Introduction to Electronics and Semiconductor

Chapter Objectives

- To study and understand basic electronics.
- To study and understand semiconductor principles.

Definition

Electronics is the branch of science and technology that deals with electrical circuits involving active electrical components such as vacuum tubes, transistors, diodes and integrated circuits.

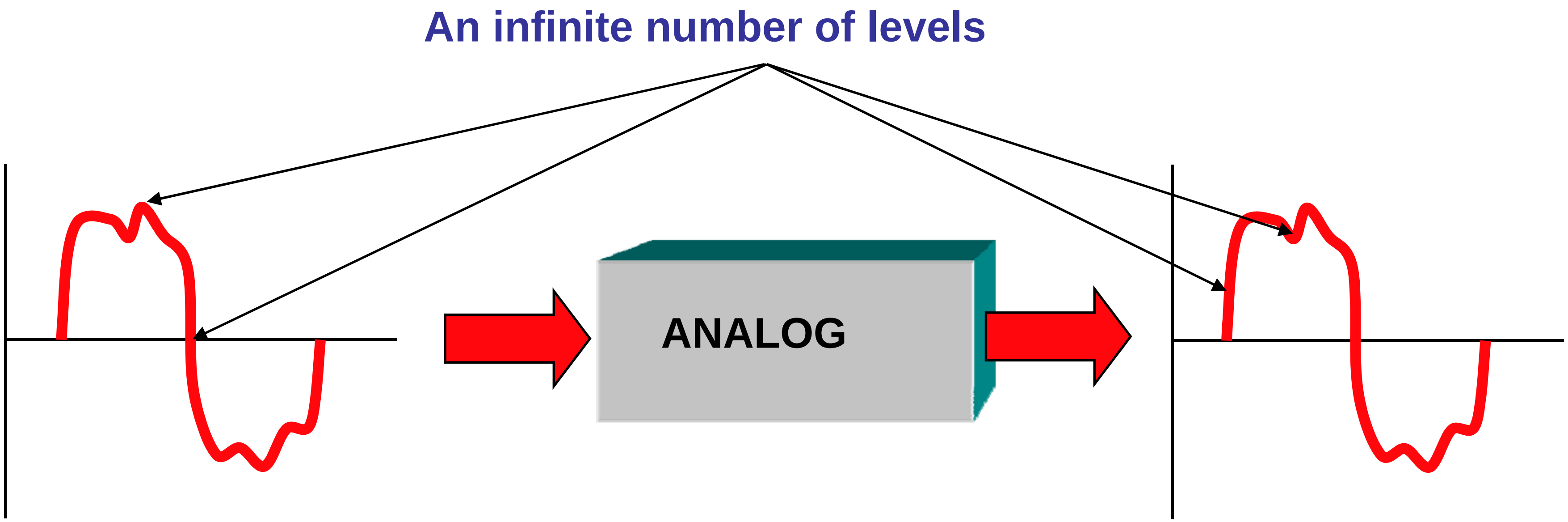
Nowadays, most electronic devices use *semiconductor* components to perform electron control. The study of semiconductor devices and related technology is considered a branch of solid state physics, whereas the design and construction of electronic circuits to solve practical problems come under electronics engineering.

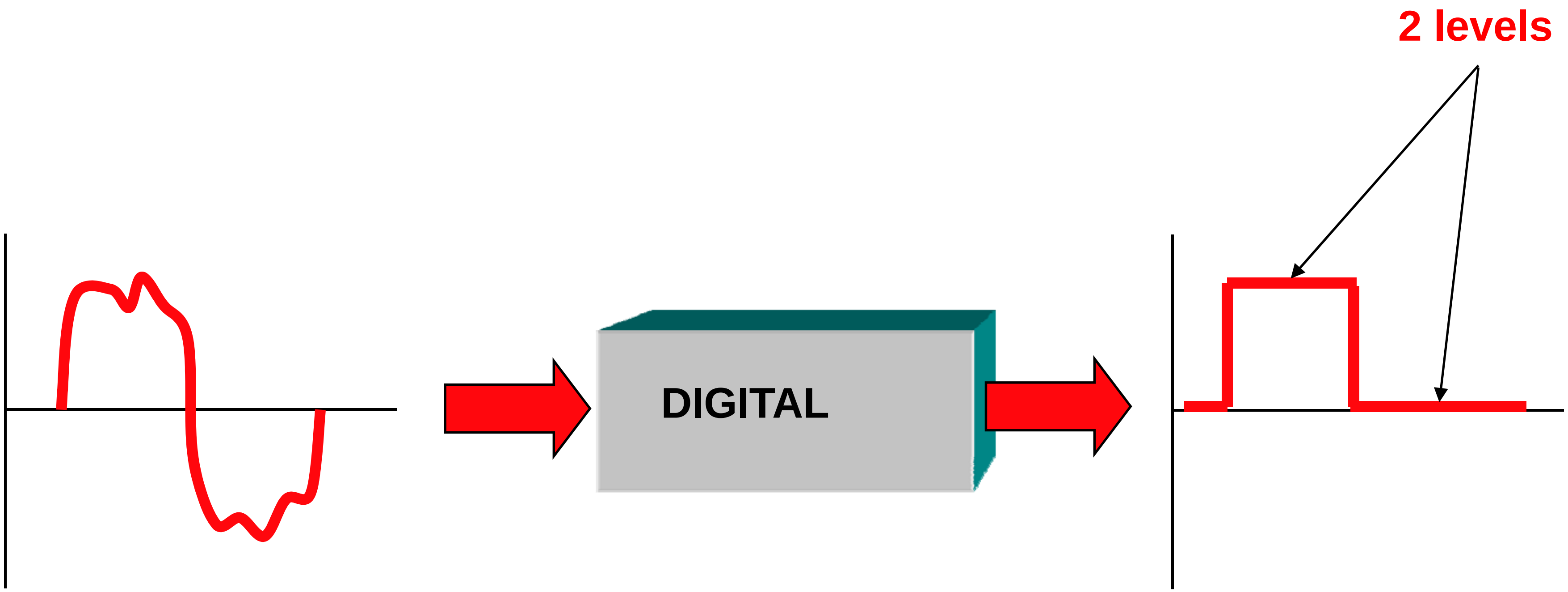
History

- **1899 Discovery of the Electron**
- **1901 Radio**
- **1906 Vacuum Tube**
- **1943 First Computer**
- **1947 Transistor**
- **1958 Integrated Circuit**
- **1971 Microprocessor**
- **1982 Single Chip DSP**

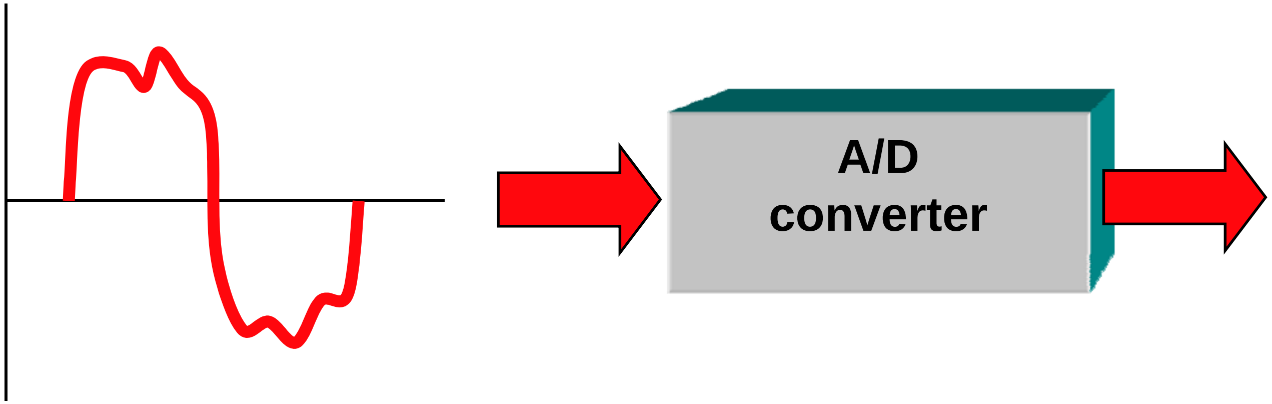
Analog vs Digital

- The world of electronics can be divided into digital or analog.
- Analog signals come from nature and from physical systems.
- Analog signals have an infinite variety of levels.
- Digital signals usually have only two levels.
- Digital signals are often represented as binary numbers.
- A/D and D/A conversions are commonplace.


An infinite number of levels
ANALOG


2 levels
DIGITAL

Analog in … digital out

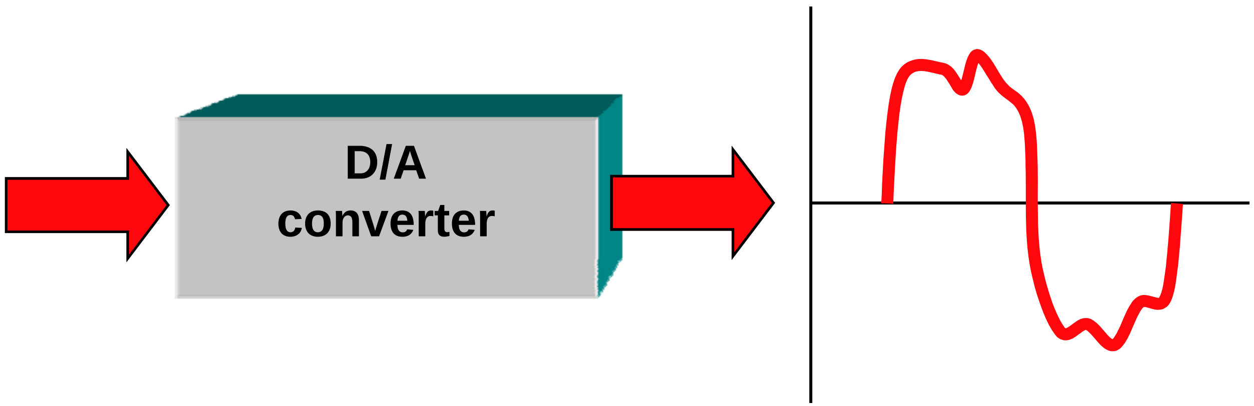


Binary numbers

01101110
11001000
11000010
01101110
00001110
00001001
01101110

Digital in … analog out

01101110
11001000
11000010
01101110
00001110
00001001
01101110



Analog Electronics Function

Oscillator

Controller

Divider

Adder

Switch

Clipper

Amplifier

Detector

Mixer

Comparator

Subtractor

Filter

Regulator

Converter

Multiplier

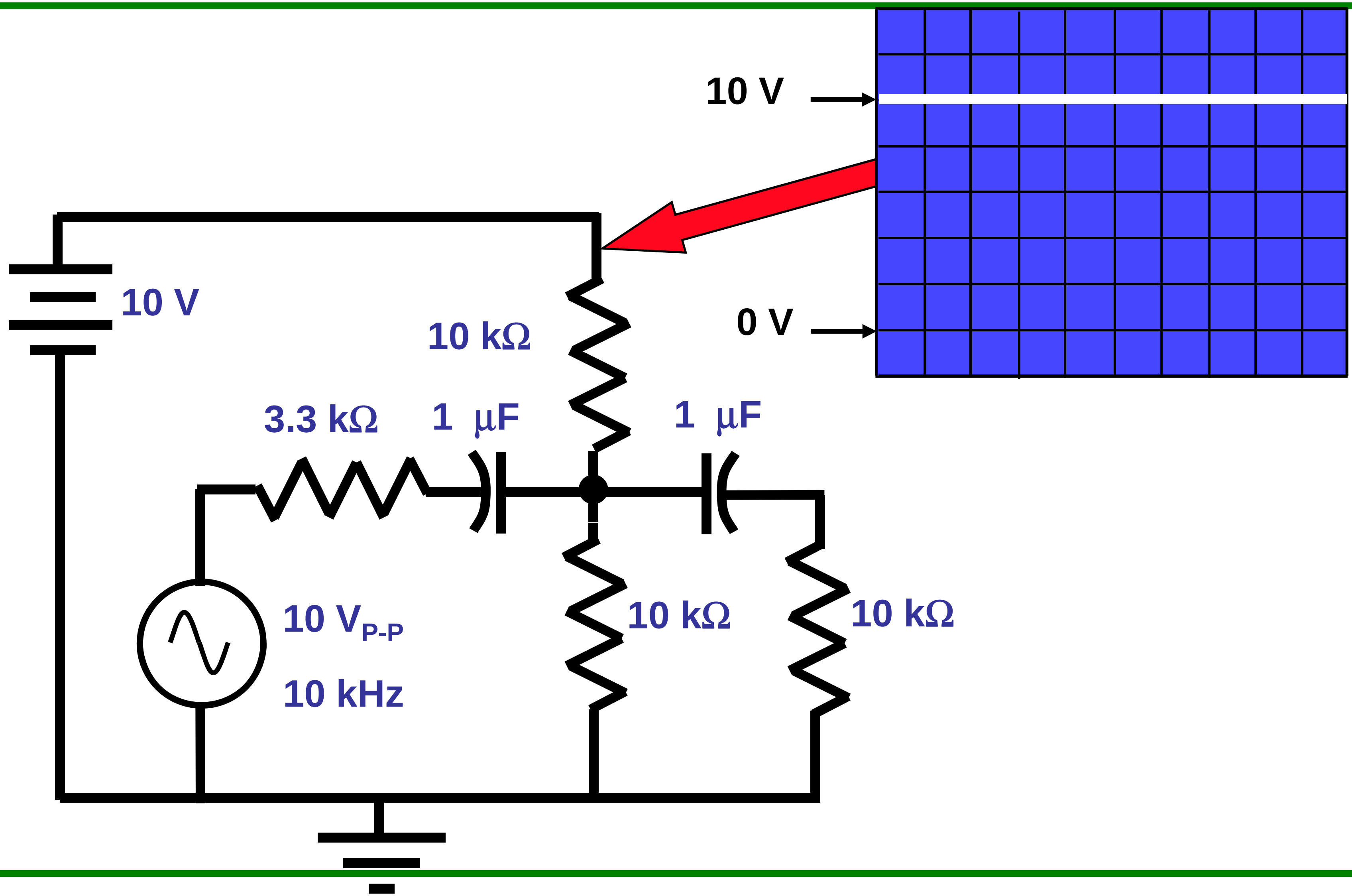
Attenuator

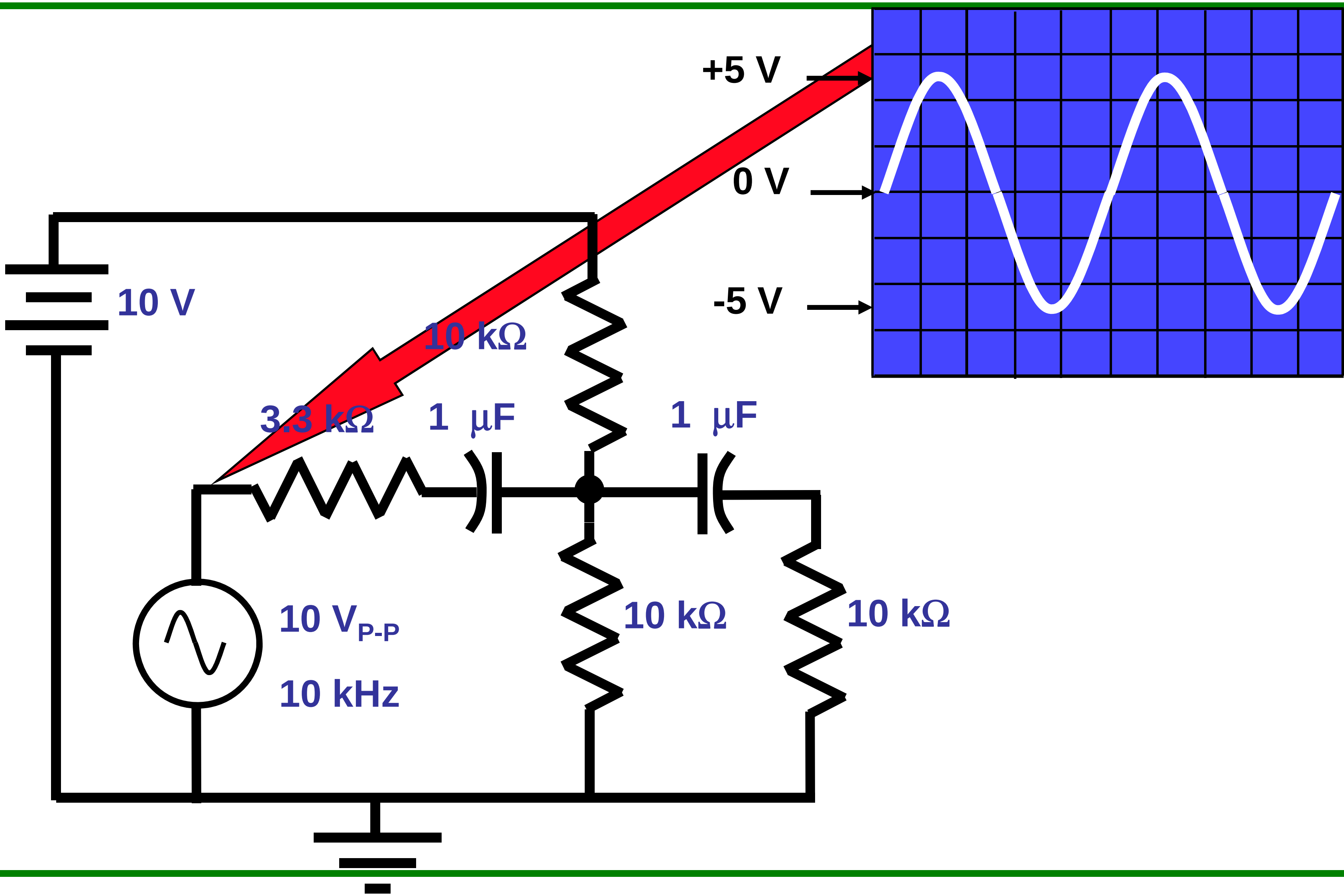
Rectifier

Concept Preview

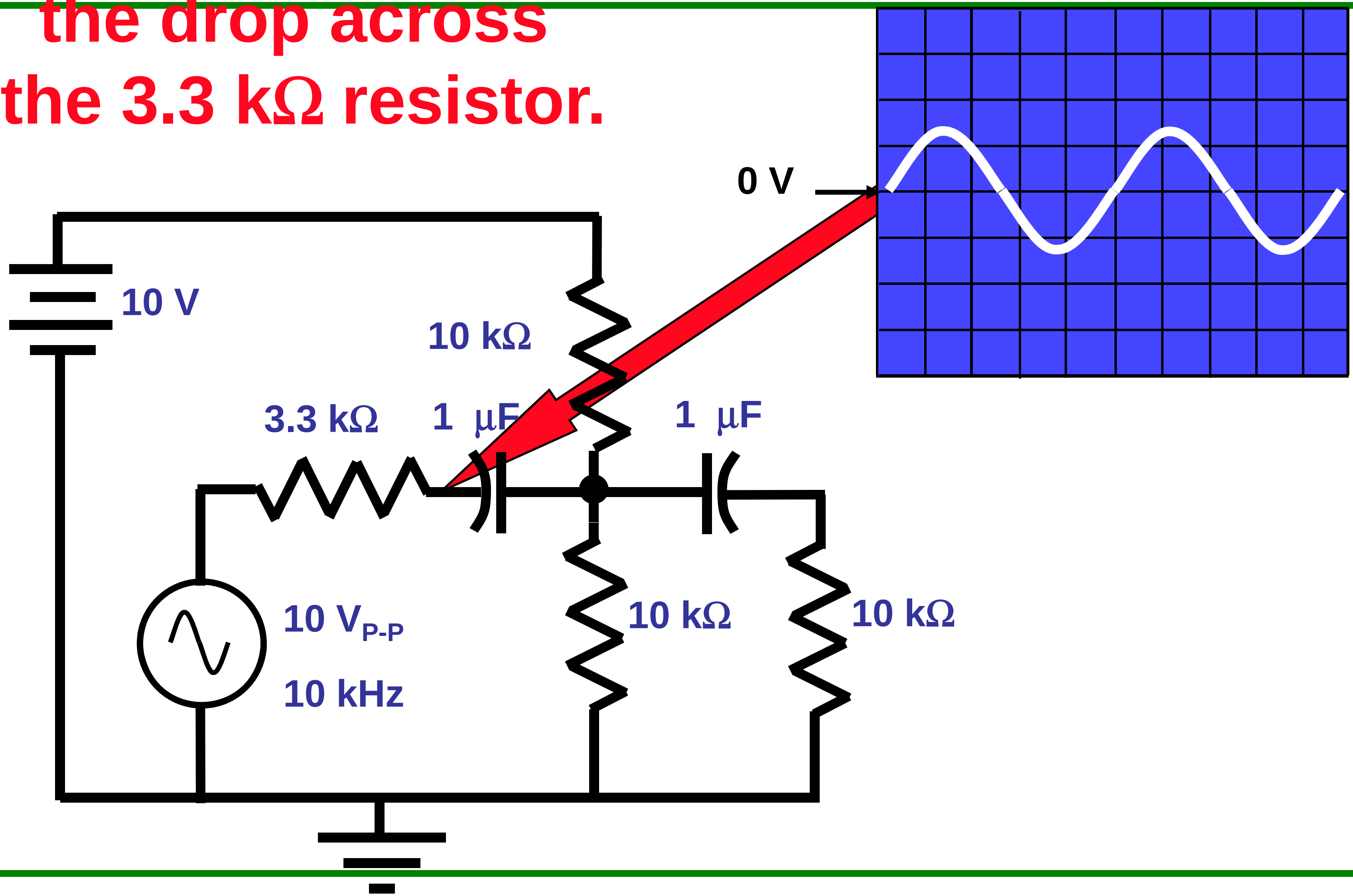
- Many circuits and signals have both ac and dc components.
- Capacitors can couple ac signals from one point to another.
- Coupling capacitors have low reactance at the signal frequency.
- Capacitors block dc since they have infinite reactance at 0 Hz.
- Bypass capacitors remove the ac component.
- Bypass capacitors have one lead grounded.

Many circuits are a mix of ac and dc.

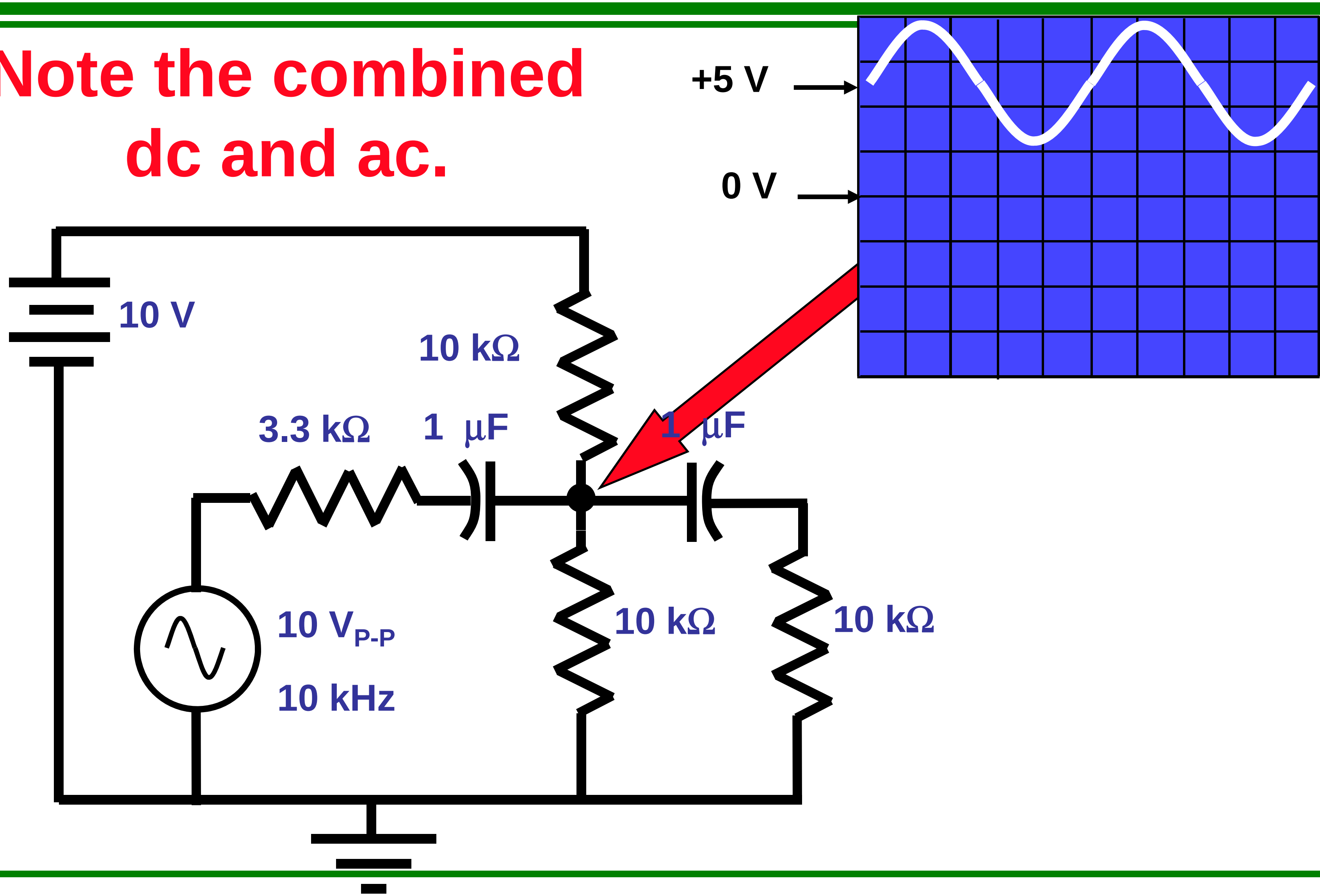



+5 V
0 V
-5 V
10 V
10 kΩ
3.3 kΩ
1 µF
1 µF
10 V P-P
10 kHz
10 kΩ
10 kΩ

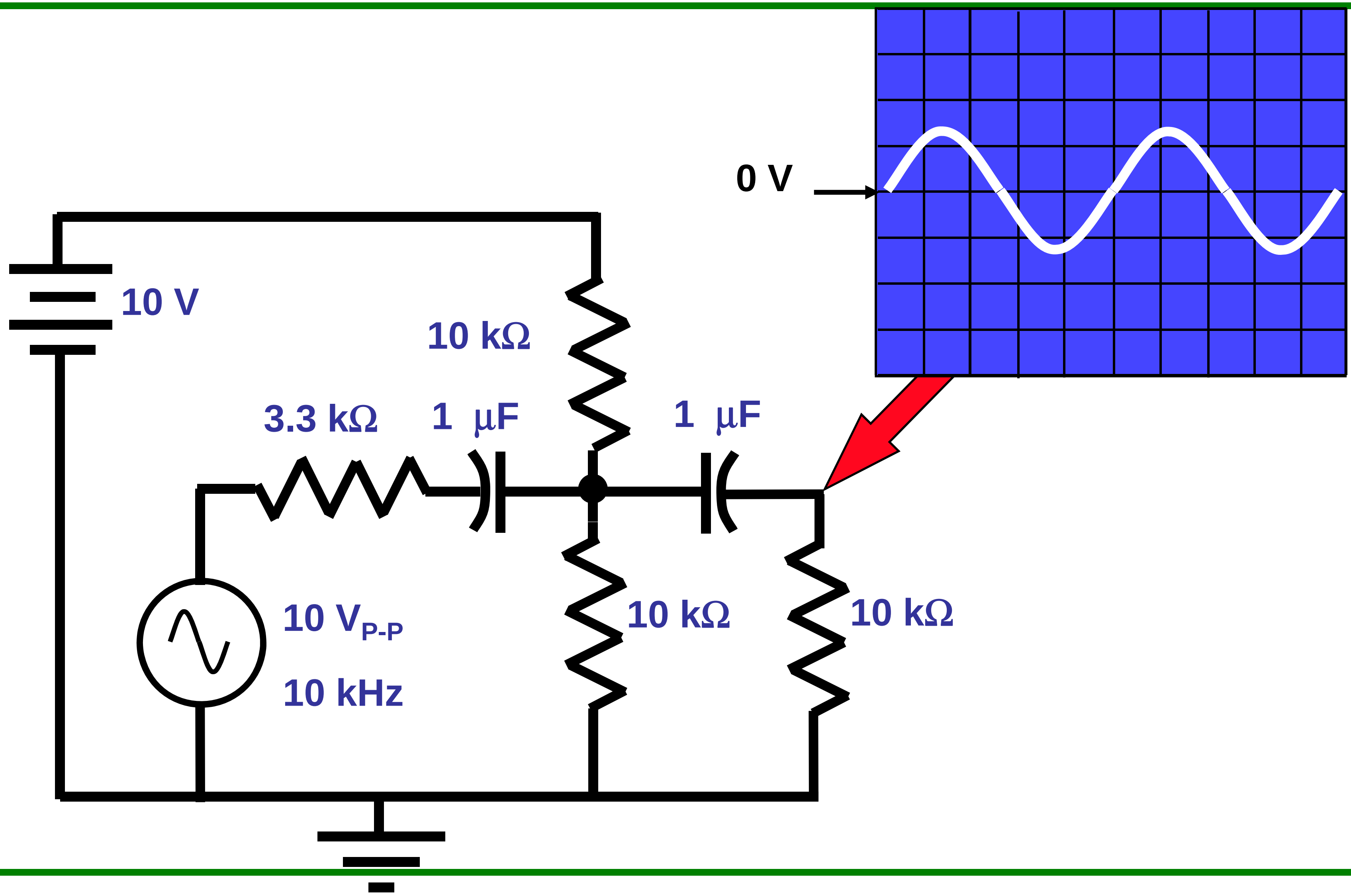
Note the loss in ac amplitude due to the drop across the 3.3 kΩ resistor.



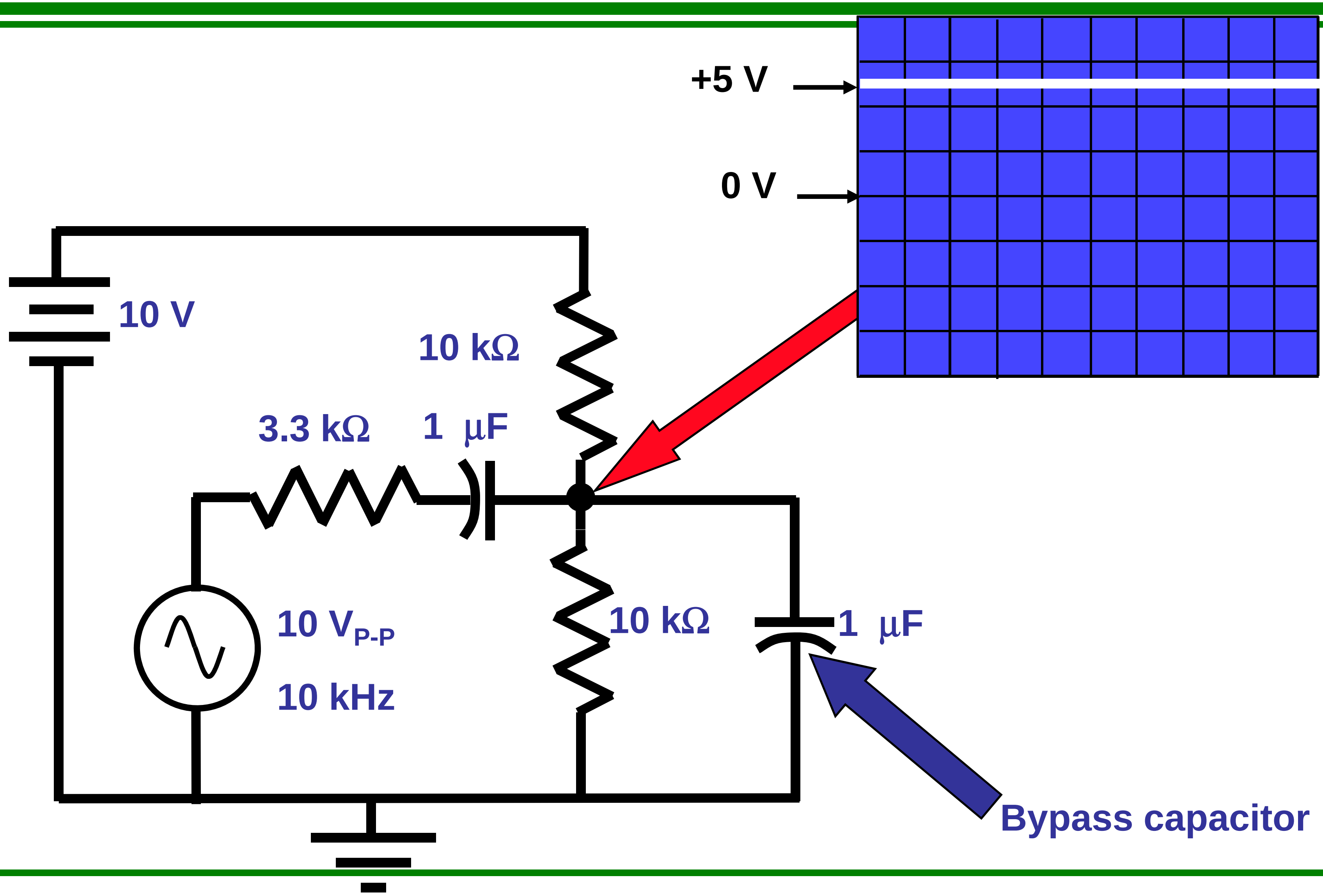
Note the combined dc and ac.



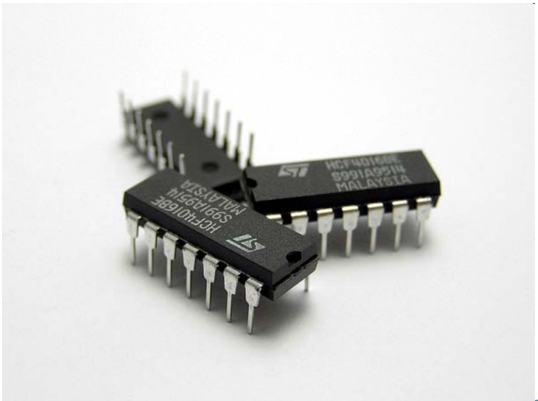
Note that the dc signal is blocked by the capacitor.



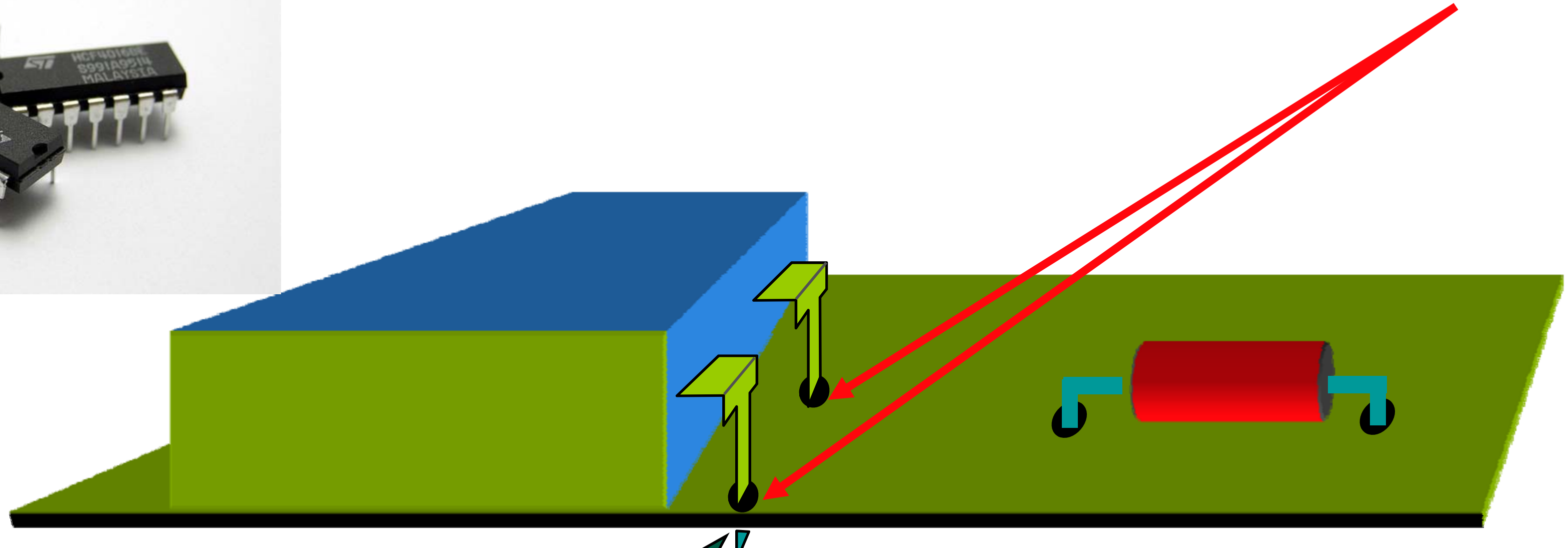
Bypass capacitors are used to eliminate the ac component.

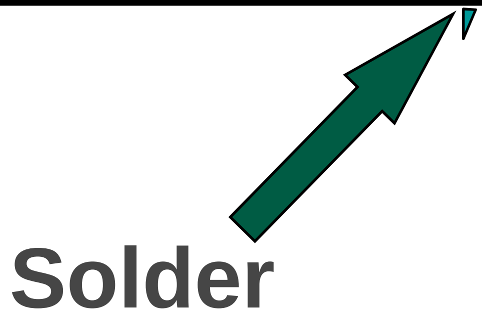


Through-hole soldering

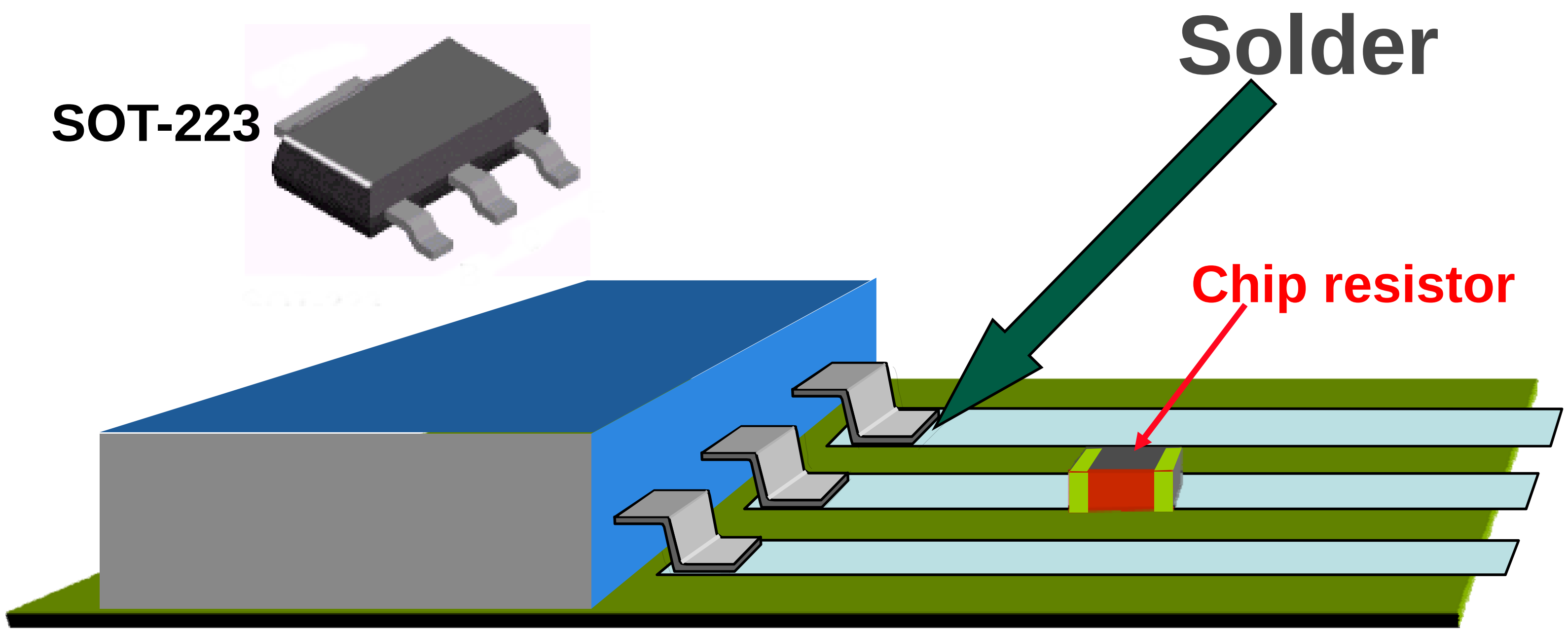


Device leads pass through holes in the circuit board.





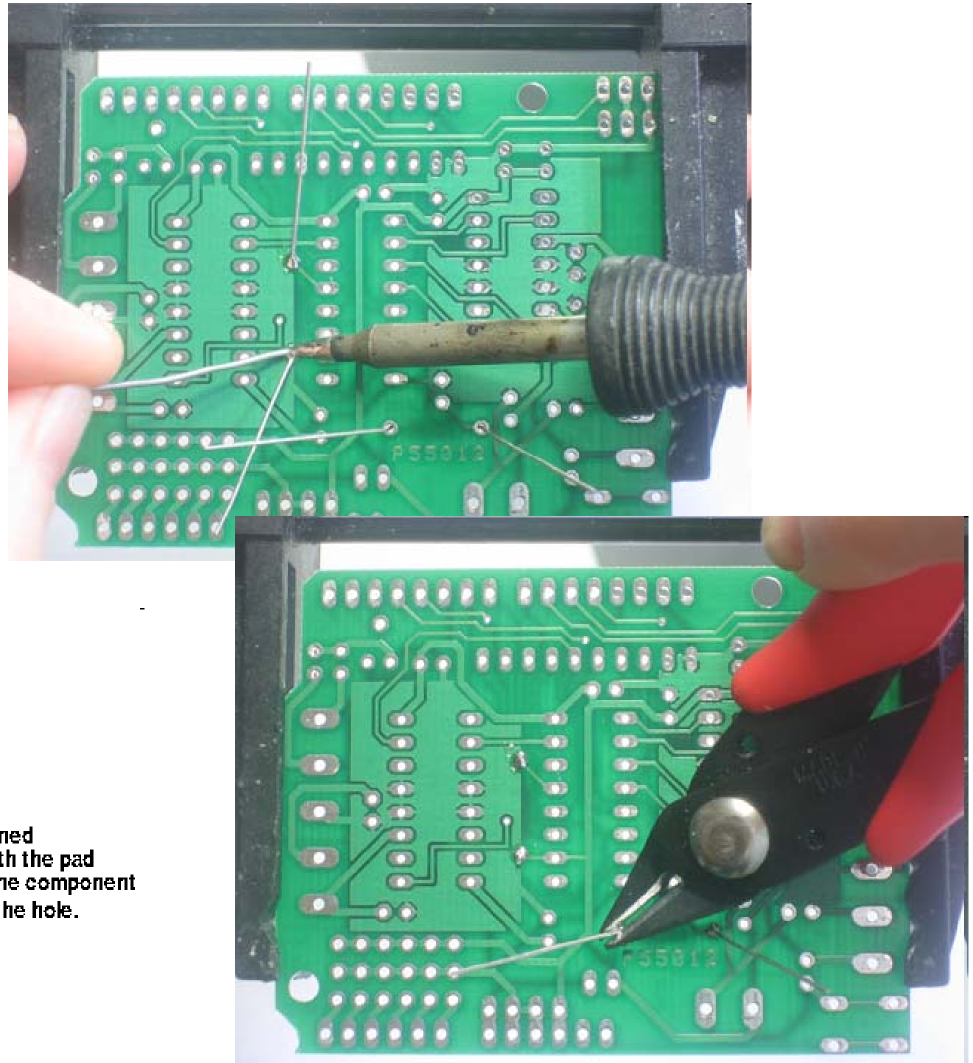
Surface mouth soldering(1)

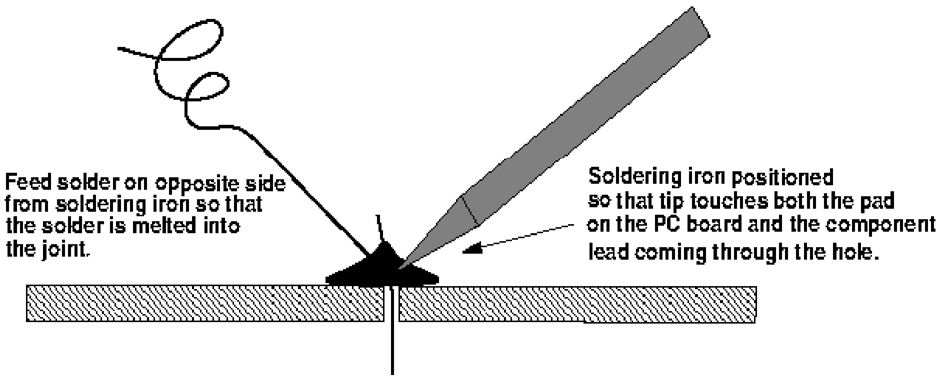


Devices placed by automatic equipment
Circuit boards cost less (fewer holes)
Higher connection density
Smaller and less expensive products
Difficult to repair

Surface mouth soldering(2)

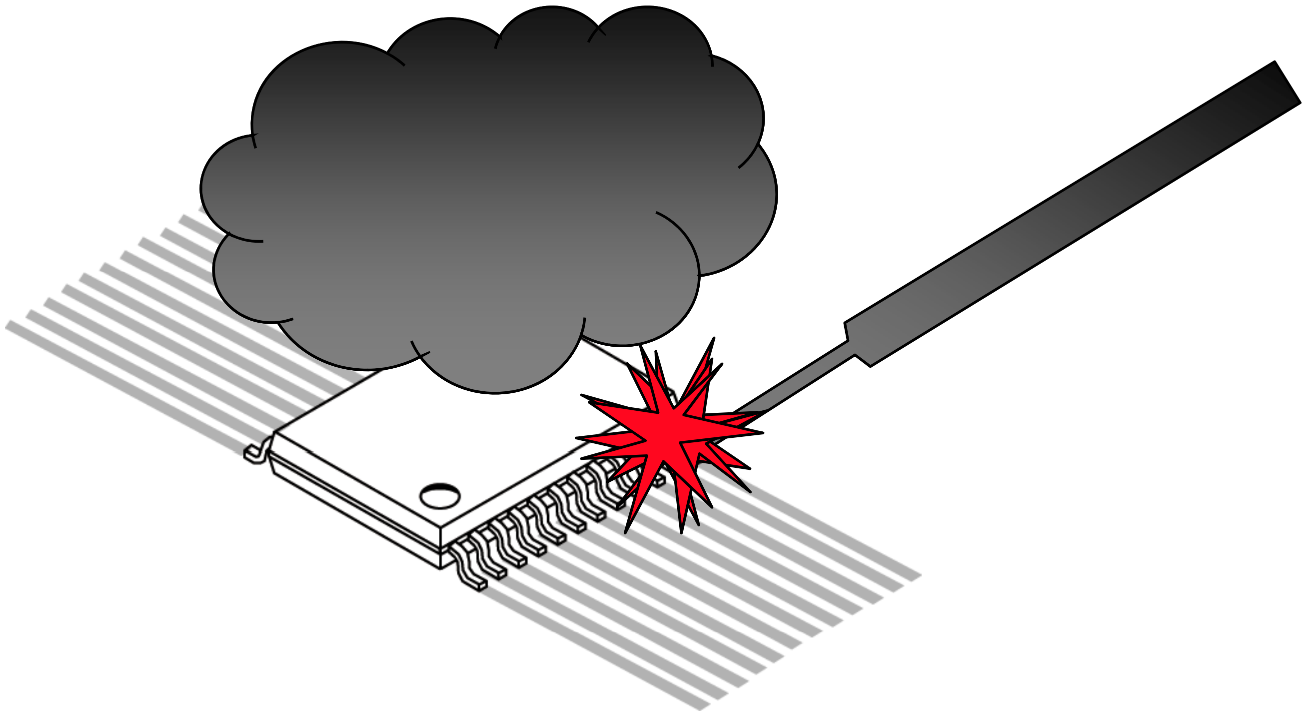
Equipments




Feed solder on opposite side from soldering iron so that the solder is melted into the joint.
Soldering iron positioned so that tip touches both the pad on the PC board and the component lead coming through the hole.

Be careful!!

Probing fine-pitch ICs is difficult without the right tools!



Semiconductor

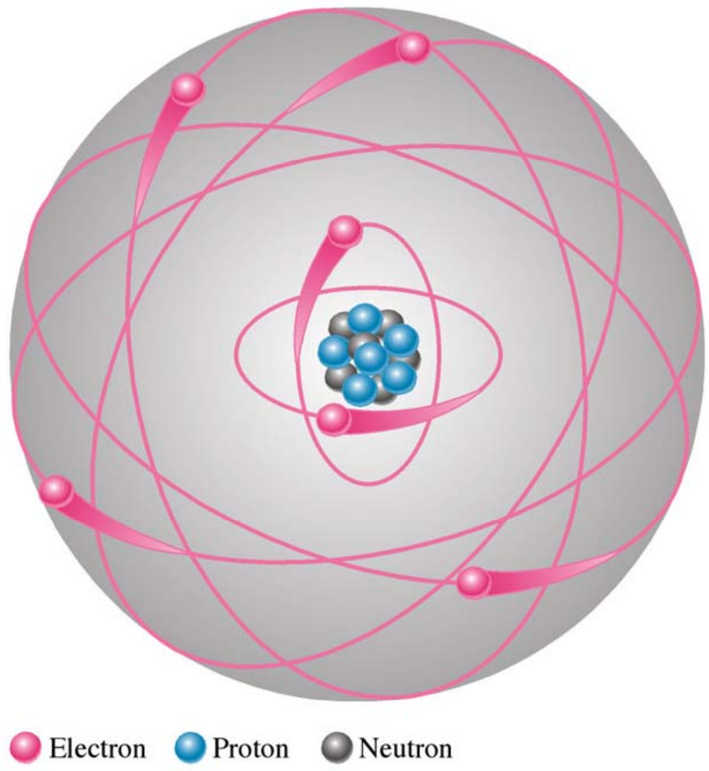
- A semiconductor is a material with electrical conductivity due to electron flow (as opposed to ionic conductivity) intermediate in magnitude between that of a conductor and an insulator.
- Semiconductor materials are the foundation of modern electronics, including radio, computers, telephones, and many other devices.
- Such devices include transistors, solar cells, many kinds of diodes including the light-emitting diode, the silicon controlled rectifier, and digital and analog integrated circuits.

Contents

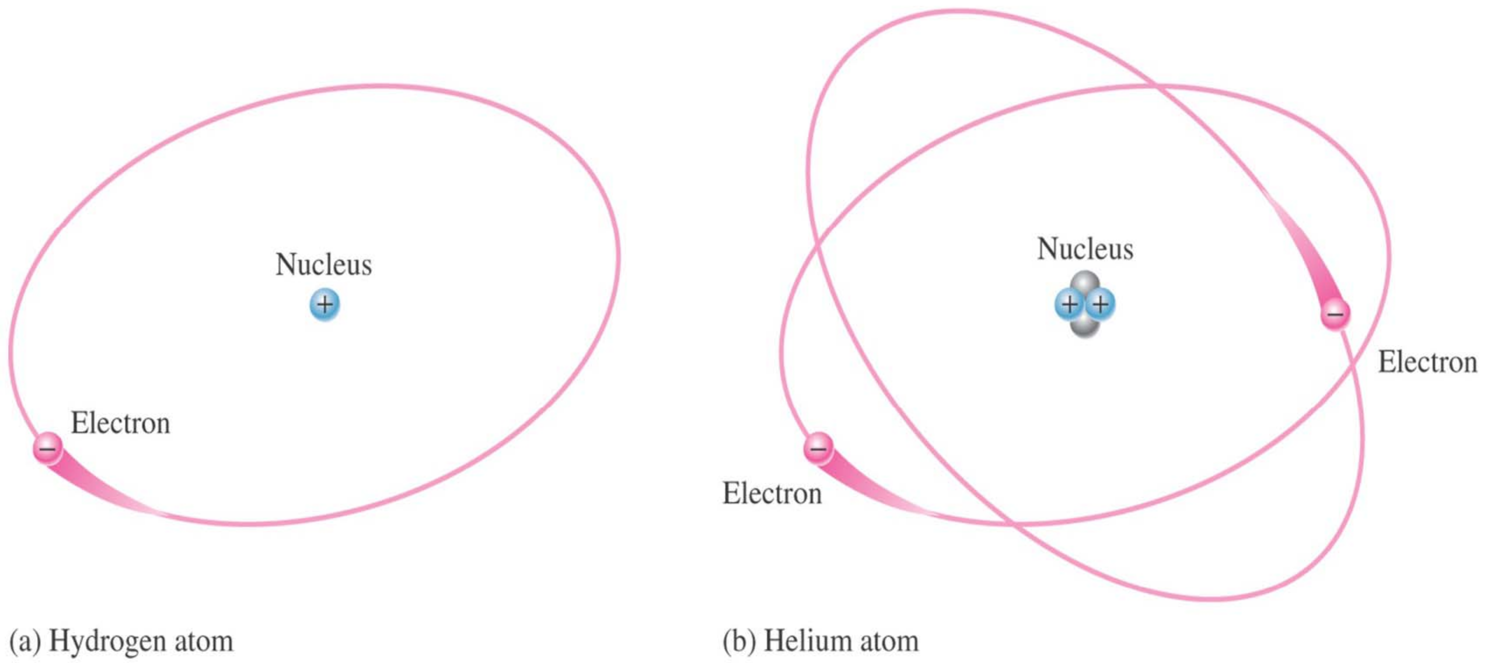
- **Conductors and Insulators**
- **Semiconductors**
- **N-type Semiconductors**
- **P-type Semiconductors**
- **Majority and Minority Carriers**

Bohr model of an atom

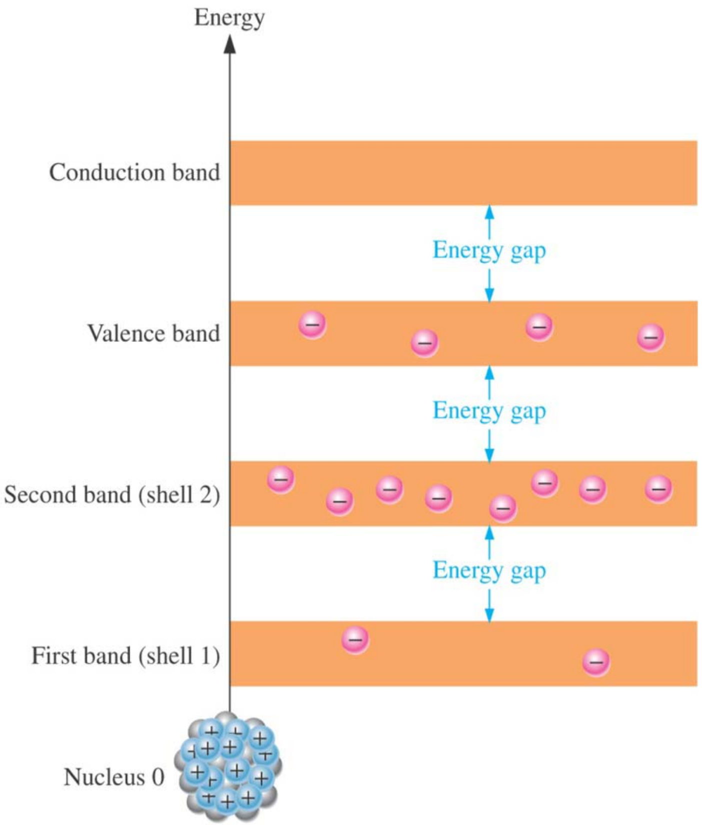
As seen in this model, electrons circle the nucleus. Atomic structure of a material determines its ability to conduct or insulate.

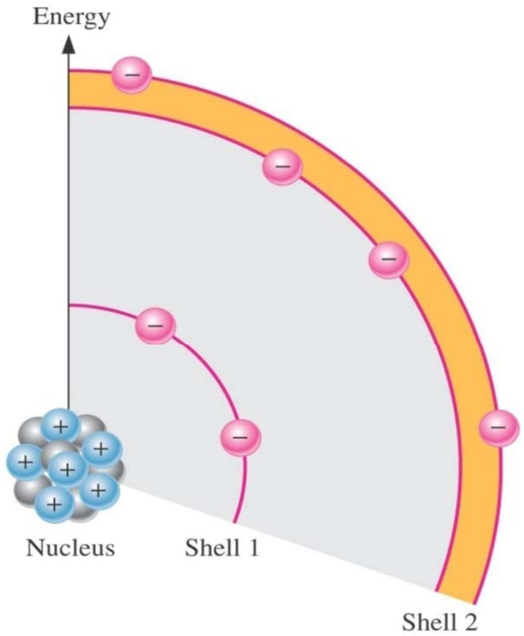


Two simple atoms, hydrogen and helium.



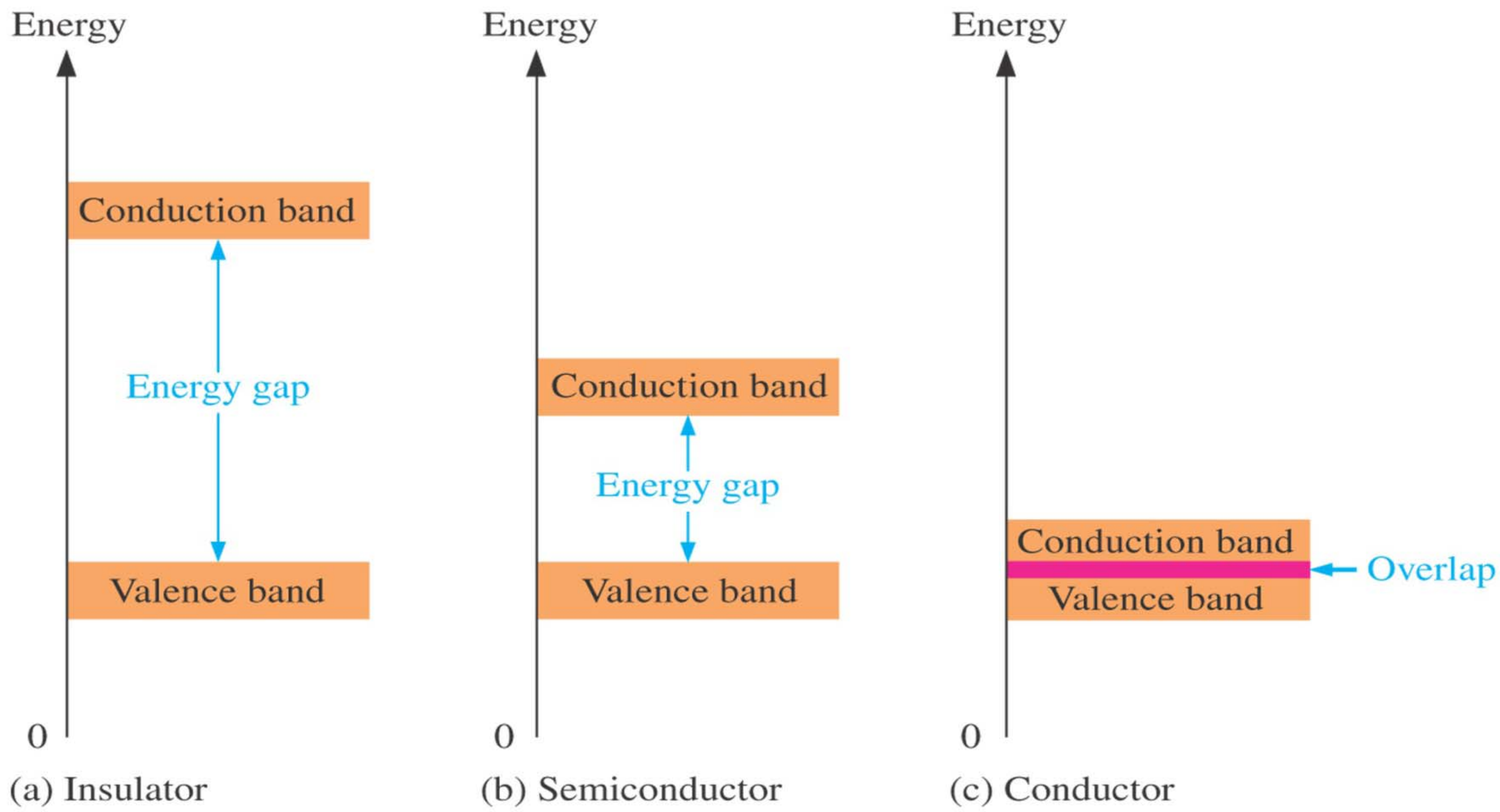
Energy vs Distance





Energy increases as the distance from the nucleus increases.

Energy Diagram



Conductors, Insulators, and Semiconductors

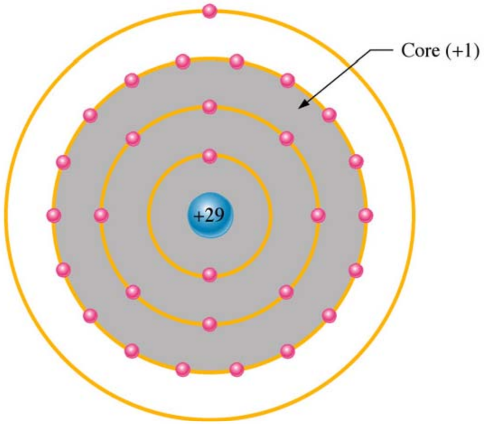
- The ability of a material to conduct current is based on its atomic structure.
- The orbit paths of the electrons surrounding the nucleus are called shells.
- Each shell has a defined number of electrons it will hold. This is a fact of nature and can be determined by the formula, $2n^2$.
- The outer shell is called the valence shell.
- The less complete a shell is filled to capacity the more conductive the material is.

Conductors, Insulators, and Semiconductors

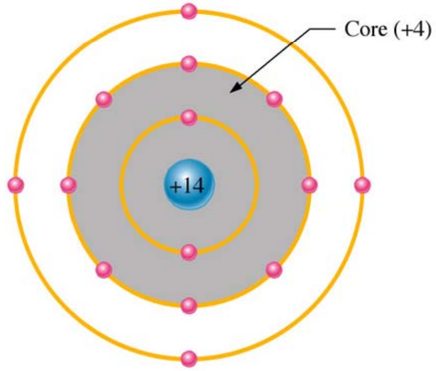
The valence shell determines the ability of material to conduct current.

A Copper atom has only 1 electron in its valence ring. This makes it a good conductor. It takes $2n^2$ electrons or in this case 32 electrons to fill the valence shell.

A Silicon atom has 4 electrons in its valence ring. This makes it a semiconductor. It takes $2n^2$ electrons or in this case or 18 electrons to fill the valence shell.



(b) Copper atom



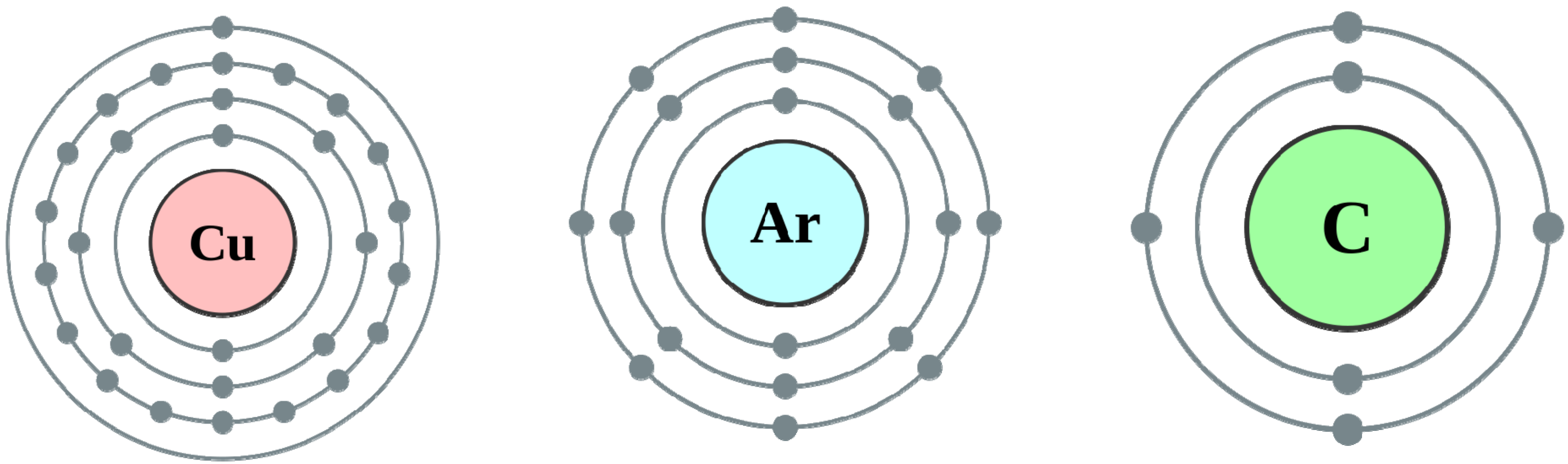
(a) Silicon atom

Conductors, Insulators, and Semiconductors

Conductor: Number of valence electron =1-3

Semiconductor: Number of valence electron = 4

Insulator : Number of valence electron = 5-8

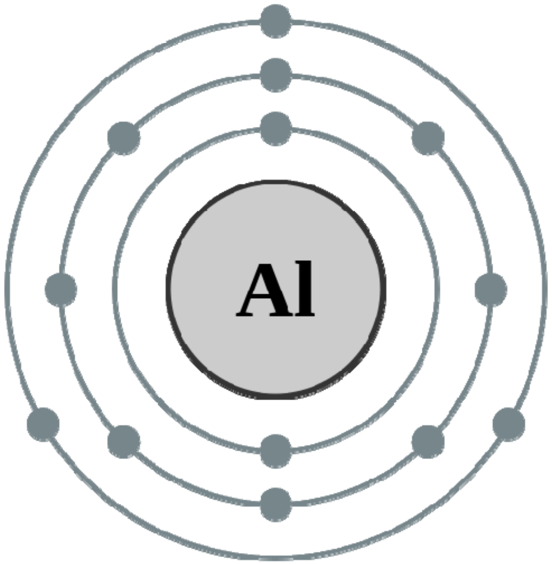


(a) Copper atom(atomic number 29)

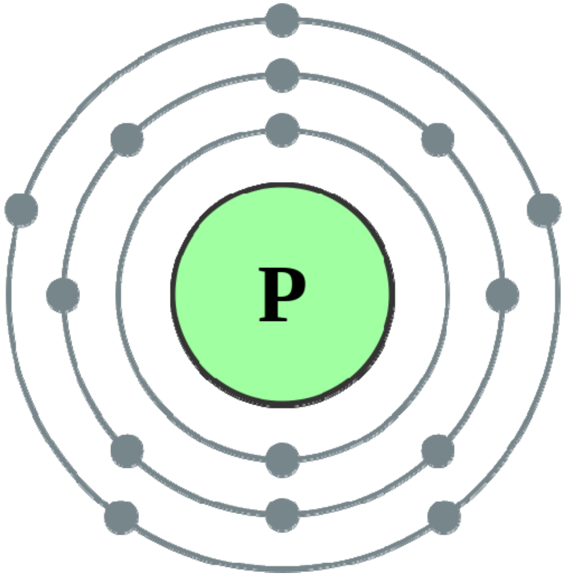
(b) Argon atom(atomic number 18)

(c) carbon atom(atomic number 6)

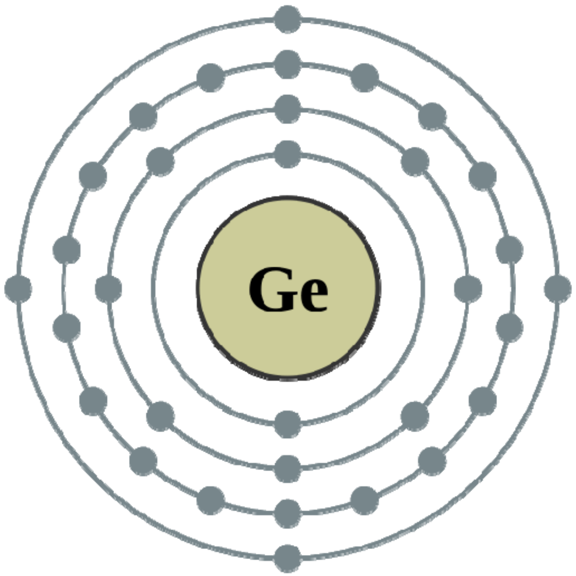
Conductors, Insulators, and Semiconductors



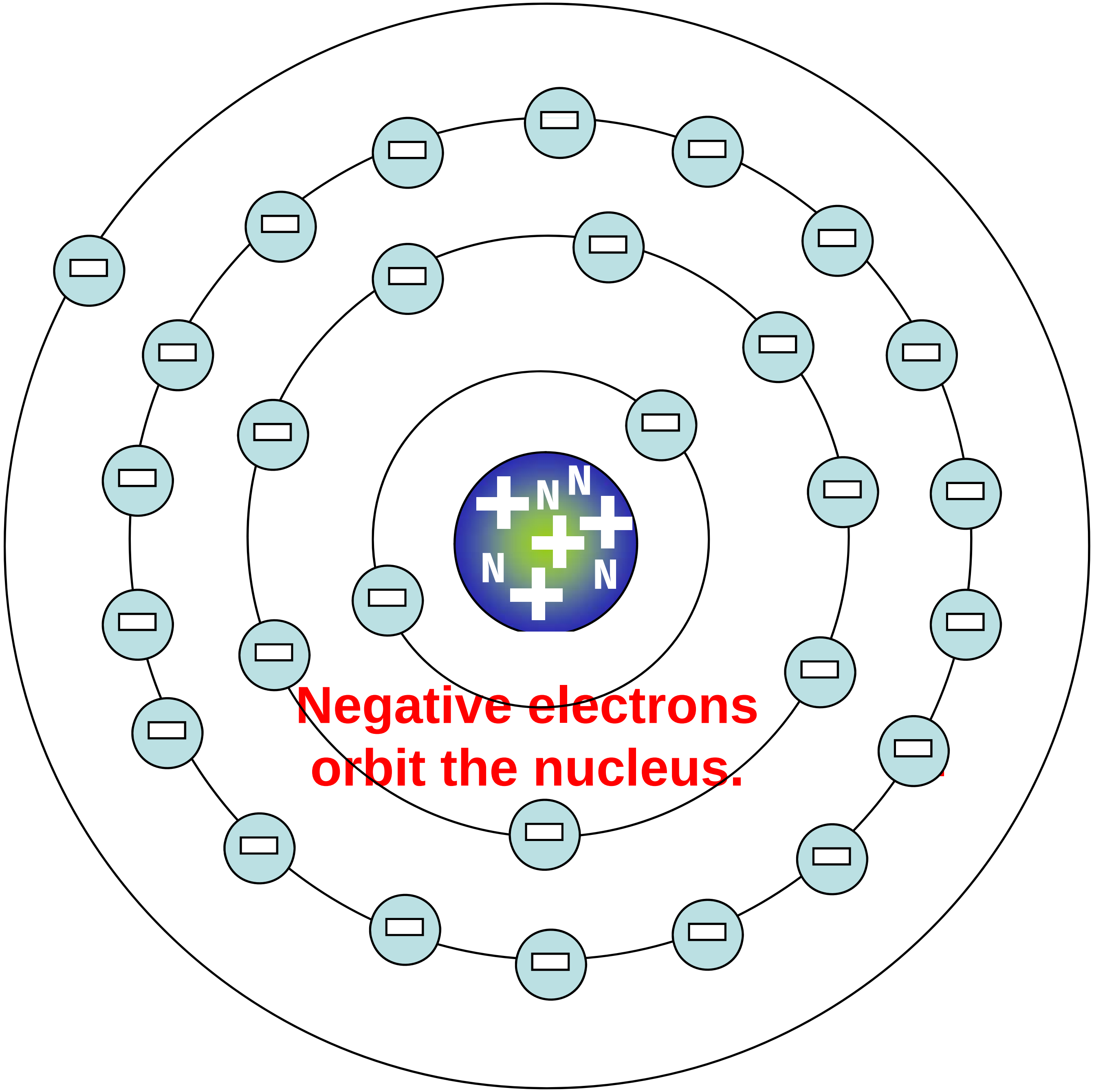
(d) Aluminum atom(atomic number 13)

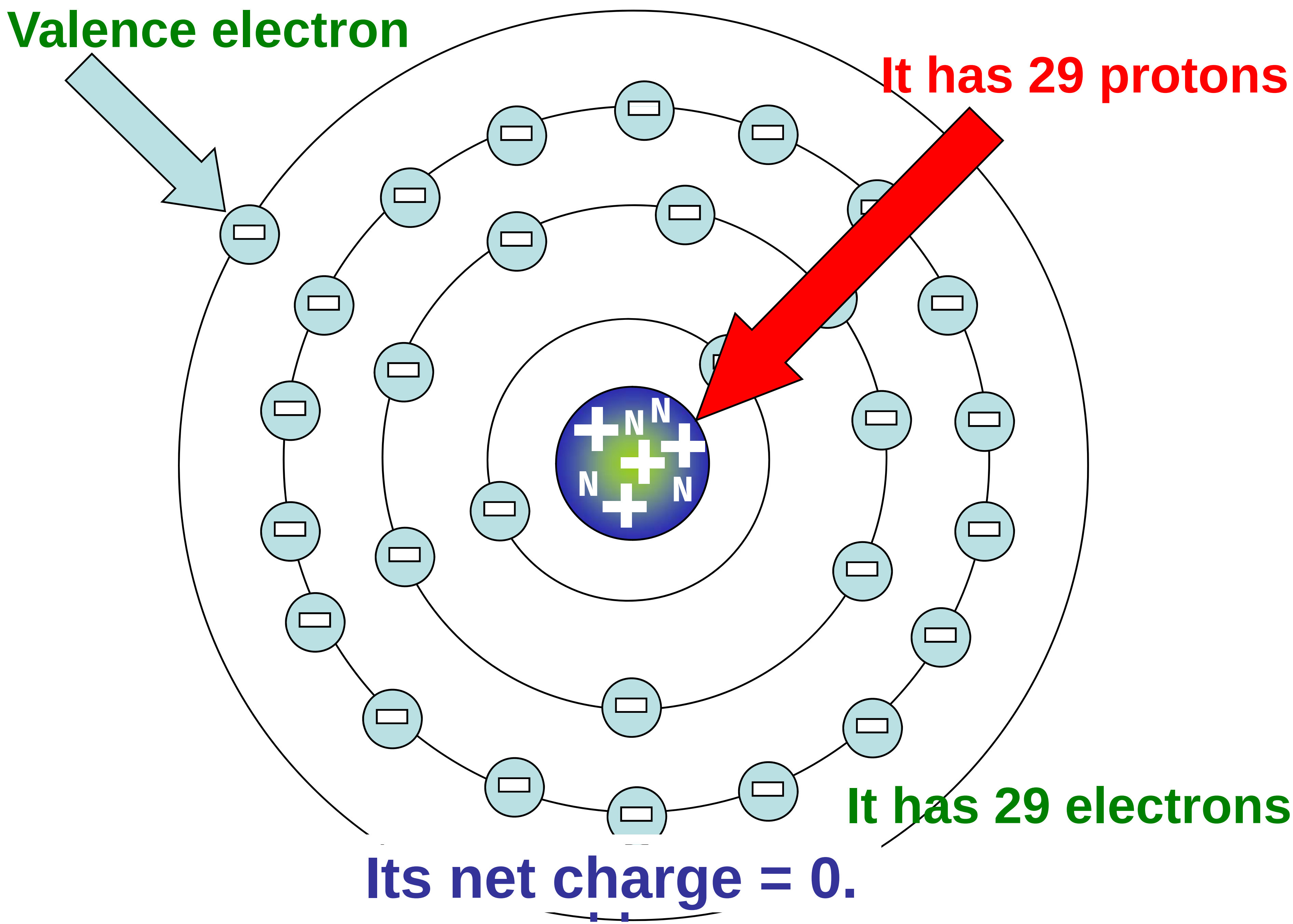


(e) Phosphorus atom(atomic number 15)

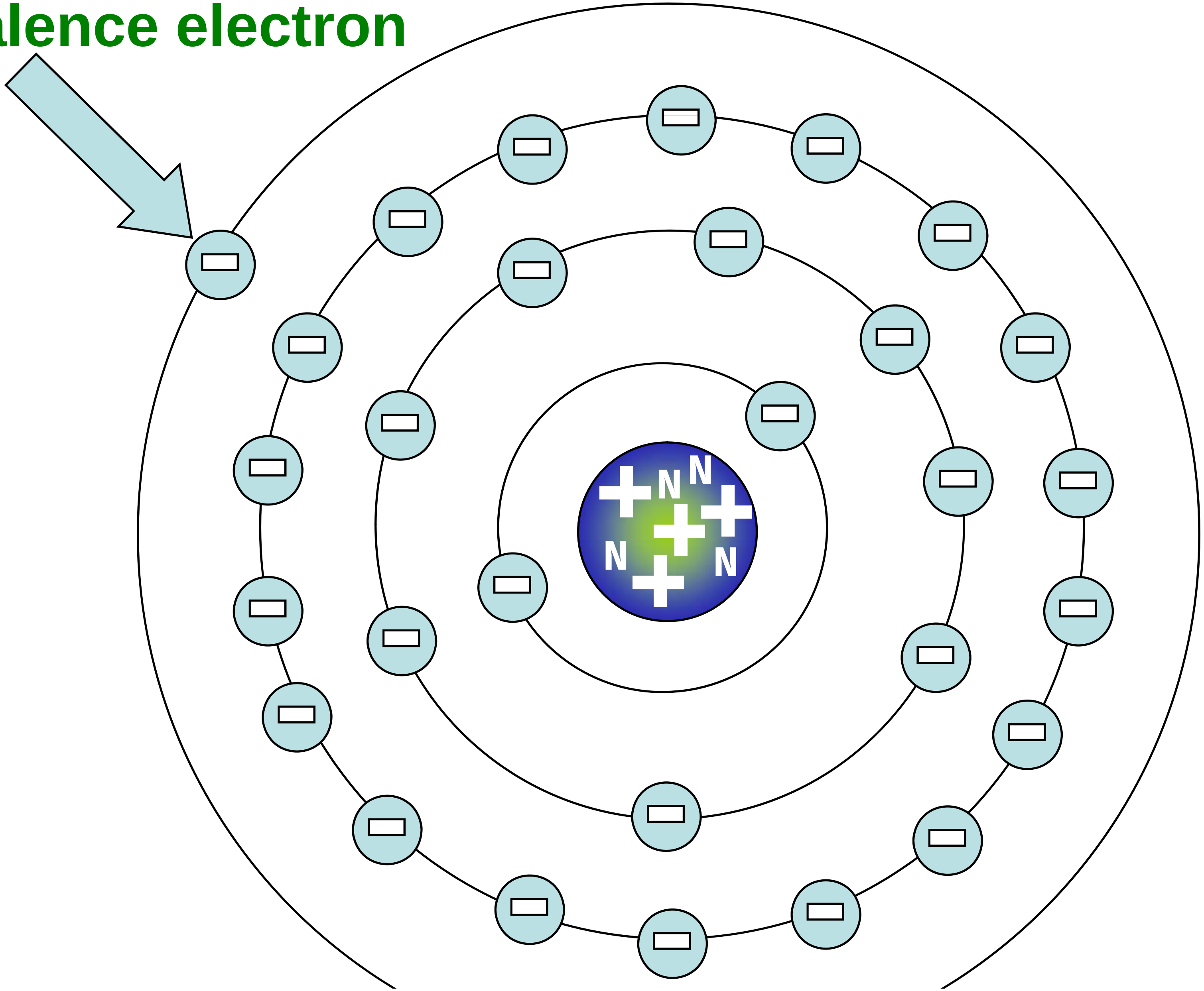


(f) Germanium atom(atomic number 32)


N
N
N
N
Negative electrons
orbit the nucleus.


Valence electron
It has 29 protons
It has 29 electrons
Its net charge = 0.

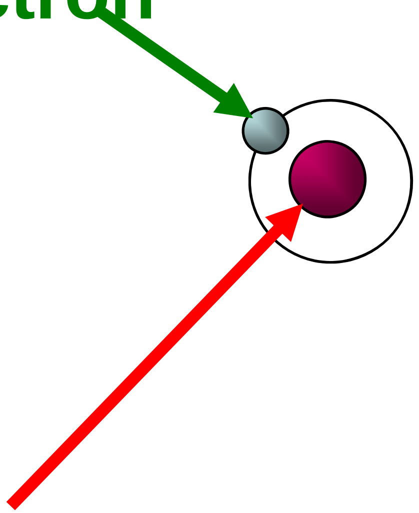
Valence electron



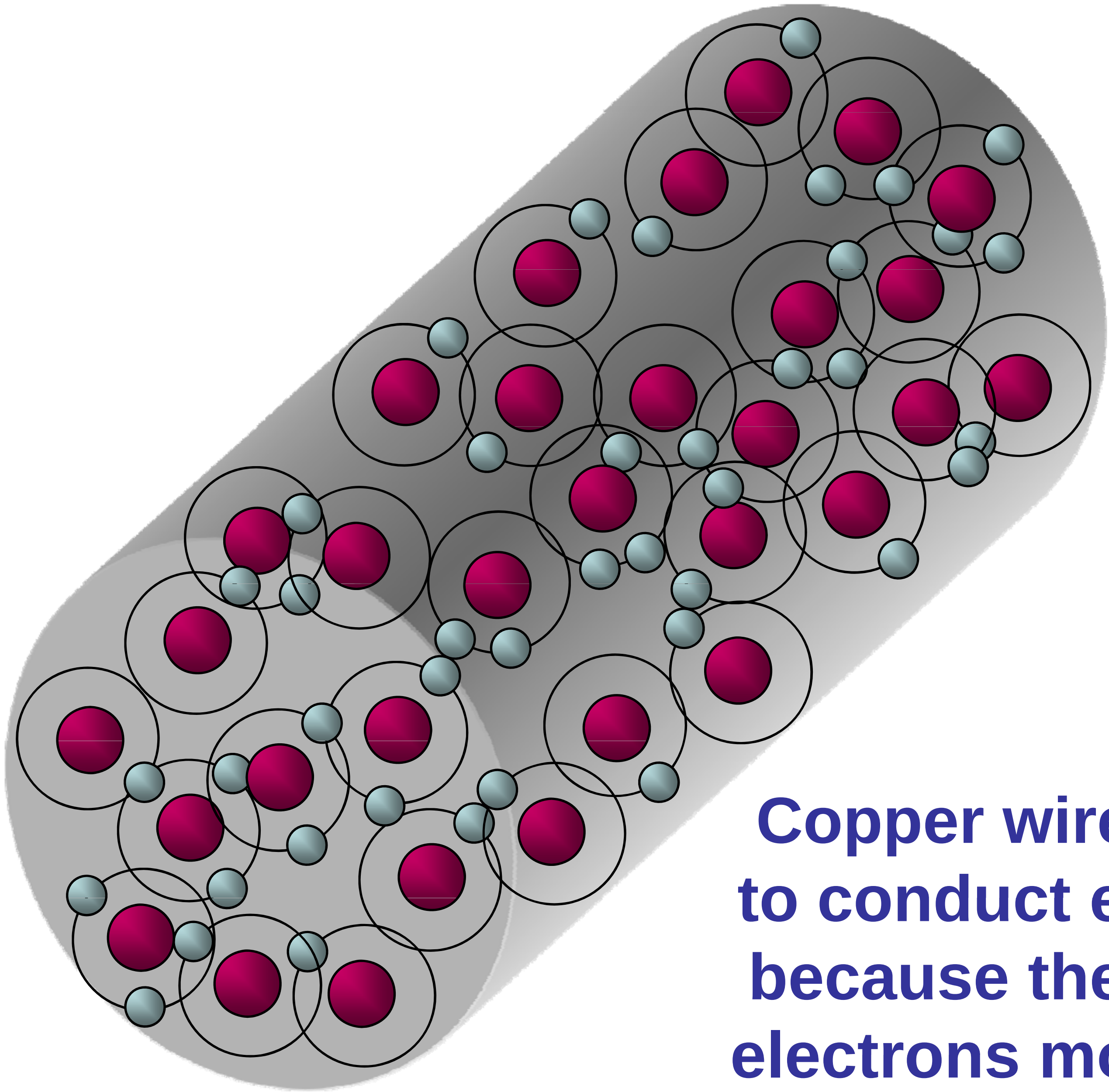
Its attraction to the nucleus is relatively weak.

A simple model of the copper atom looks like this:

The valence electron



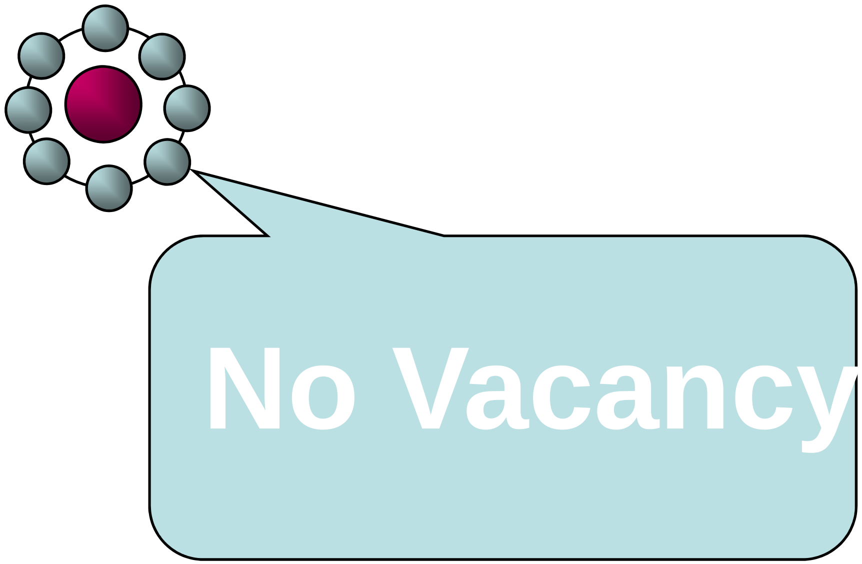
The nucleus plus the inner electron orbits



Copper wire is used to conduct electricity because the valence electrons move freely through its structure.

So far, we know that copper's single valence electron makes it a good conductor.

The rule of eight states that a material like this would be stable since its valence orbit is full.



It acts as an electrical insulator.

Concept Review

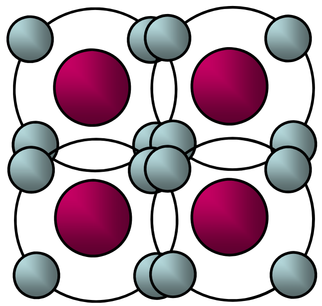
- The nucleus of any atom is positively charged.
- Negatively charged electrons orbit the nucleus.
- The net charge on any atom is zero because the protons and electrons are equal in number.
- The valence orbit is the outermost orbit.
- Copper has only one valence electron and is an excellent conductor.
- Materials with a full valence orbit act as insulators.
- Materials with 8 electrons in the valence orbit act as insulators.

Concept Preview

- **Silicon has 4 valence electrons.**
- **Silicon atoms can form covalent bonds with each other.**
- **Covalent silicon satisfies the rule of 8 and acts as an insulator at room temperature.**
- **Donor impurities have 5 valence electrons.**
- **N-type silicon has been doped with a donor impurity to make it semiconduct.**
- **Acceptor impurities have 3 valence electrons.**
- **P-type silicon has been doped with an acceptor impurity to make it semiconduct.**

Atoms of the same type can join together and form covalent bonds.

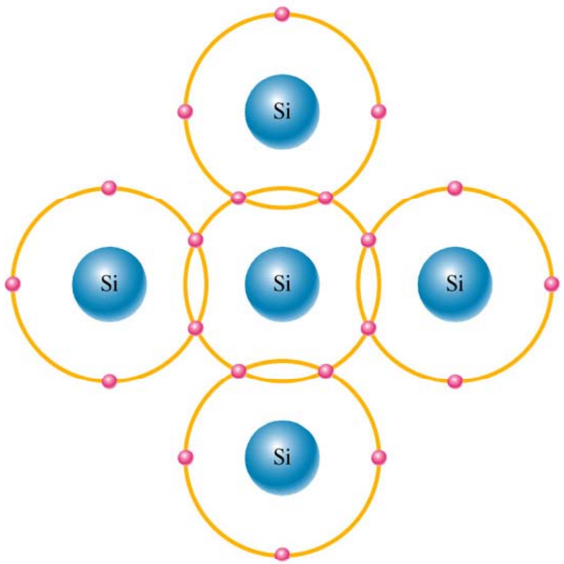
This is an electron sharing process.



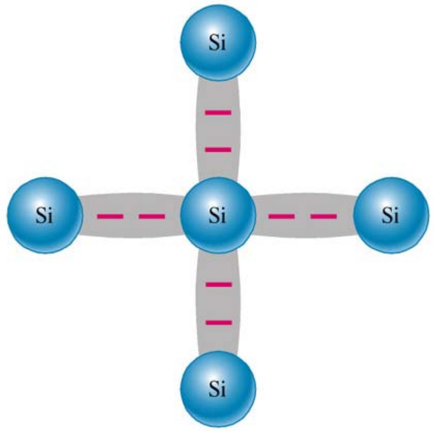
Silicon atoms have four valence electrons.

Covalent Bonding

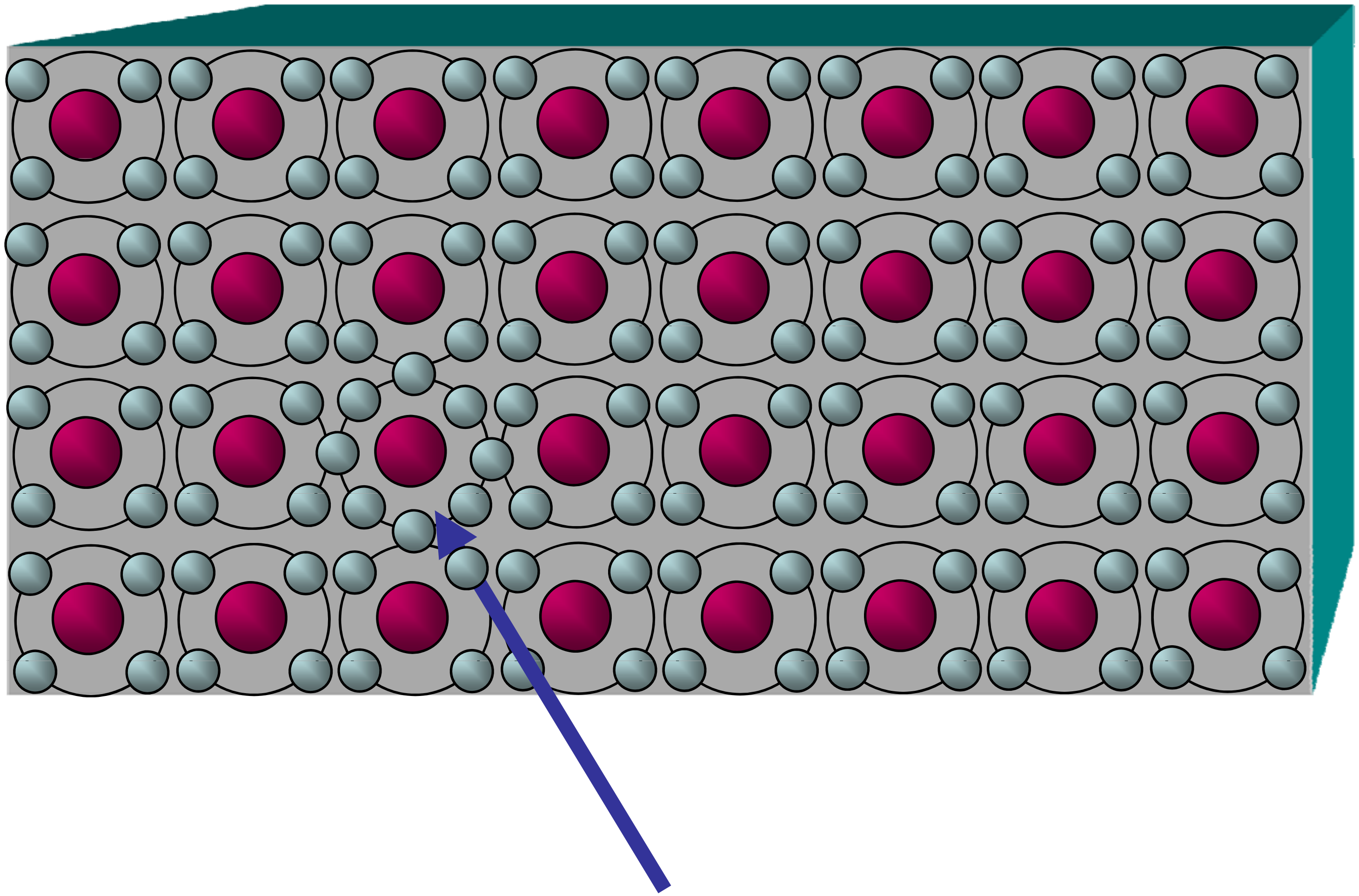
Covalent bonding is a bonding of two or more atoms by the interaction of their valence electrons.



(a) The center atom shares an electron with each of the four surrounding atoms, creating a covalent bond with each. The surrounding atoms are in turn bonded to other atoms, and so on.



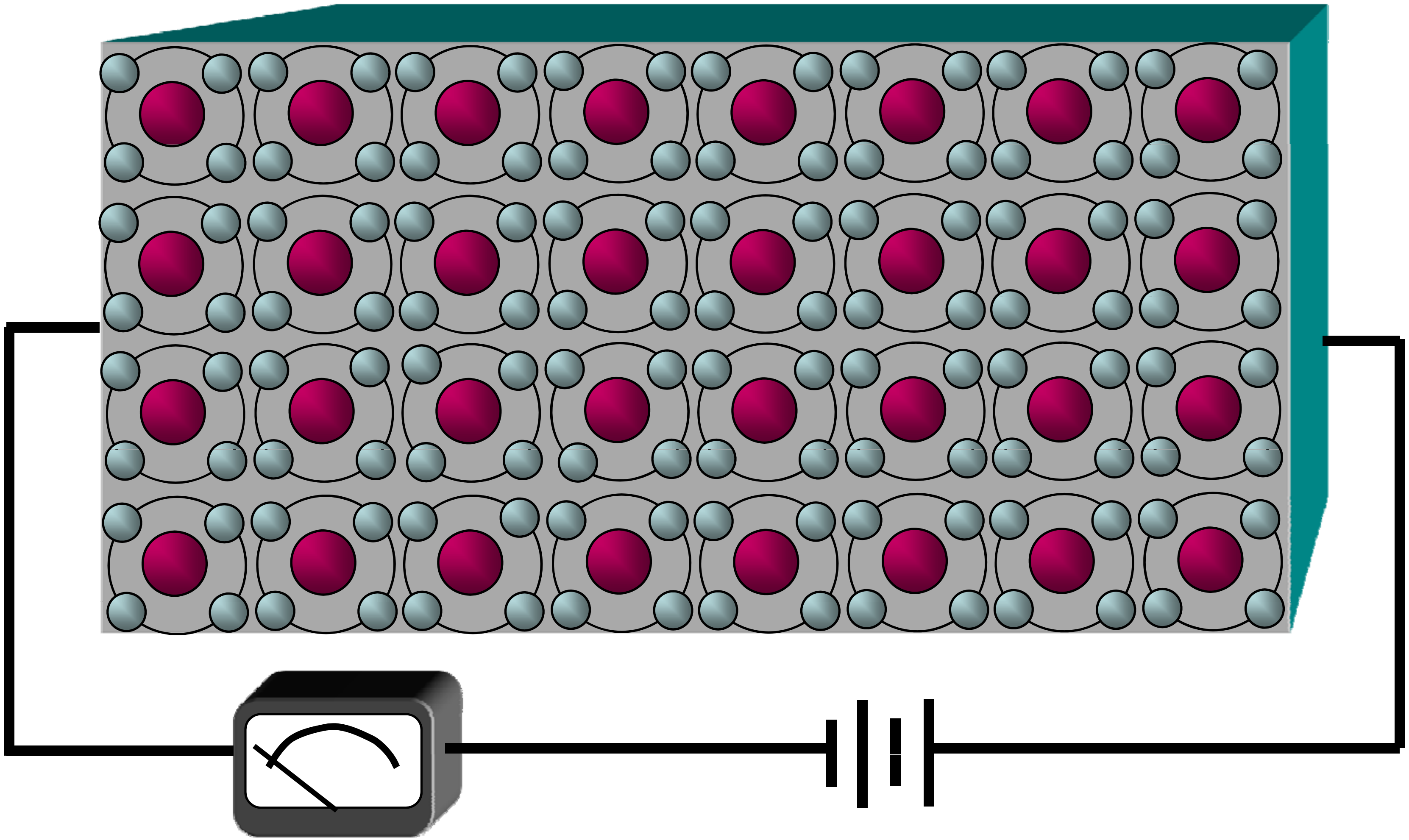
(b) Bonding diagram. The red negative signs represent the shared valence electrons.



The covalent sharing satisfies the rule of eight.

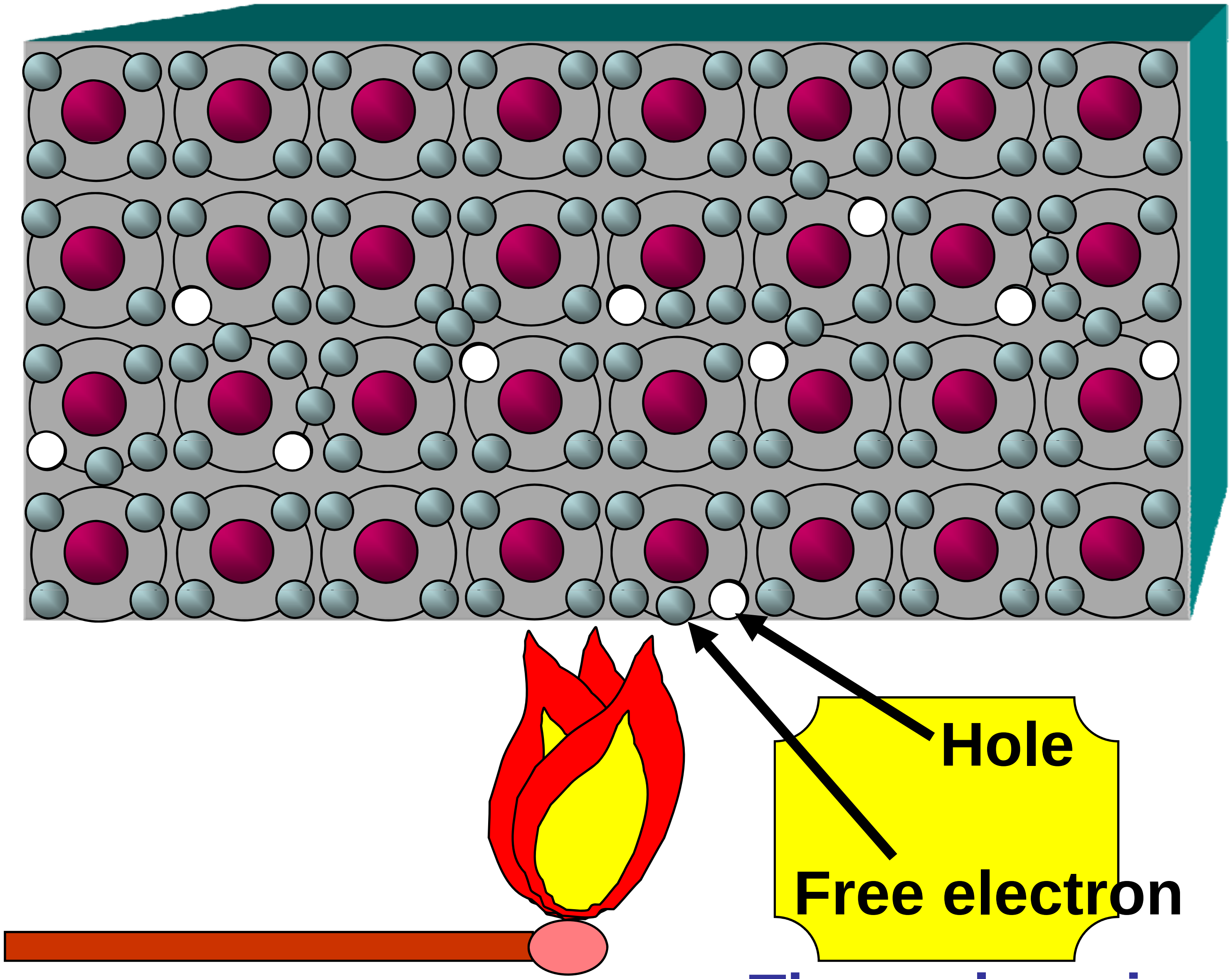
In this structure, one bond is formed with each neighbor.

This is a silicon crystal.

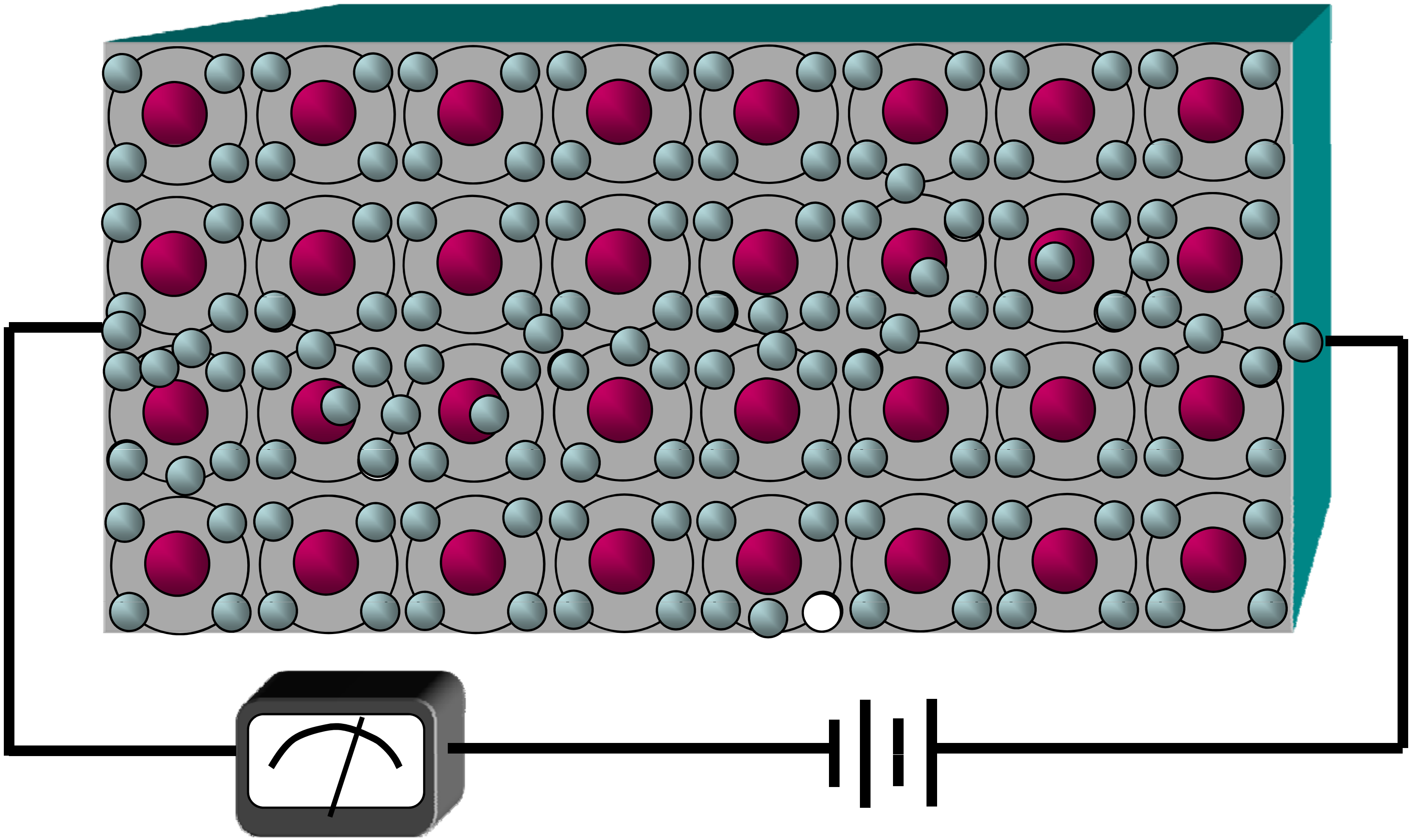


It does not conduct because its valence electrons are captured by covalent bonds.

Covalent bonds can be broken by heating a silicon crystal.

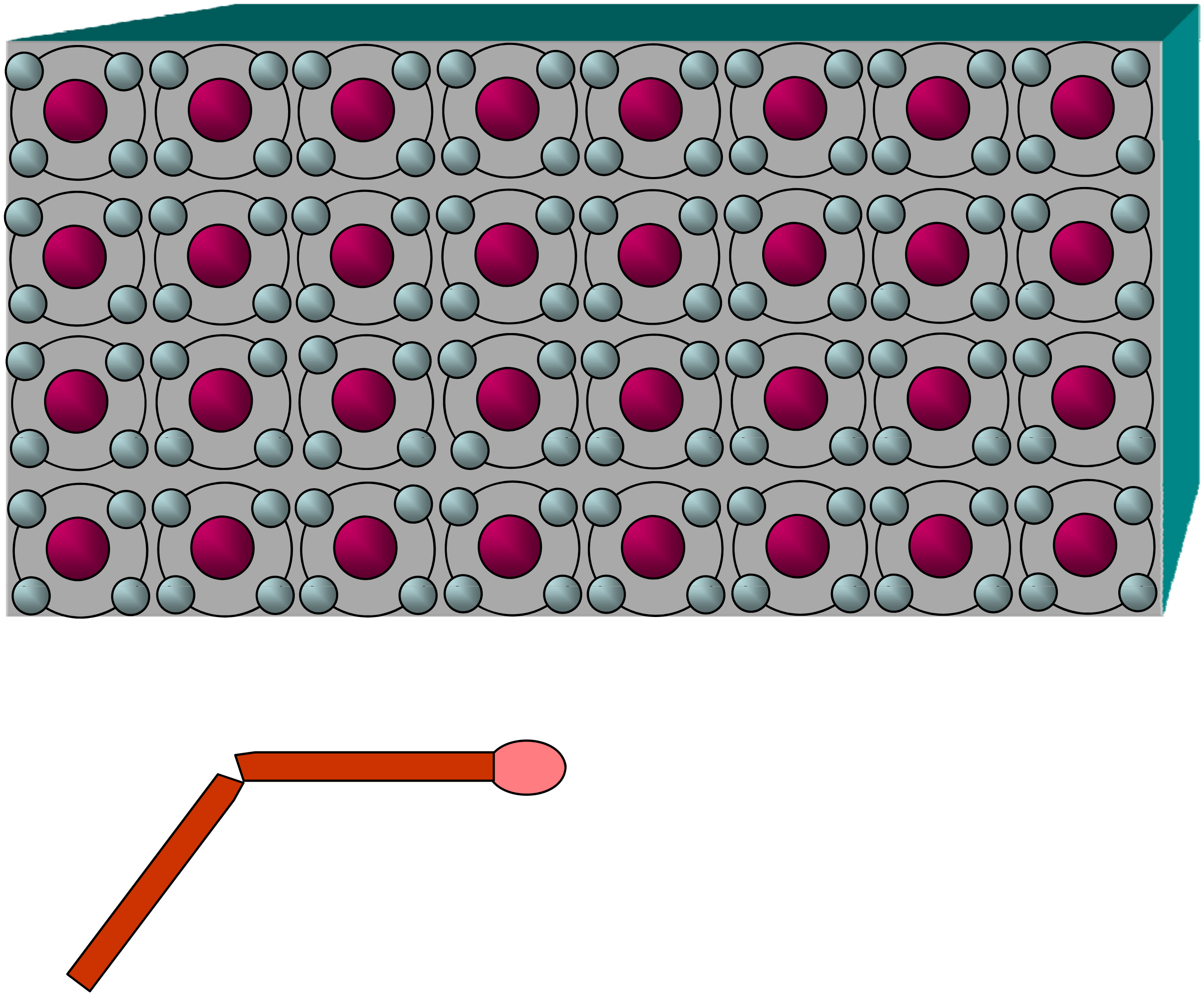


Thermal carriers



The thermal carriers support the flow of current.

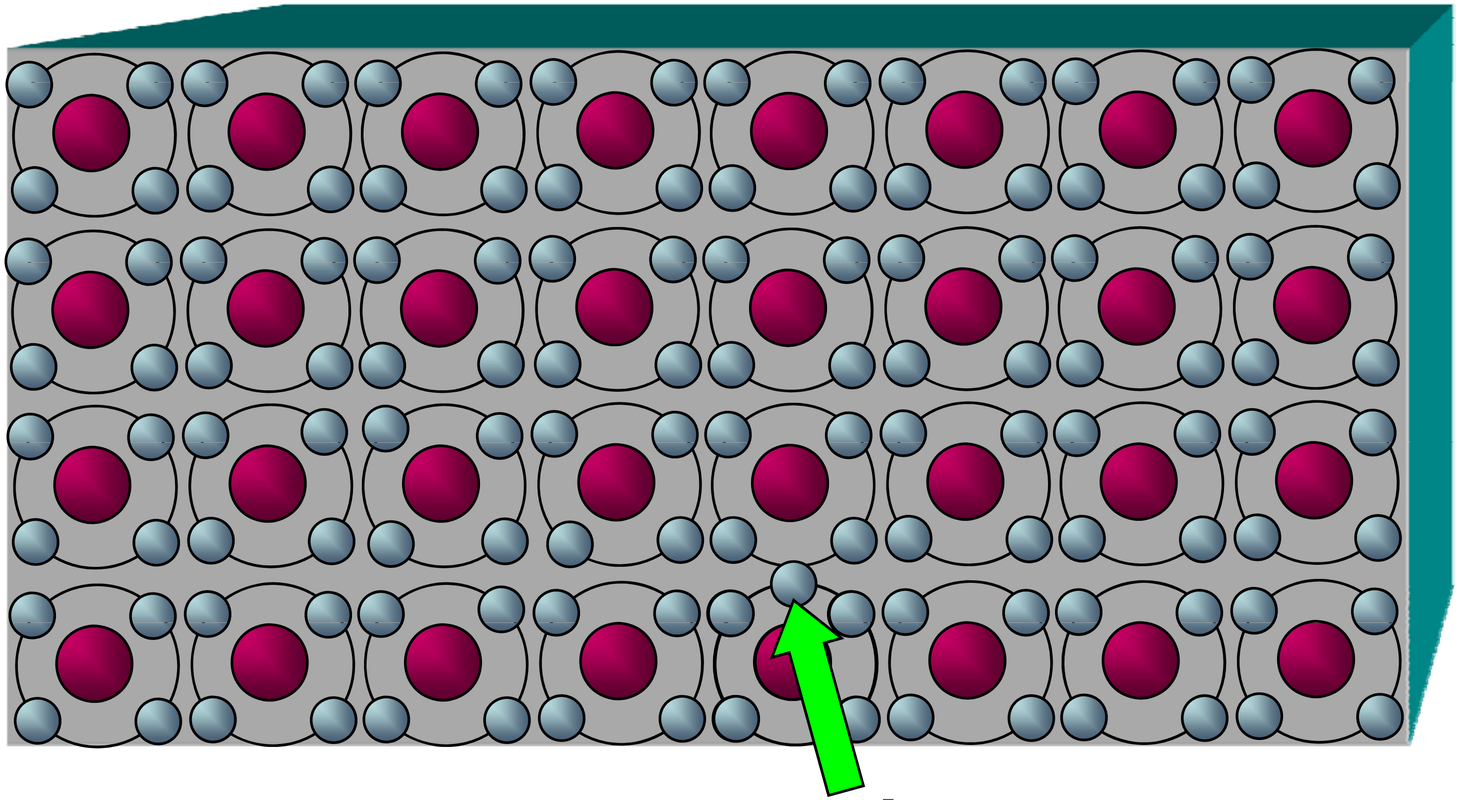
Heating silicon crystals to make them conduct is not practical!



Silicon

- Silicon is used to create most semiconductors.
- A pure semiconductor is often called an "intrinsic" semiconductor.
- The electronic properties and the conductivity of a semiconductor can be changed in a controlled manner by adding very small quantities of other elements, called "dopants" to the intrinsic material.
- In semiconductor production, doping intentionally introduces impurities into an extremely pure (also referred to as intrinsic) semiconductor for the purpose of modulating its electrical properties.

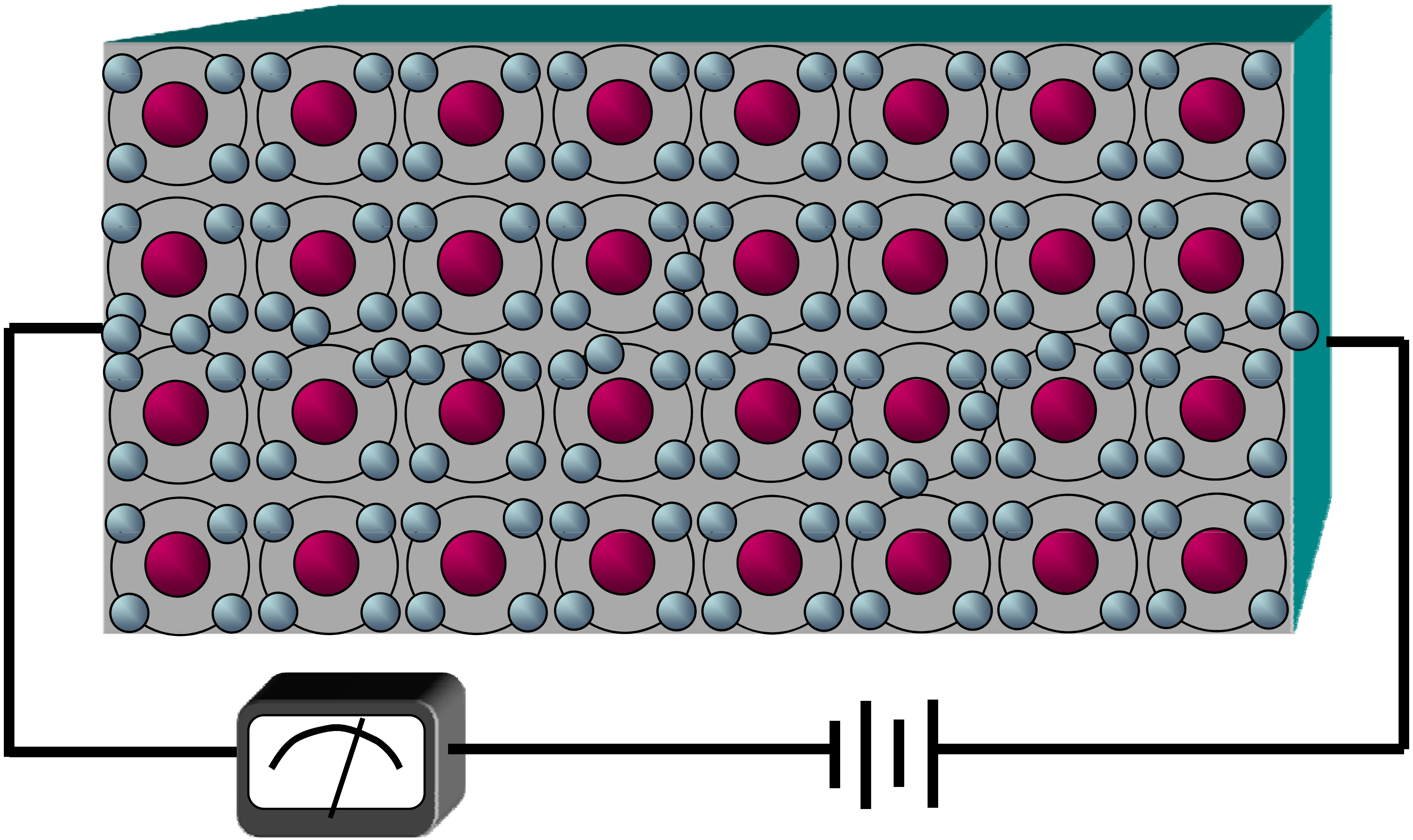
A silicon crystal can be doped with a donor impurity.



Free electron

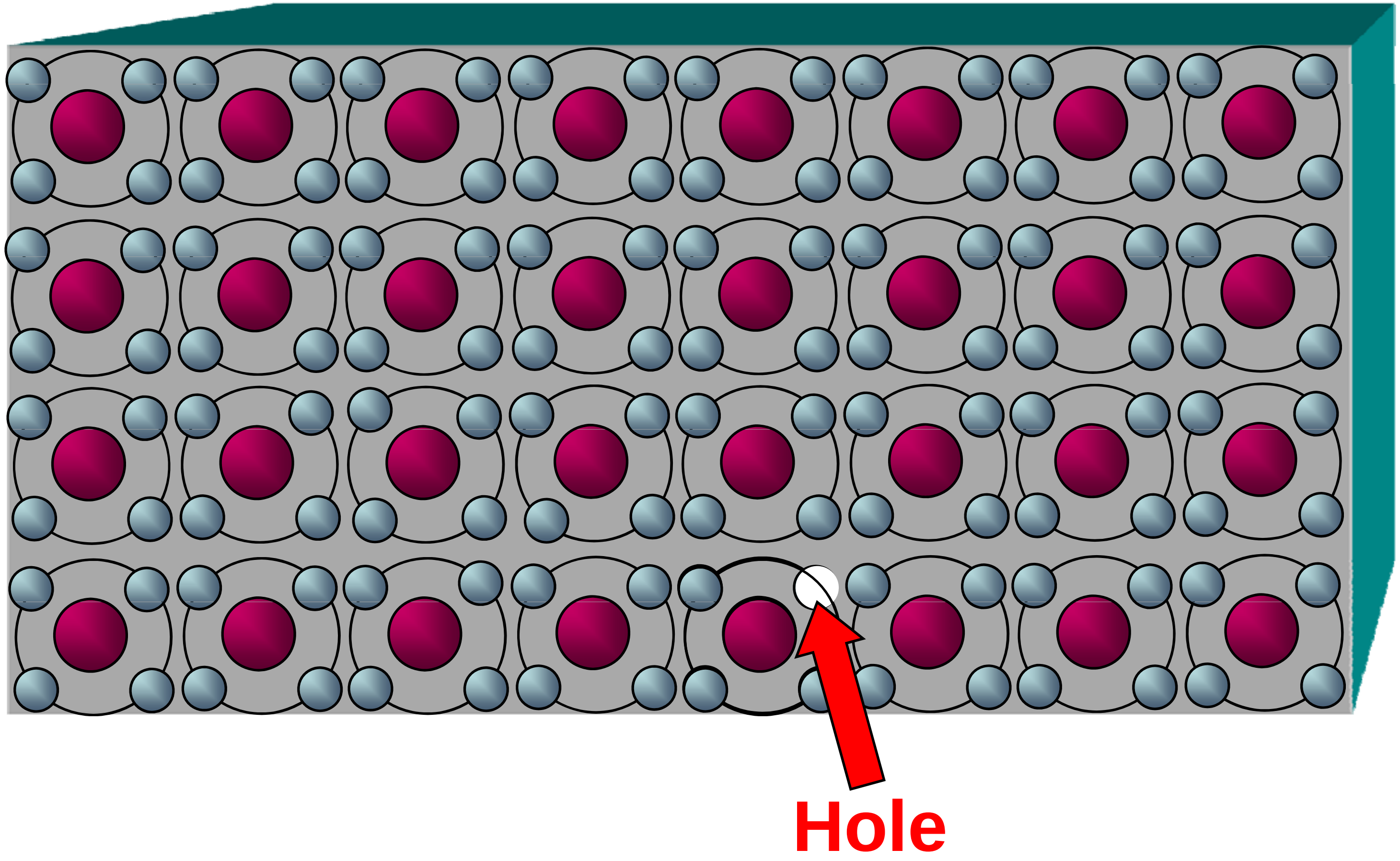
Each donor atom that enters the crystal adds a free electron.

Silicon that has been doped with arsenic is called N-type.



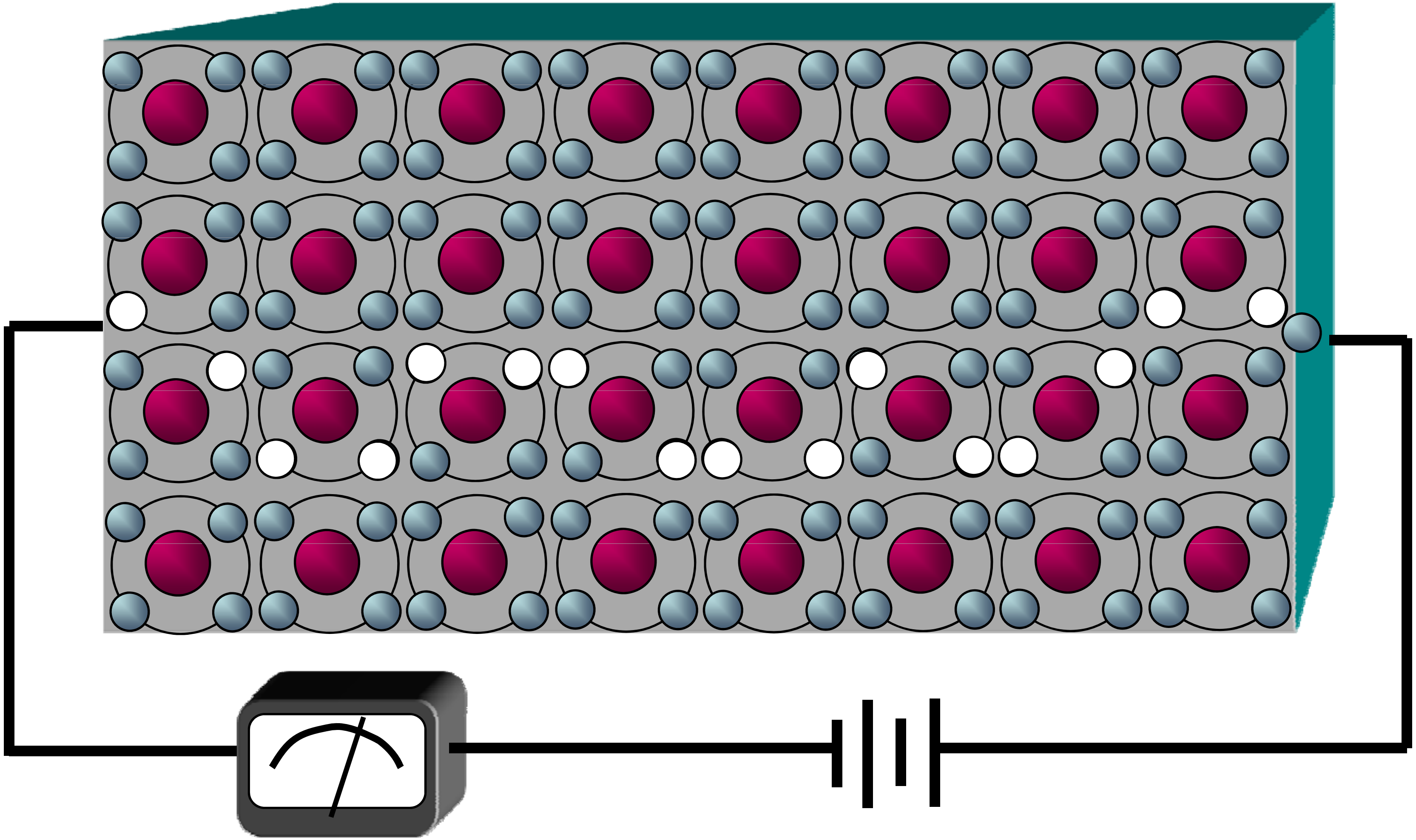
The free electrons in N-type silicon support the flow of current.

A silicon crystal can be doped with an acceptor impurity.



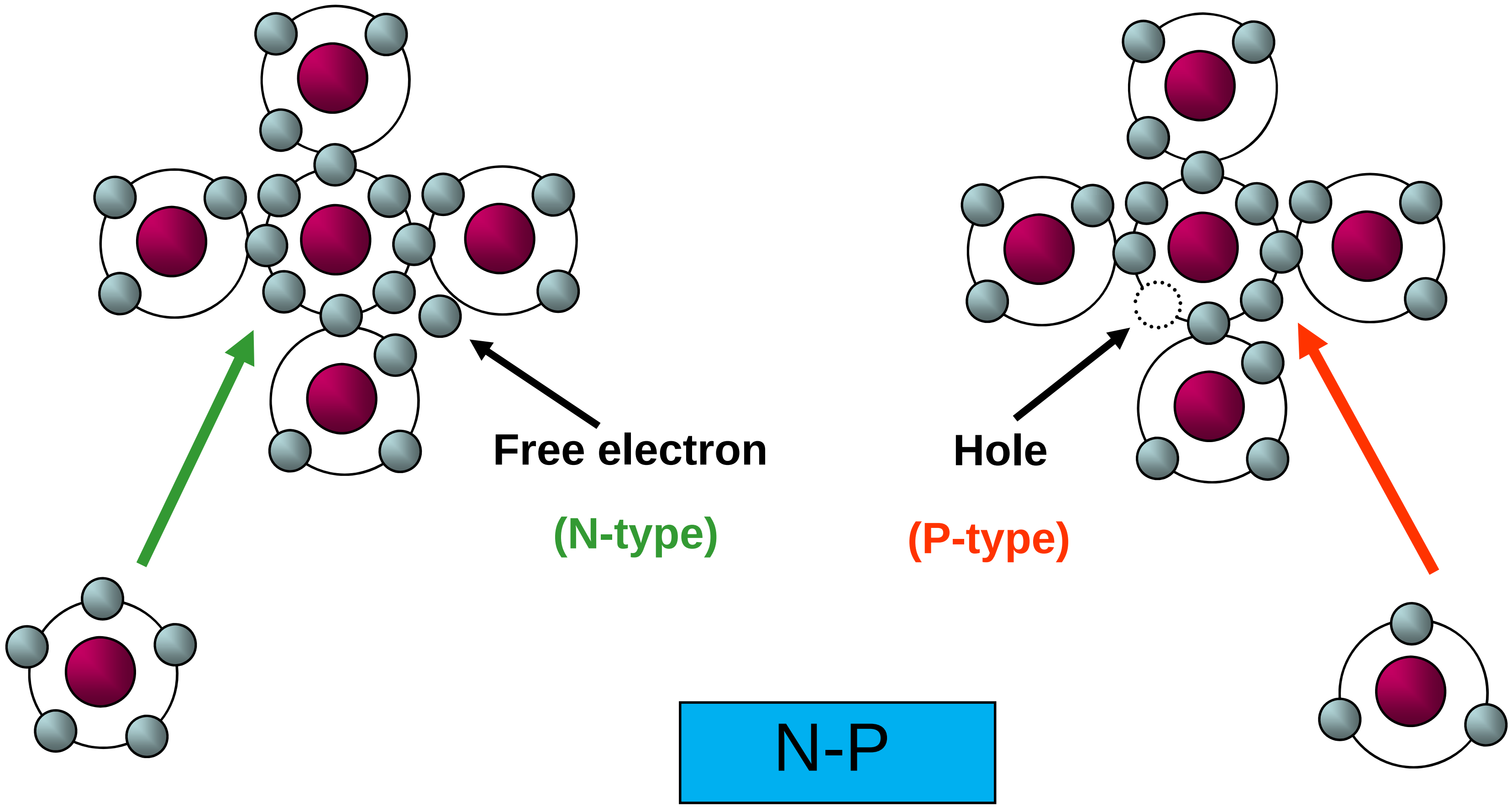
Each acceptor atom that enters the crystal creates a hole.

Silicon that has been doped with boron is called P-type.



The holes in P-type silicon support the flow of current.

What are two practical methods of making silicon semiconduct?



Add a pentavalent impurity.

Add a trivalent impurity.

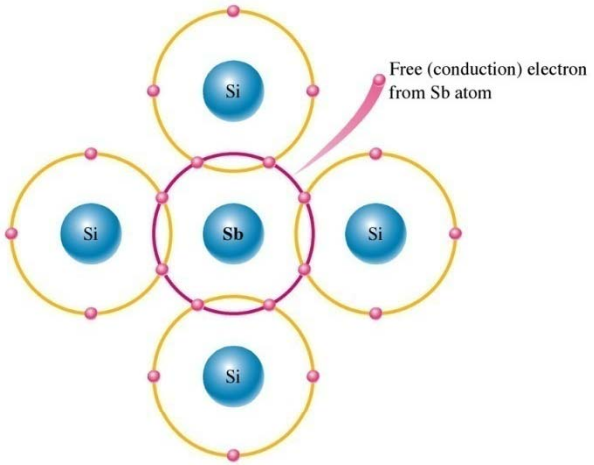
N-type and P-type Semiconductors

The process of creating N- and P-type materials is called doping.

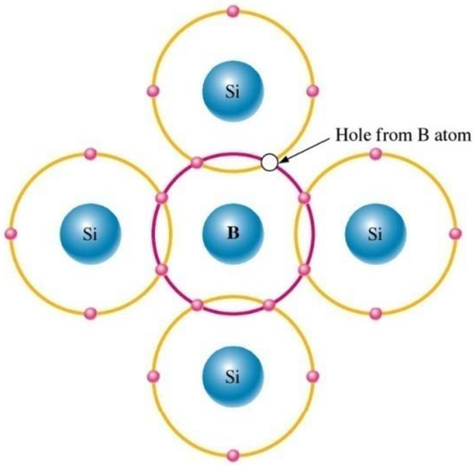
Other atoms with 5 electrons such as Antimony(Sb) are added to Silicon to increase the free electrons.

Other atoms with 3 electrons such as Boron(B) are added to Silicon to create a deficiency of electrons or hole charges.

N-type

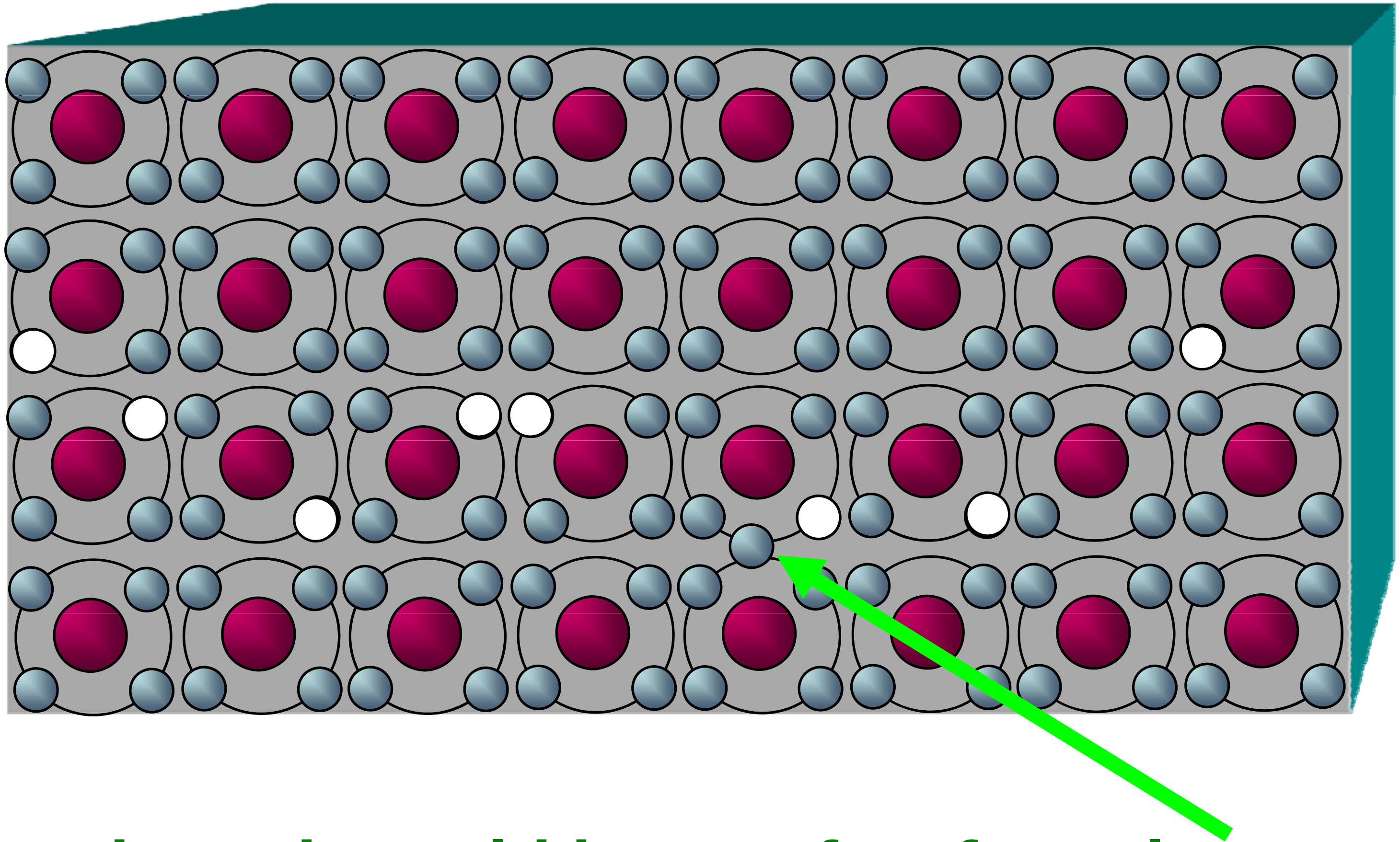


P-type



Boron(3e), arsenic(5e), phosphorus(5e), and gallium(3e) are normally used to dope silicon and germanium.

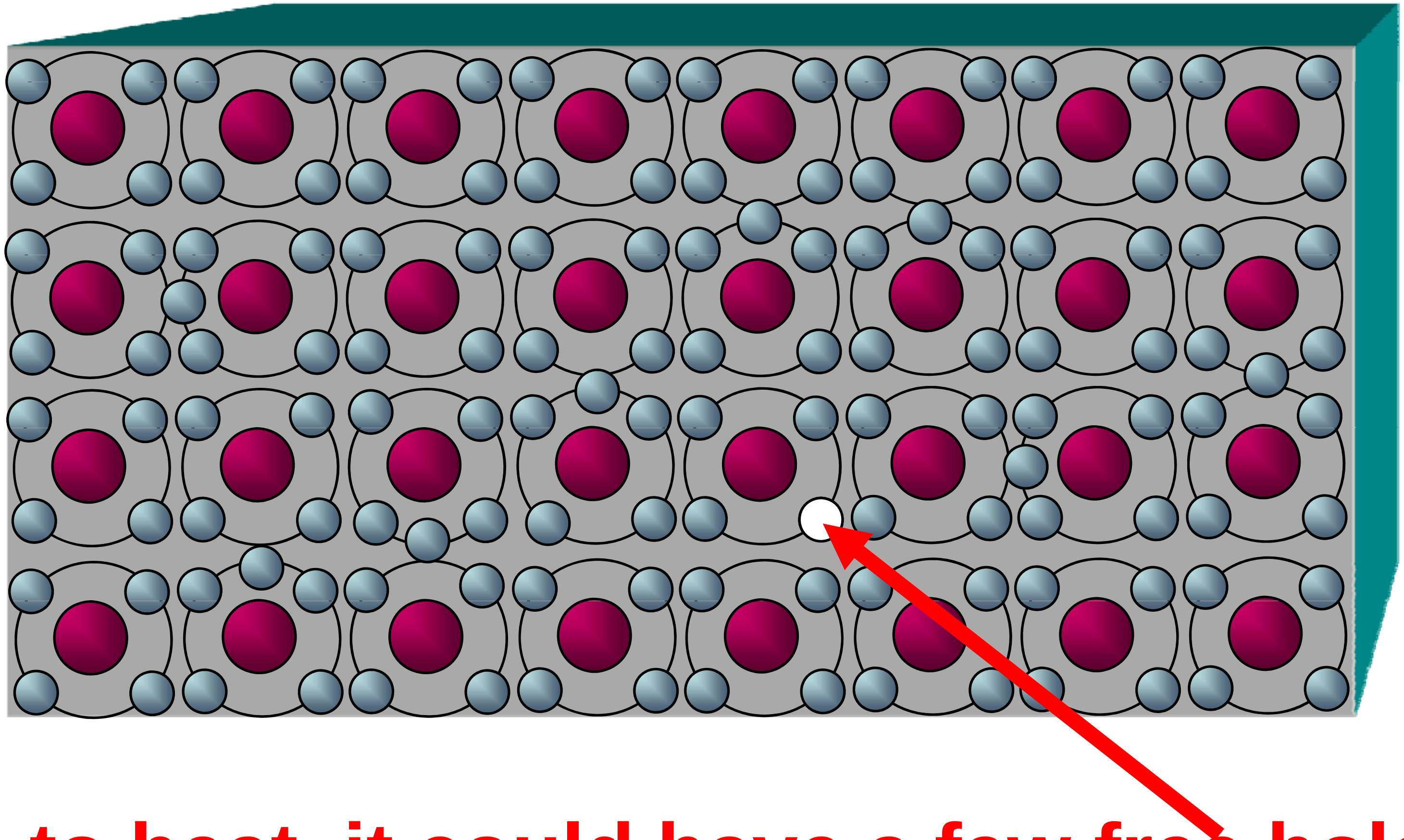
This is a P-type crystal.



Due to heat, it could have a few free electrons.

These are called *minority* carriers.

This is an N-type crystal.

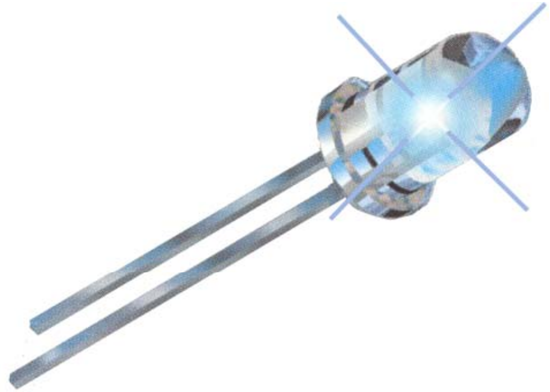


Due to heat, it could have a few free holes.

These are called *minority* carriers.

Other Semiconductors

Silicon is the workhorse of the semiconductor industry but compound semiconductors help out in key areas.



- Gallium arsenide
- Indium phosphide
- Mercury cadmium telluride
- Silicon carbide
- Cadmium sulfphide
- Cadmium telluride