

MALVINO & BATES

**Electronic
PRINCIPLES**

SEVENTH EDITION



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**

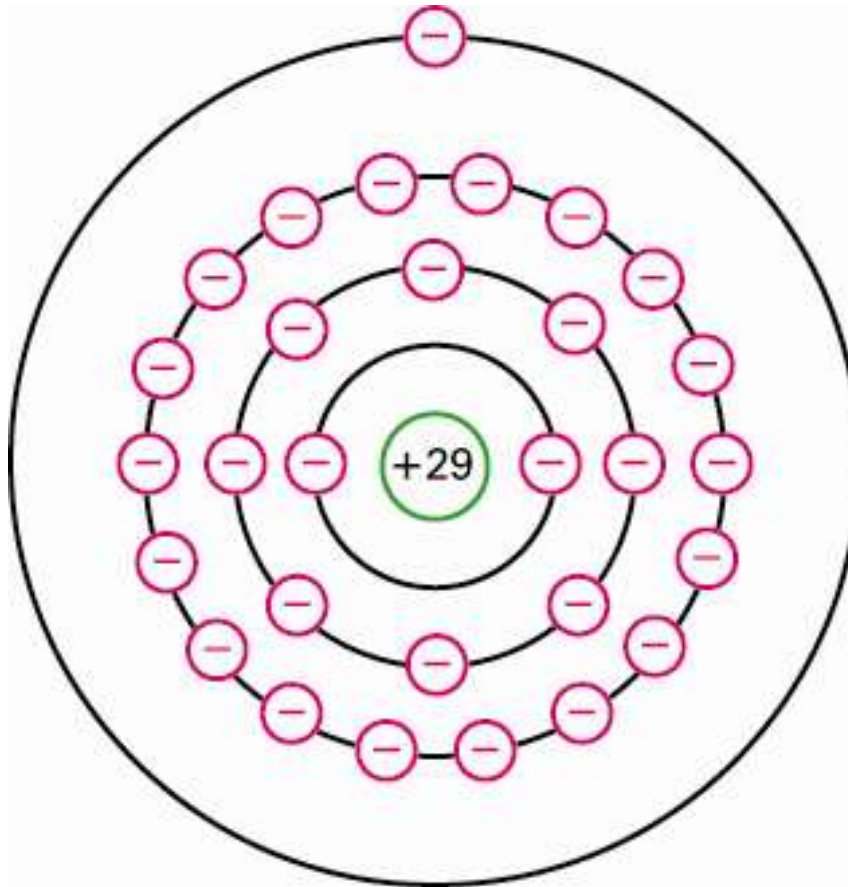
Topics Covered in Chapter 2 (Continued)

- **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

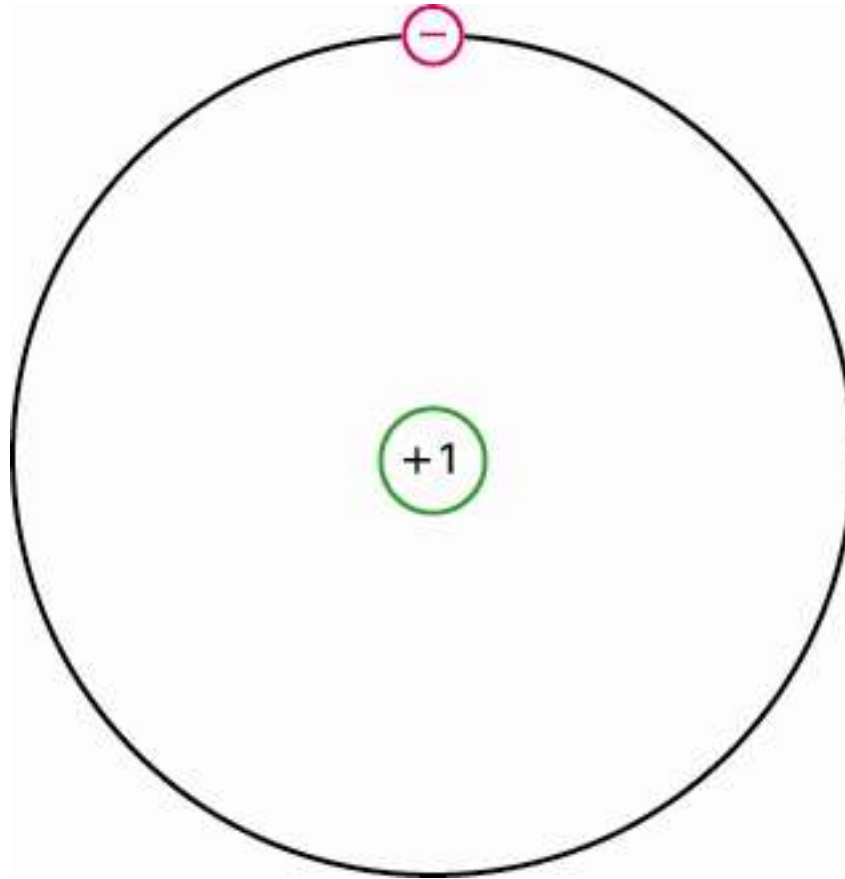
Atomic Structure of Copper



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

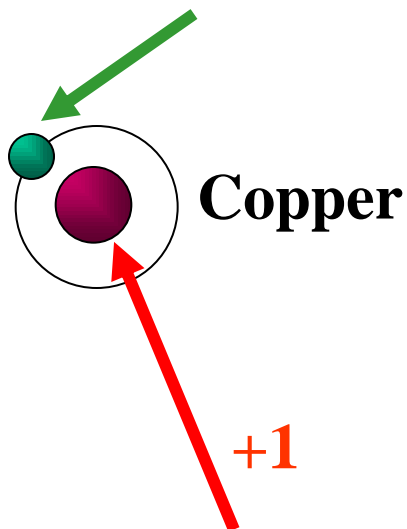
An element with electrical properties between those of a conductor and those of an insulator.

Semiconductor Examples

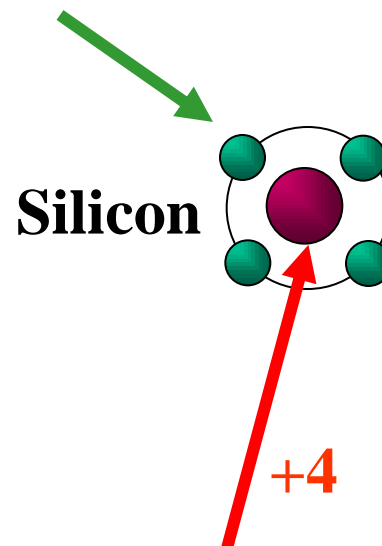
- Semiconductors typically have 4 valence electrons
- Germanium
- Silicon

Core diagrams for copper and silicon:

One valence electron

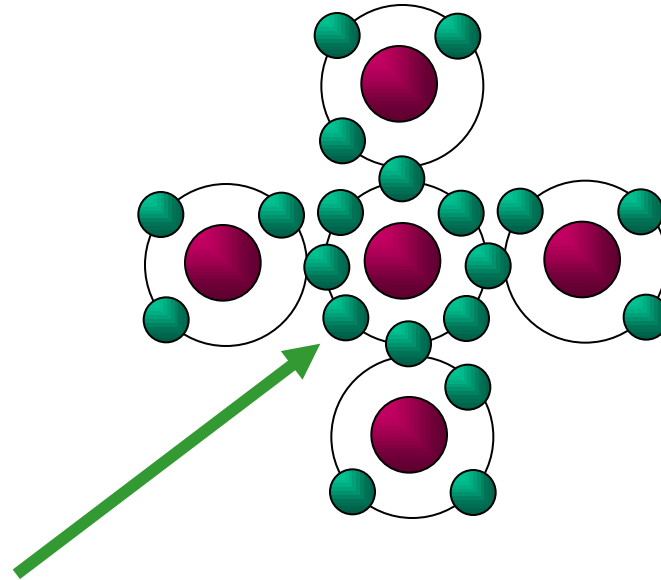


Four valence electrons



The nucleus plus the inner electron orbits

Silicon atoms in a crystal share electrons.



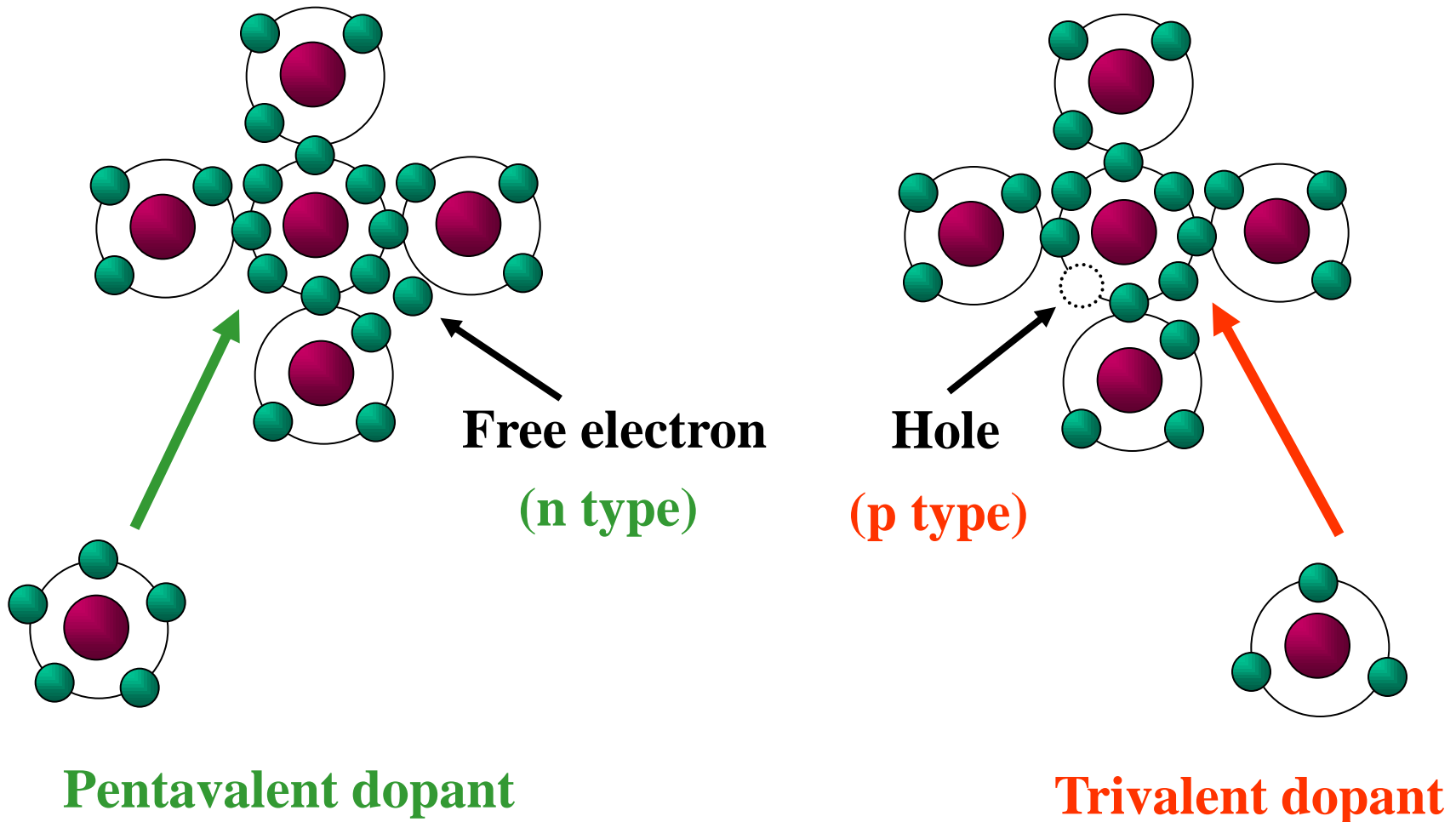
Valence saturation: $n = 8$

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.



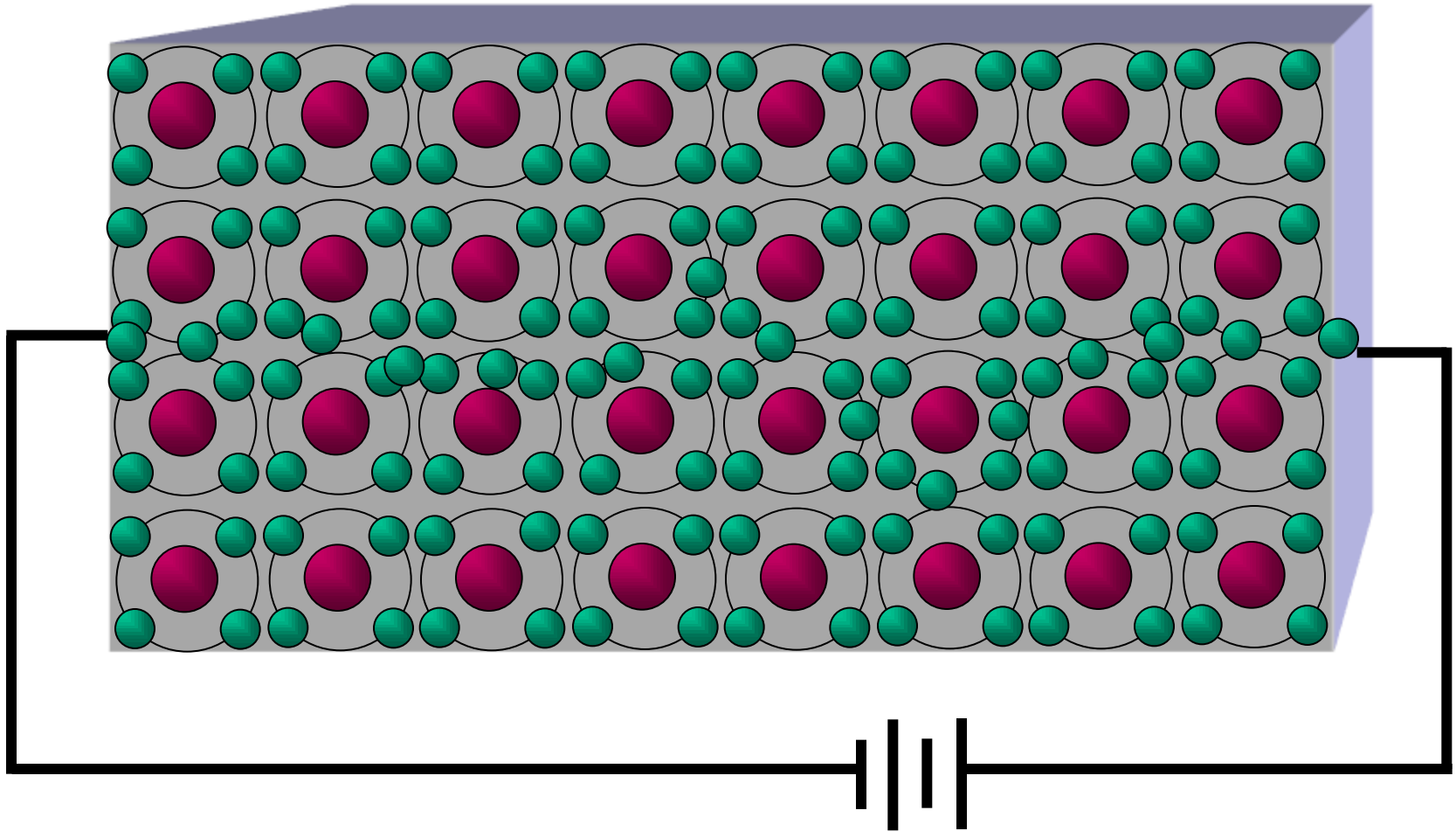
Intrinsic Semiconductor

- 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

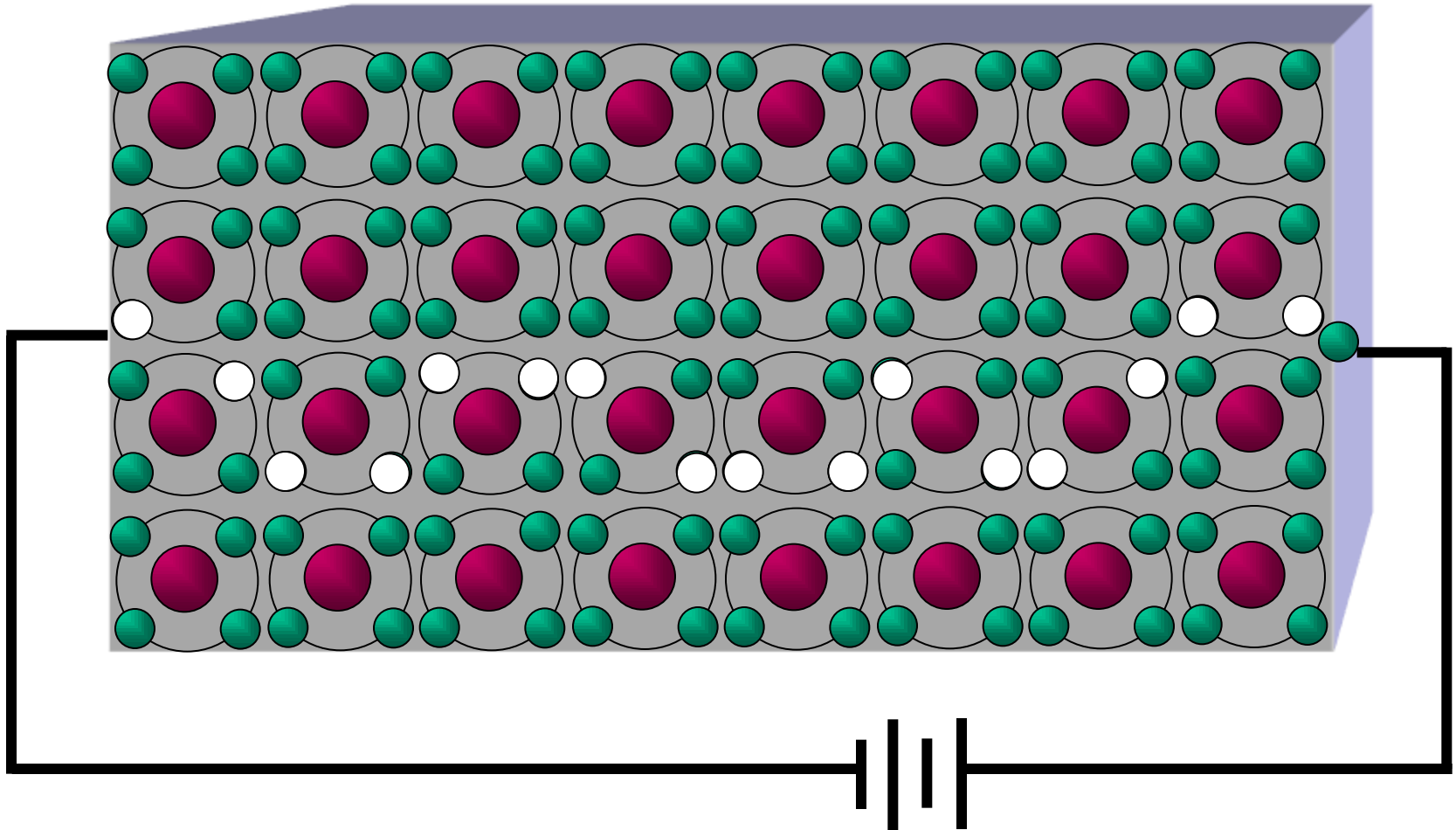
- **Adding** impurity atoms to an intrinsic crystal to alter its electrical conductivity
- A doped semiconductor is called an **extrinsic** semiconductor

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.

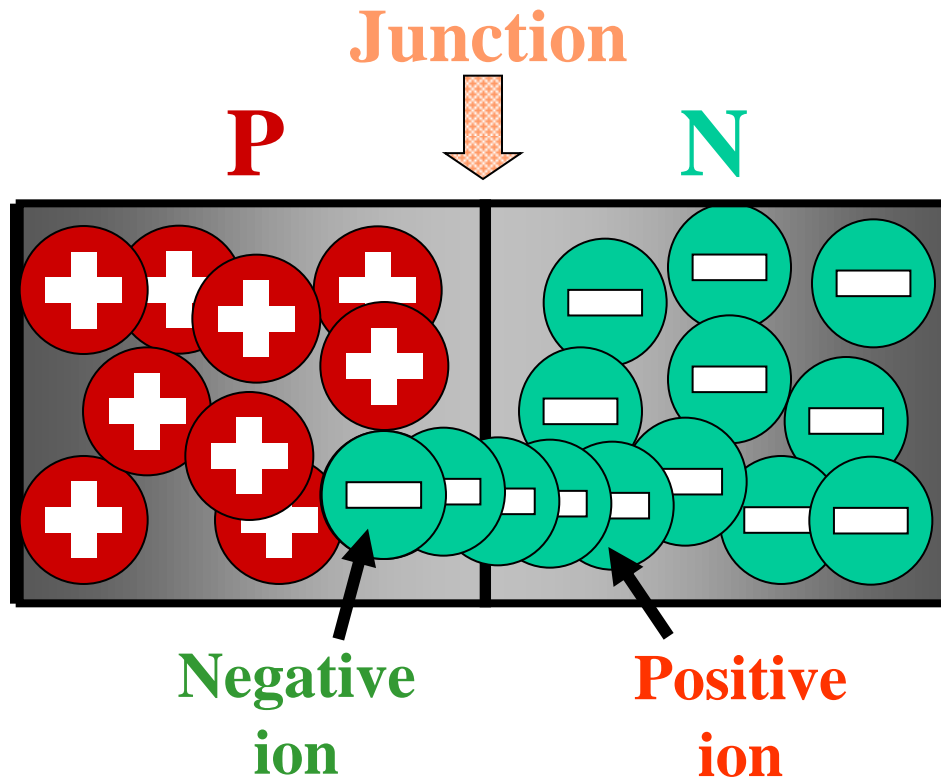
Note that hole current is opposite in direction to electron current.

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.

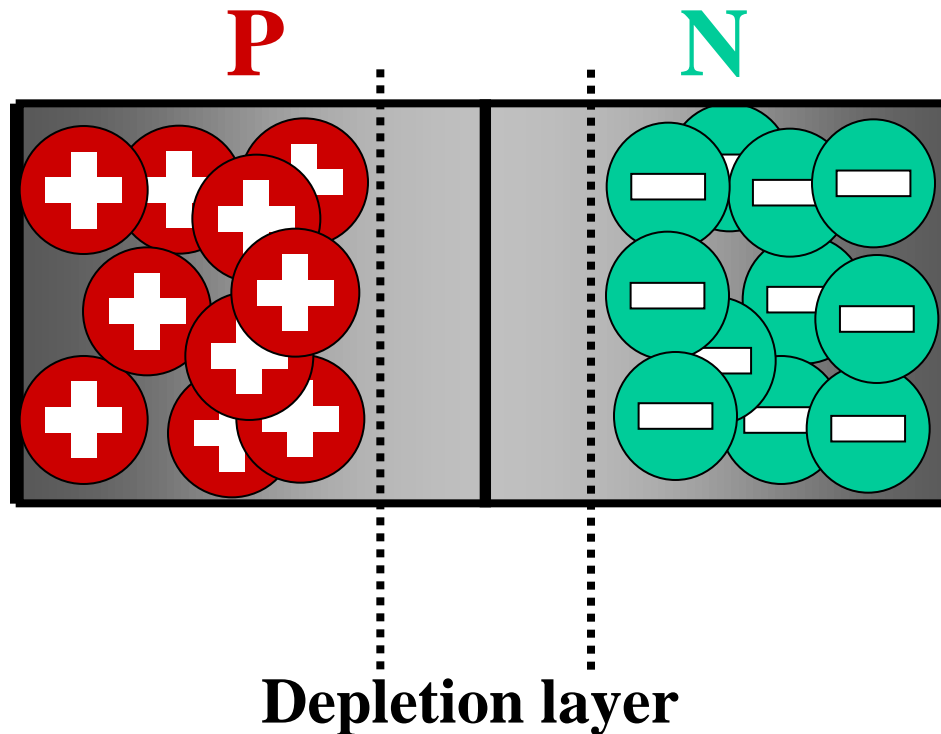


Some electrons will cross the junction and fill holes.
A pair of ions is created each time this happens.
As this ion charge builds up, it prevents further
charge migration across the junction.

The pn barrier potential

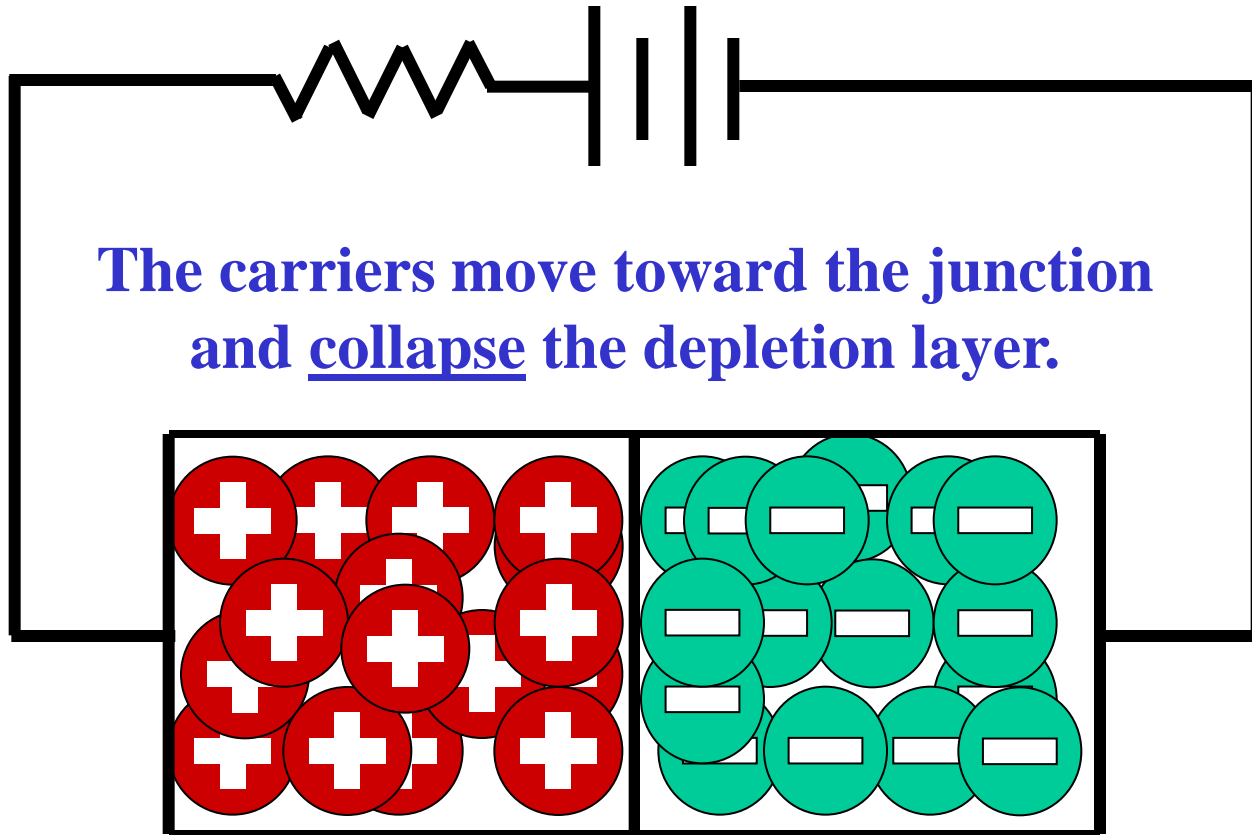
- Electron diffusion creates ion pairs called **dipoles**.
- Each dipole has an associated **electric field**.
- The junction goes into **equilibrium** when the barrier potential prevents further diffusion.
- At 25 degrees C, the **barrier potential** for a silicon pn junction is about **0.7** volts.

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



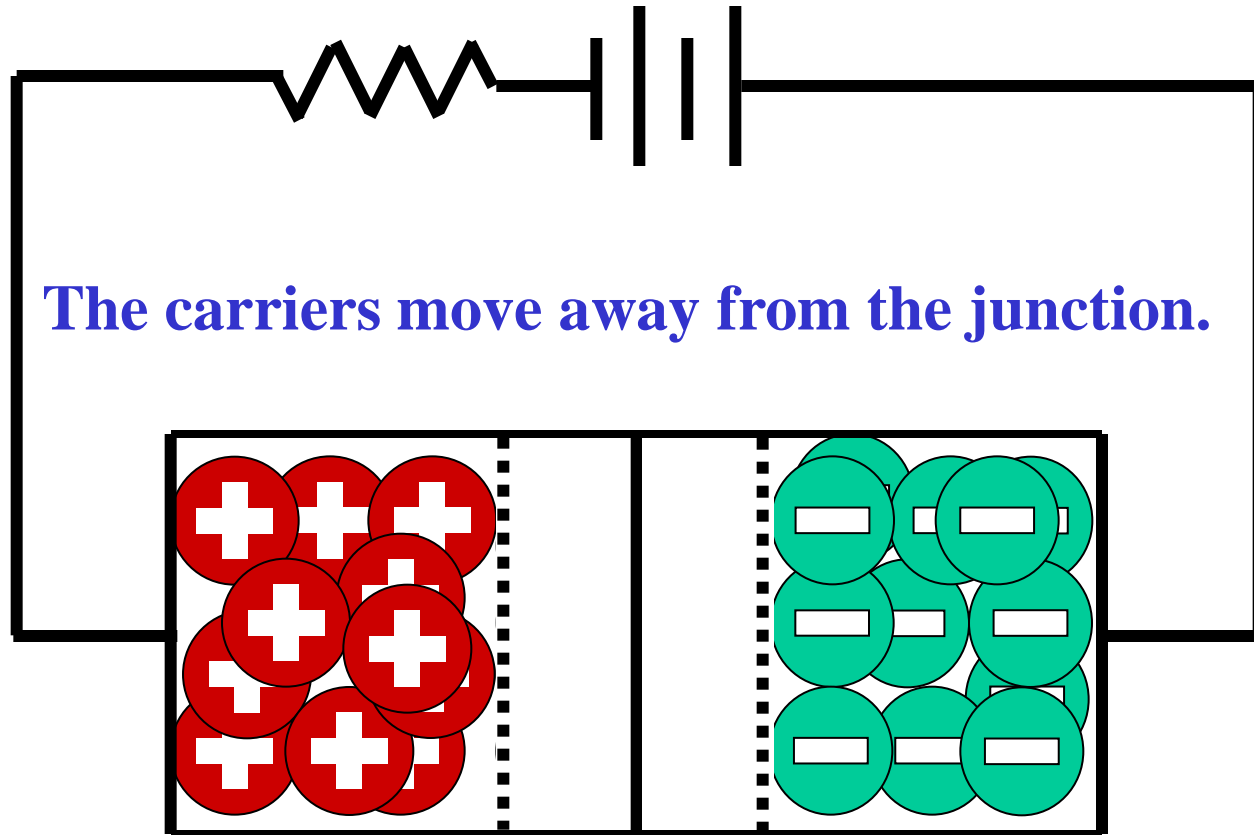
This results in a region at the junction that is depleted of carriers and acts as an insulator.

Forward bias



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

Reverse bias



**The depletion layer is reestablished
and the diode is off.**

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.

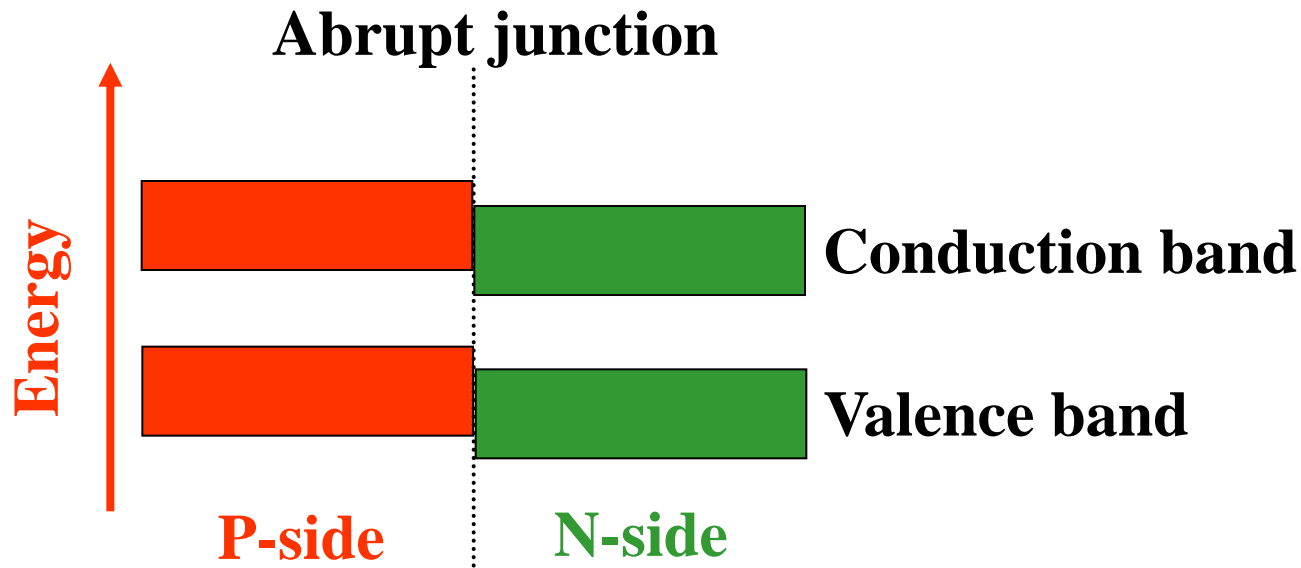
Energy levels

- 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

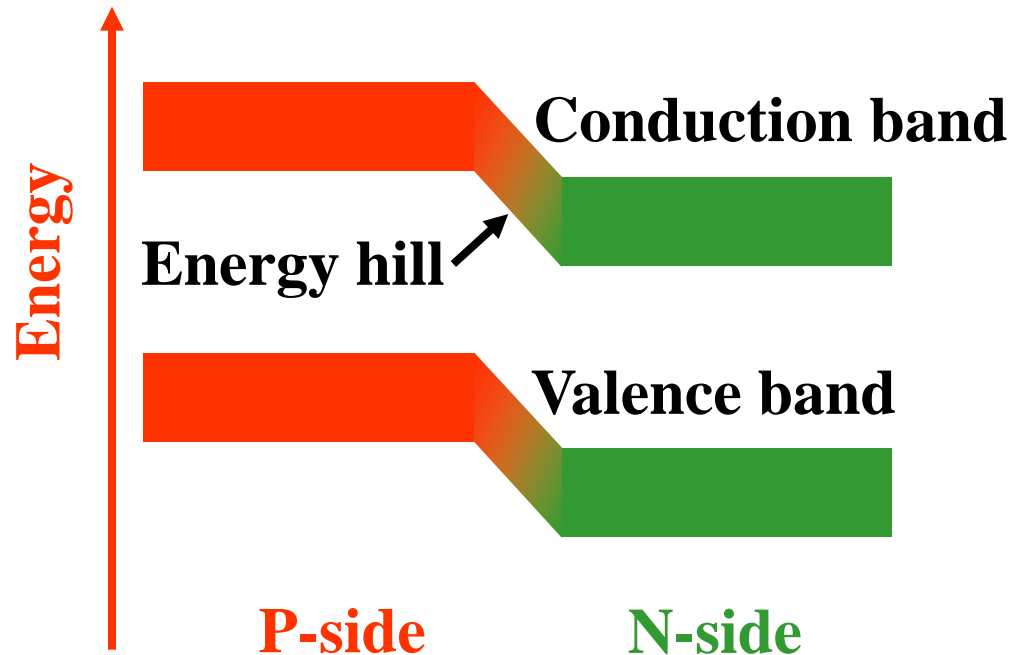
The p side of a pn junction has trivalent atoms with a core charge of +3. This core attracts electrons less than a +5 core.



In an abrupt 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.