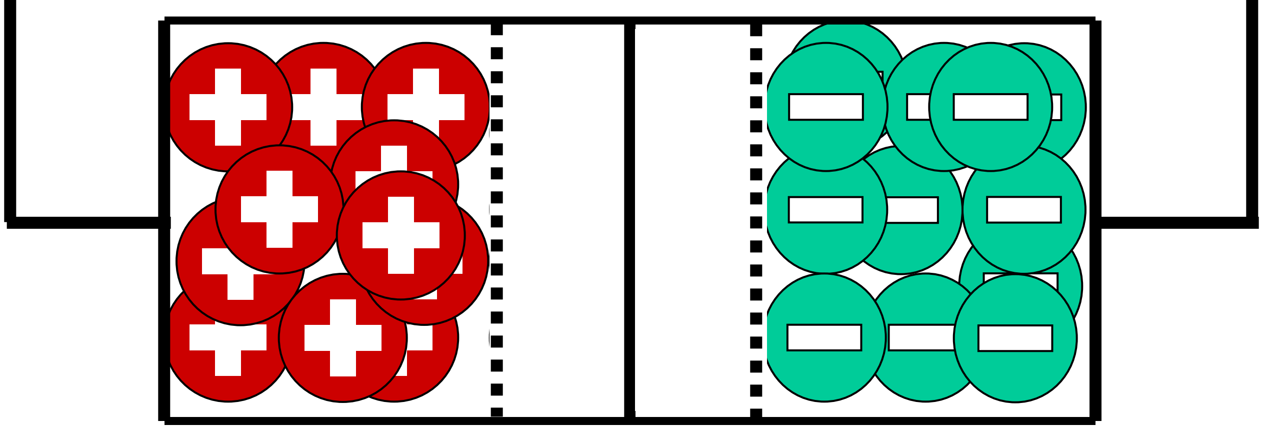
The carriers move toward the junction and collapse the depletion layer.

If the applied voltage is greater than the barrier potential, the diode conducts.

Reverse bias



The carriers move away from the junction.



The depletion layer is reestablished and the diode is <u>off</u>.

Diode bias

- Silicon diodes turn on with a forward bias of approximately 0.7 volts.
- With reverse bias, the depletion layer grows wider and the diode is off.
- A small minority carrier current exists with reverse bias.
- The reverse flow due to thermal carriers is called the saturation current.

Diode breakdown

- **Diodes cannot withstand extreme values of reverse bias.**
- **At high reverse bias, a carrier avalanche will result due to rapid motion of the minority carriers.**
- **Typical breakdown ratings range from 50 volts to 1000 volts.**

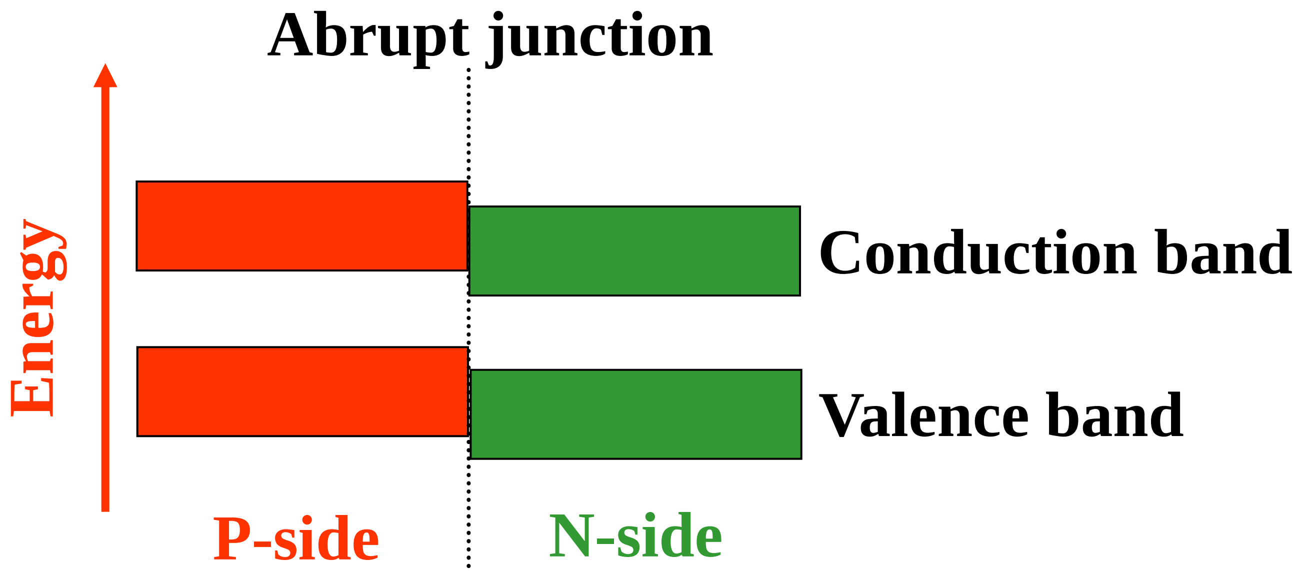
Energy levels

- Extra energy is needed to lift an electron into a higher orbit.
- Electrons farther from the nucleus have higher potential energy.
- When an electron falls to a lower orbit, it loses energy in the form of heat, light, and other radiation.
- An LED is an example where some of the potential energy is converted to light.

Energy Hill

- Barrier potential of a diode
- Electrons need sufficient energy to cross the junction
- An external voltage source that forward biases the diode provides energy

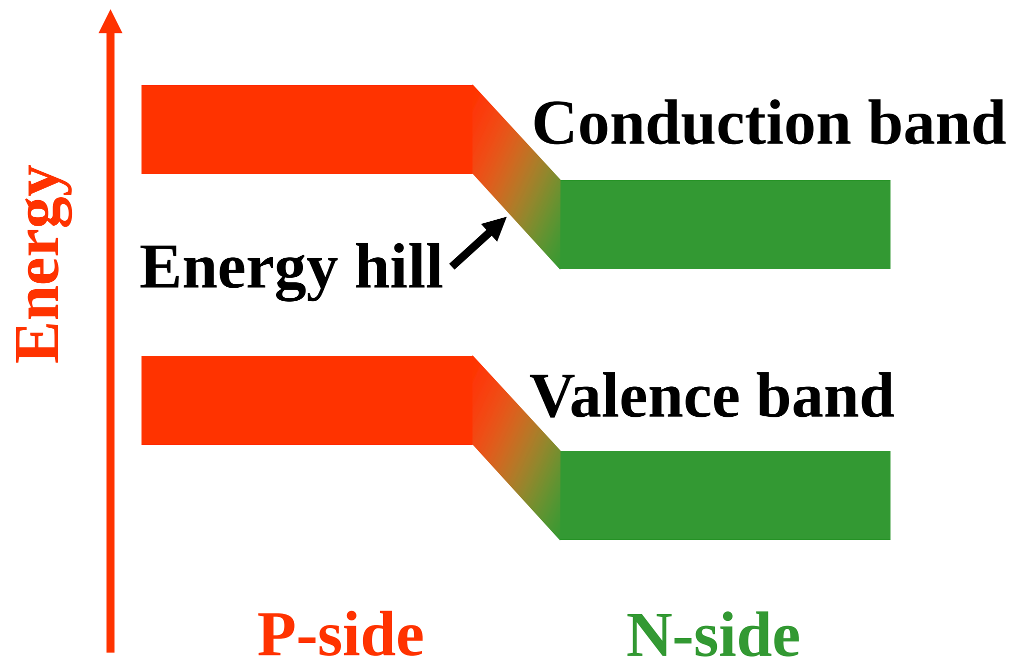
The p side of a pn junction has <u>trivalent</u> atoms with a core charge of +3. This core <u>attracts</u> electrons less than a +5 core.



In an <u>abrupt</u> junction, the p side bands are at a slightly higher energy level.

Real diodes have a gradual change from one material to the other. The abrupt junction is conceptual.

Energy bands after the depletion layer has formed



To an electron trying to diffuse across the junction, the path it must travel looks like an energy hill. It must receive the extra energy from an outside source.

Junction temperature

- The junction temperature is the temperature inside the diode, right at the pn junction.
- When a diode is conducting, its junction temperature is higher than the ambient.
- There is less barrier potential at elevated junction temperatures.
- The barrier potential decreases by 2 mV for each degree Celsius rise.

Reverse diode currents

- Transient current occurs when reverse voltage changes.
- I_S, the saturation or minority-carrier current, doubles for each 10 degree Celsius rise in temperature. It is not proportional to reverse voltage.
- The surface of a crystal does not have complete covalent bonds. The holes that result produce a surface-leakage current that is directly proportional to reverse voltage.