KMITL Engineer คณะวิศวกรรมศาสตร์ ลาดกระบัง

INTRODUCTION TO ELECTRONICS

วิศวลาดกระบัง
ต้องเป็นหนึ่ง
และเป็นที่พึ่งของสังคม

01076232ELECTRONICS FOR COMPUTER ENGINEERING

- Room: ECC Bldg., Room 810
- Instructor : Amnach Khawne, Ph.D.
- Grading :
  - – Mid. 30 %
  - – Final 50%
  - – Assignment+HW 20%

Electronics

- Def:
  - Electronics, in the strictest sense, is the science and technology of the motion of changes in a gas, vacuum, or semiconductor.

Historical Review:

Short History Of Electronics From The Beginning

(1) While Hittorf and William Crooks 1869 --------> Cathode Ray → vaccum blocks.

(2) Maxwell 1869 --------> Theory of Electromagnetic Radiation

(3) Edison 1883 --------> Observed Electronically Conduction in a Vacuum

(4) Hertz 1888 --------> Radiowave but predicted by Maxwell

(5) J.J Thomson 1897 --------> Measure e- (1.6021x10-19 coulomb) m (9.109x10-31 Kg)

(6) Marconi 1901 --------> Interested Wireless Communication

(7) Marconi 1904 --------> Interested Photoelectric Effect

(8) Fleming 1904 --------> Invented 1st Electronic Tube (Vacuum Diode)

(9) De.Forest 1906 --------> Vacuum Triode

(10) Armstrong 1912 --------> Oscillator

(11) Zworykin 1924 --------> Picture Tube

(12) Watson Watt 1939 --------> Radio Detection & Ranging (RADAR)

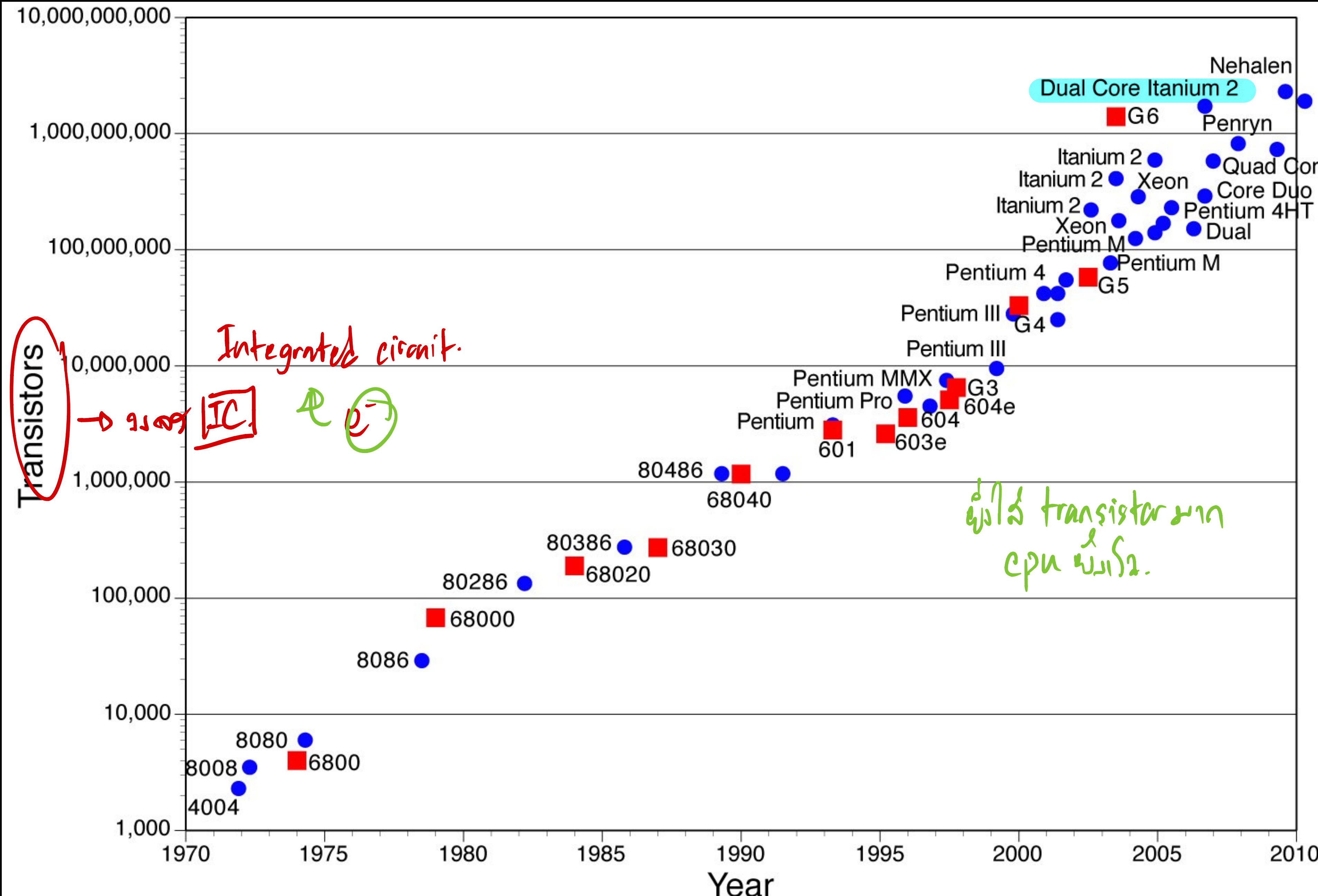
(13) Postwar 1942 --------> Demands and increase knowledge of Semiconductor

(14) Schockley, Bardeen, Bretain 1947 --------> Transistor

(15) Peason 1954 --------> Silicon Soloar Cell

(17) Kilbey 1958 --------> Integrated Circuits (IC's)

(18) Maimon 1960 --------> Ruby Lazer (Schowlows concept 1958 that MASER's Principle into Optical region)

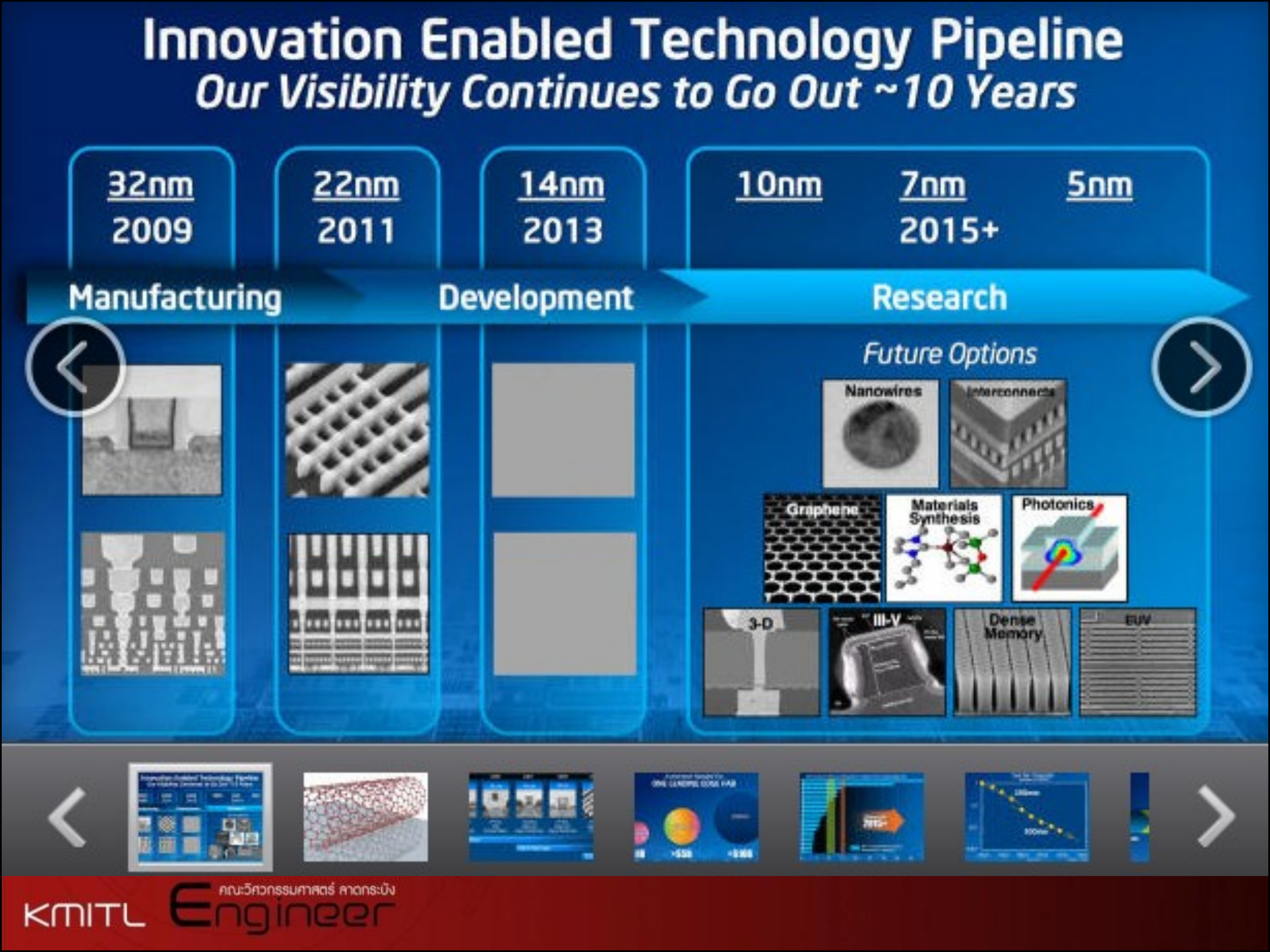


Integrated circuit.

→ จะเจอ IC

e e⁻

ยิ่งใส่ transistor มาก cpu ยิ่งเร็ว.


Innovation Enabled Technology Pipeline
Our Visibility Continues to Go Out ~10 Years
32nm
2009
22nm
2011
14nm
2013
10nm
7nm
5nm
2015+
Manufacturing
Development
Research
Future Options
Nanowires
Interconnects
Graphene
Materials Synthesis
Photonics
3-D
III-V
Dense Memory
EUV
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CHAPTER OUTLINE

- **1–1 The Atom**
- **1–2 Materials Used in Electronics**
- **1–3 Current in Semiconductors**
- **1–4 N-Type and P-Type semiconductors**
- **1–5 The PN Junction**
  - GreenTech Application 1: *Solar Power*

CHAPTER OBJECTIVES

- Describe the structure of an atom
- Discuss insulators, conductors, and semiconductors and how they differ
- Describe how current is produced in a semiconductor
- Describe the properties of *n-type and p-type* semiconductors
- Describe how a *pn junction is formed*

INTRODUCTION

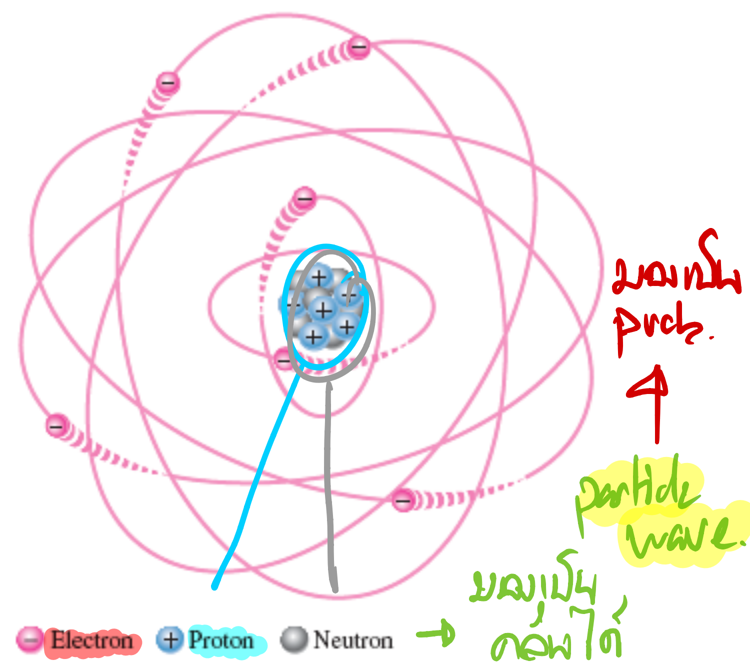
- Electronic devices such as diodes, transistors, and integrated circuits are made of a semiconductive material.
- To understand how these devices work, you should have a basic knowledge of the structure of atoms and the interaction of atomic particles.
- An important concept introduced in this chapter is that of the pn junction that is formed when two different types of semiconductive material are joined.
- The *pn* junction is fundamental to the operation of devices such as the solar cell, the diode, and certain types of transistors

1–1 THE ATOM

- ❑ **Describe the structure of an atom**
  - ◆ Discuss the Bohr model of an atom
  - ◆ Define *electron, proton, neutron, and nucleus*
- ❑ Define *atomic number*
- ❑ Discuss electron shells and orbits
  - ◆ Explain energy levels
- ❑ Define *valence electron*
- ❑ Discuss ionization
  - ◆ Define *free electron and ion*
- ❑ Discuss the basic concept of the quantum model of the atom

The Bohr Model

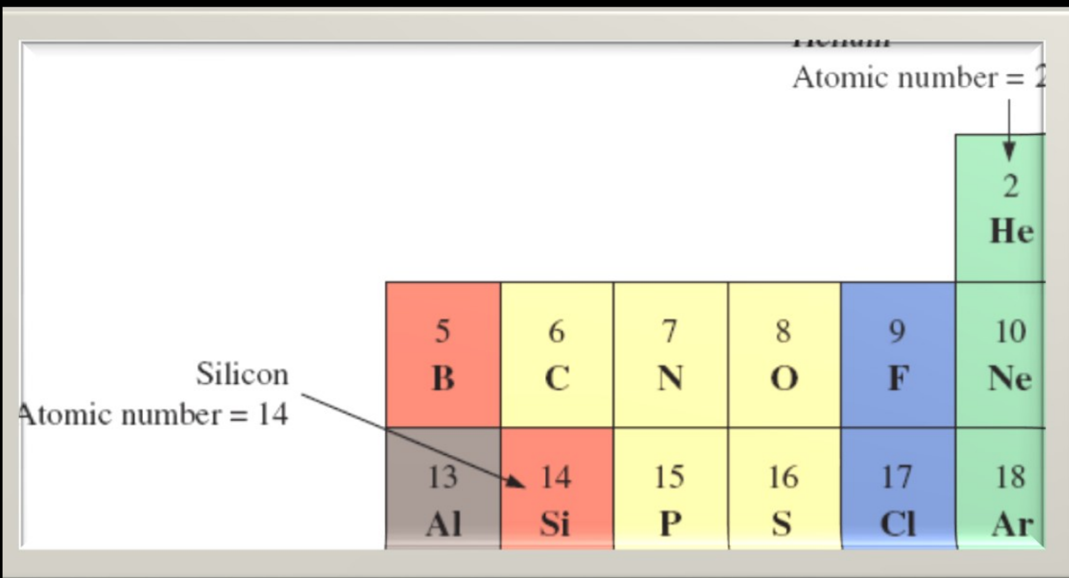
- An **atom*** is the smallest particle of an element that retains the characteristics of that element.



▲ FIGURE 1–1

The Bohr model of an atom showing electrons in orbits around the nucleus, which consists of protons and neutrons. The "tails" on the electrons indicate motion.

Atomic Number



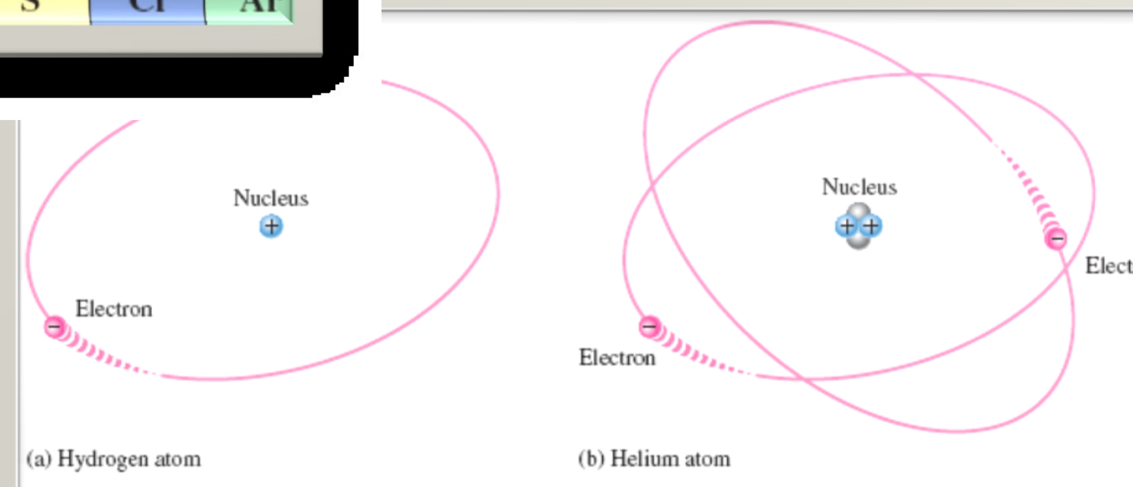
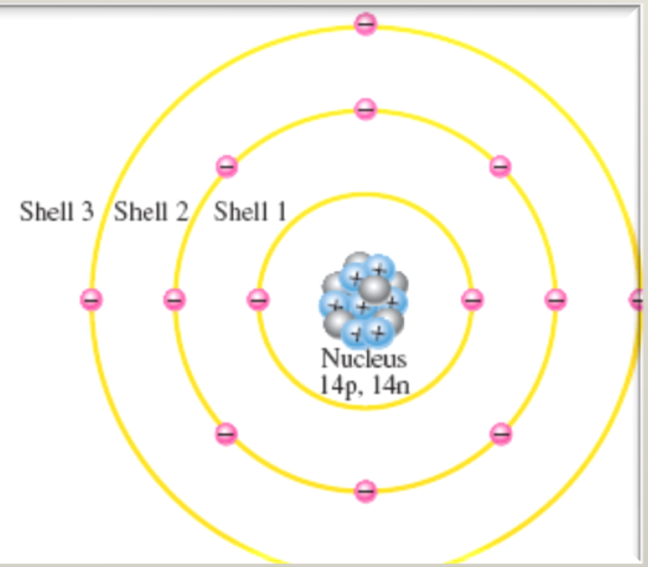


FIGURE 1–2

Electrons and Shells

- ***Energy Levels*** Electrons orbit the nucleus of an atom at certain distances from the nucleus.
- **Electrons near the nucleus have less energy than those in more distant orbits.**
- Each discrete distance (**orbit**) from the nucleus corresponds to a certain energy level.
- In an a … wn as **shells**



▶ FIGURE 1–4

Illustration of the Bohr model of the silicon atom.

The Maximum Number of Electrons in Each Shell

- Each shell has a fixed maximum number of electrons N_e .
- The shells (energy levels) are designated 1, 2, 3, and so on, with 1 being closest to the nucleus.

The Maximum Number of Electrons in Each Shell The maximum number of electrons (N_e) that can exist in each shell of an atom is a fact of nature and can be calculated by the formula,

$$N_e = 2n^2$$

where n is the number of the shell. The maximum number of electrons that can exist in the innermost shell (shell 1) is

$$N_e = 2n^2 = 2(1)^2 = 2$$

The Maximum Number of Electrons in Each Shell

The maximum number of electrons that can exist in shell 2 is

$$N_e = 2n^2 = 2(2)^2 = 2(4) = 8$$

The maximum number of electrons that can exist in shell 3 is

$$N_e = 2n^2 = 2(3)^2 = 2(9) = 18$$

The maximum number of electrons that can exist in shell 4 is

$$N_e = 2n^2 = 2(4)^2 = 2(16) = 32$$

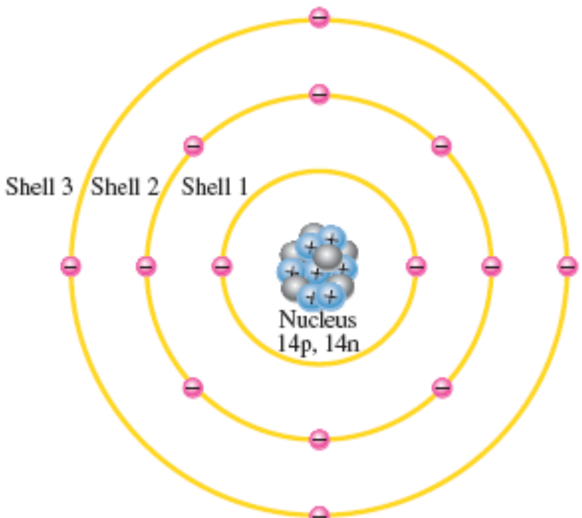
Atoms are extremely small and cannot be seen even with the strongest optical microscopes; however, a scanning tunneling microscope can detect a single
atom. The nucleus is so small and the electrons orbit at such distances that the atom is mostly empty space. To put it in perspective, if the proton in a hydrogen atom were the size of a golf ball, the electron orbit would be approximately one mile away.

Valence Electrons

- This outermost shell is known as the **valence shell and electrons in this shell are called *valence electrons*.**
- Electrons with the highest energy exist in the outermost shell of an atom and are relatively loosely bound to the atom.

▶ FIGURE 1–4

Illustration of the Bohr model of the silicon atom.



Ionization

- If a valence electron acquires a sufficient amount of energy, called *ionization energy*, It can actually escape from the outer shell and the atom's influence.
- The departure of a valence electron leaves a previously neutral atom with an excess of positive charge (more protons than electrons).
- The process of losing a valence electron is known as **ionization**, and the resulting positively charged atom is called a *positive ion*.
- The escaped valence electron is called a **free electron.**

The Quantum Model

- Although the Bohr model of an atom is widely used because of its simplicity and ease of visualization, it is not a complete model.
- The quantum model, a more recent model, is considered to be more accurate.
- The quantum model is a statistical model and very difficult to understand or visualize.
- Like the Bohr model, the quantum model has a nucleus of protons and neutrons surrounded by electrons.
- Unlike the Bohr model, the electrons in the quantum model do not exist in precise circular orbits as particles.

The Quantum Model

- In the quantum model, each shell or energy level consists of up to four subshells called **orbitals, which are designated *s, p, d, and f*.**
- Orbital *s can hold a maximum of two electrons,* orbital *p can hold six electrons, orbital d can hold ten electrons, and orbital f can hold fourteen* electrons.
- The first full-size number is the shell or energy level, the letter is the orbital, and the exponent is the number of electrons in the orbital.

TABLE 1–1

Electron configuration table for nitrogen.

NOTATION	EXPLANATION
$1s^2$	2 electrons in shell 1, orbital *s*
$2s^2$ $2p^3$	5 electrons in shell 2: 2 in orbital *s*, 3 in orbital *p*

Example

Using the atomic number from the periodic table in Figure 1–3, describe a silicon (Si) atom using an electron configuration table.

Solution The atomic number of silicon is 14. This means that there are 14 protons in the nucleus. Since there is always the same number of electrons as protons in a neutral atom, there are also 14 electrons. As you know, there can be up to two electrons in shell 1, eight in shell 2, and eighteen in shell 3. Therefore, in silicon there are two electrons in shell 1, eight electrons in shell 2, and four electrons in shell 3 for a total of 14 electrons. The electron configuration table for silicon is shown in Table 1–2.

NOTATION	EXPLANATION
$1s^2$	2 electrons in shell 1, orbital *s*
$2s^2 \quad 2p^6$	8 electrons in shell 2: 2 in orbital *s*, 6 in orbital *p*
$3s^2 \quad 3p^2$	4 electrons in shell 3: 2 in orbital *s*, 2 in orbital *p*

12 Mg แมกนีเซียม : [Ne] $3s^2$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	
2	8		2	

13 Al อะลูมิเนียม : [Ne] $3s^2$ $3p^1$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^1$
2	8		3	

14 Si ซิลิกอน : [Ne] $3s^2$ $3p^2$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^2$
2	8		4	

15 P ฟอสฟอรัส : [Ne] $3s^2$ $3p^3$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^3$
2	8		5	

16 S กำมะถัน : [Ne] $3s^2$ $3p^4$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^4$
2	8		6	

17 Cl คลอรีน : [Ne] $3s^2$ $3p^5$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^5$
2	8		7	

18 Ar อาร์กอน : [Ne] $3s^2$ $3p^6$

$1s^2$	$2s^2$	$2p^6$	$3s^2$	$3p^6$
2	8		8	

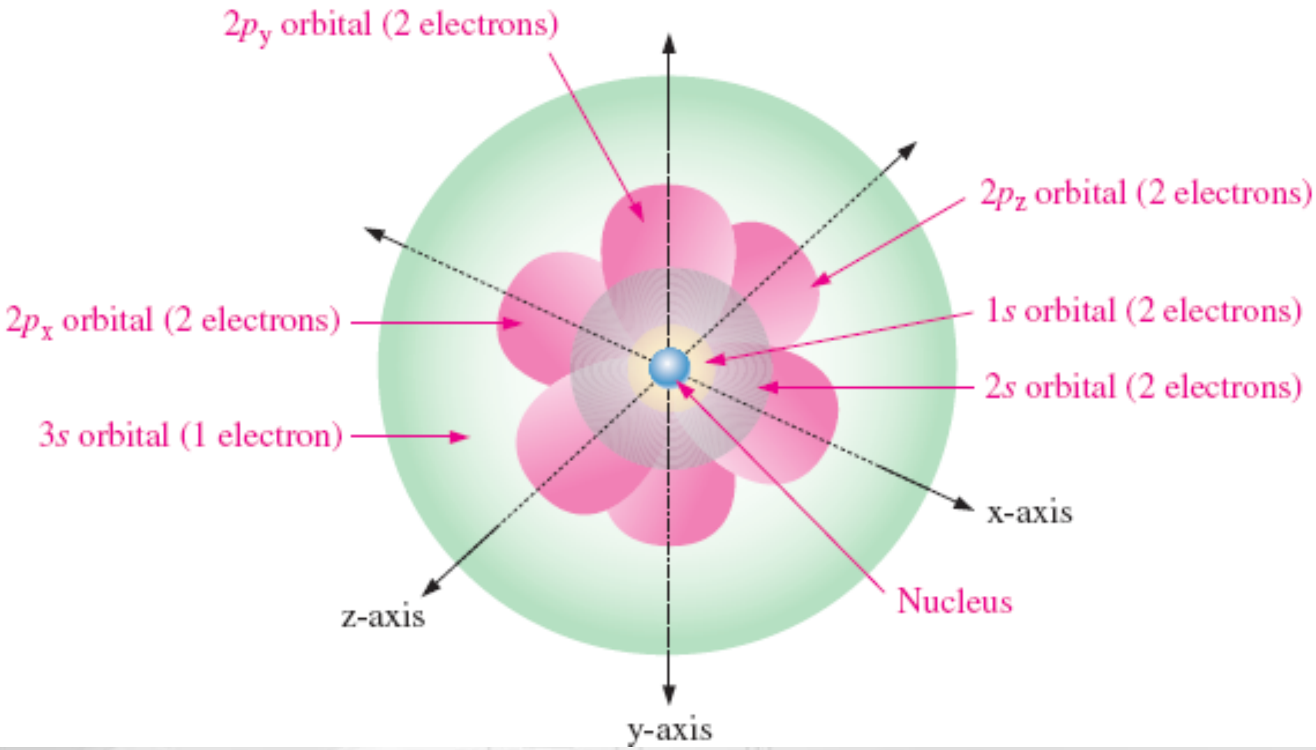


FIGURE 1–5

Three-dimensional quantum model of the sodium atom, showing the orbitals and number of electrons in each orbital.

1–2 MATERIALS USED IN ELECTRONICS

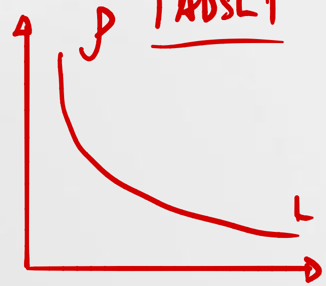
- **Discuss insulators, conductors, and semiconductors and how they differ**
  - Define the *core of an atom*
  - *Describe the carbon atom*
  - *Name two types* each of semiconductors, conductors, and insulators
- Explain the band gap
  - Define *valence band and conduction band*
  - *Compare a semiconductor atom* to a conductor atom
- Discuss silicon and gemanium atoms
- Explain covalent bonds
  - Define *crystal*

MATERIALS USED IN ELECTRONICS

- All materials are made up of atoms. These atoms contribute to the electrical properties of a material, including its ability to conduct electrical current.

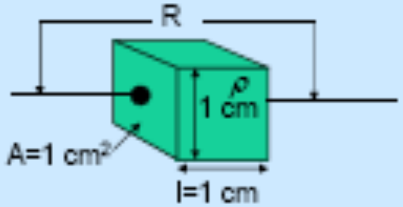
สายโทรศัพท์.

[ADSL]



ค่าต้านทาน.

Resistivity, ρ, is often used when comparing the resistance levels of materials. Its metric unit is .



resistance

Area.

$$\rho = \frac{RA}{l} = \frac{(\Omega)(cm^2)}{cm} = \Omega cm$$

length.

Conductor ตัวนำไฟฟ้า.	Semiconductor	ฉนวน. Insulator
$\rho \cong 10^{-6}\ \Omega$-cm (copper)	$\rho \cong 50\ \Omega$-cm (germanium) $\rho \cong 50 \times 10^3\ \Omega$-cm (silicon)	$\rho \cong 10^{12}\ \Omega$-cm (mica)

Insulators

- An insulator is a material that does not conduct electrical current under normal conditions.
- Most good insulators are compounds rather than single-element materials and have very high resistivity.
- Valence electrons are tightly bound to the atoms; therefore, there are very few free electrons in an insulator. Examples of insulators are rubber, plastics, glass, mica, and quartz.

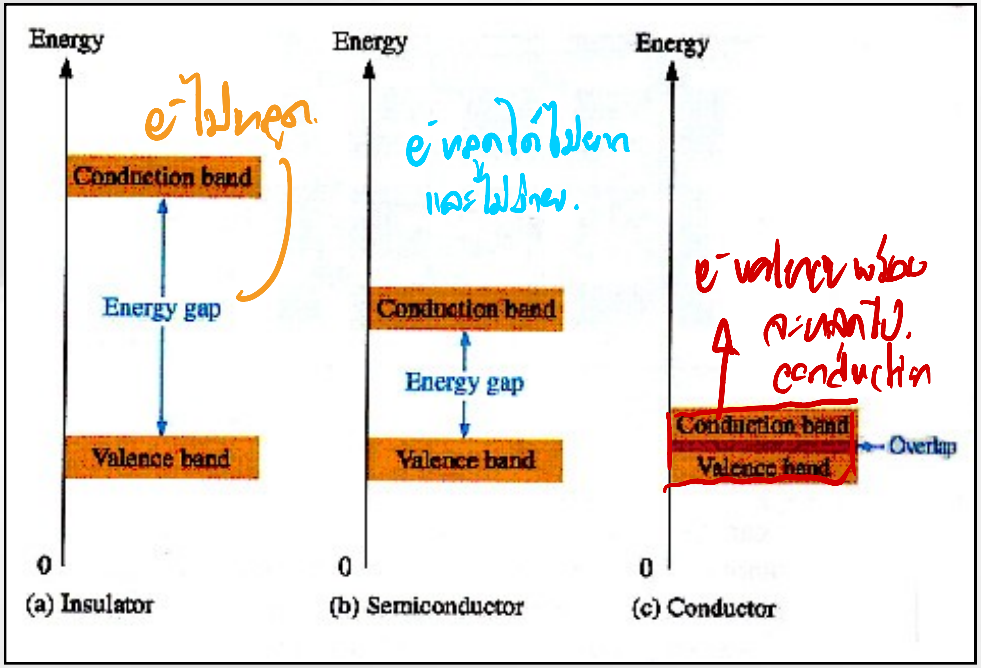
Conductors

- Conductors A conductor is a material that easily conducts electrical current.
- The best conductors are single-element materials, such as copper (Cu), silver (Ag), gold (Au), and aluminum (Al), which are characterized by atoms with only one valence electron very loosely bound to the atom.

e^- ชั้นนอกสุด

Comparison of Semiconductors to Conductors and Insulators

- Pure semiconductive materials are neither insulators nor good conductors because current in a material depends directly on the number of free electrons



semiconductor

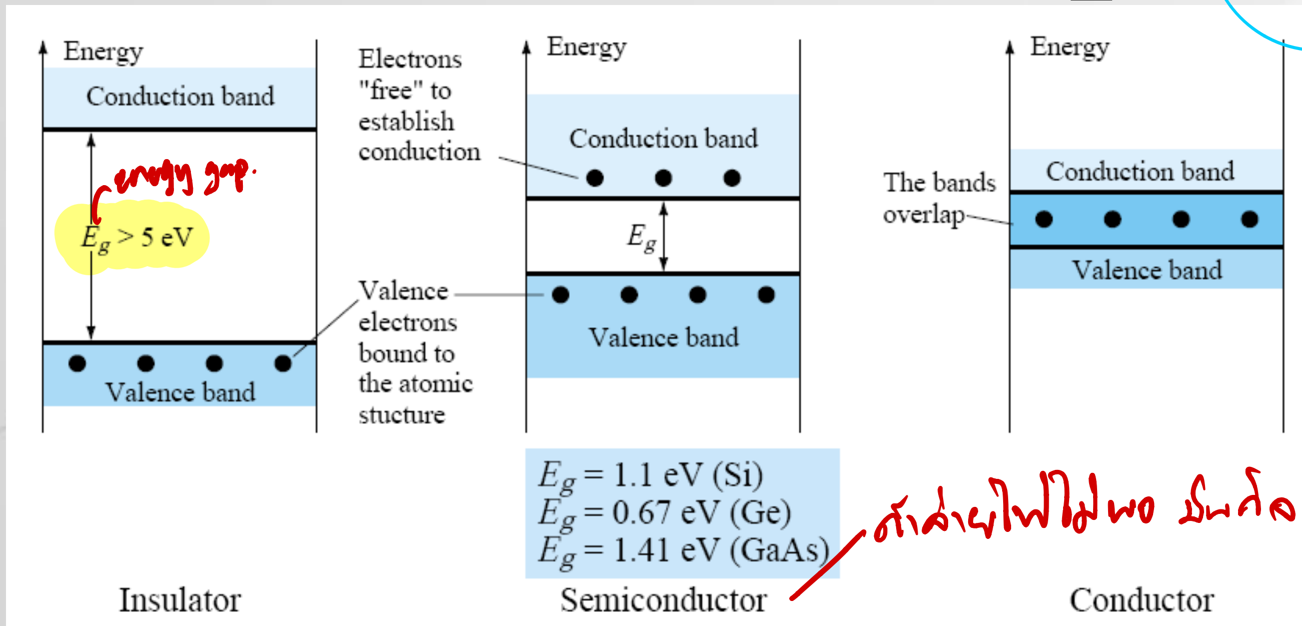
- A semiconductor is a material that is between conductors and insulators in its ability to conduct electrical current.
- A semiconductor in its pure (intrinsic) state is neither a good conductor nor a good insulator.
- Single-element semiconductors are antimony (Sb), arsenic (As), astatine (At), boron (B), polonium (Po), tellurium (Te), silicon (Si), and germanium (Ge).
- Compound semiconductors such as gallium arsenide, indium phosphide, gallium nitride, silicon carbide, and silicon germanium are also commonly used.
- The single-element semiconductors are characterized by atoms with four valence electrons. Silicon is the most commonly used semiconductor.

Band Gap

valence band.

free e⁻

go to conduction band.



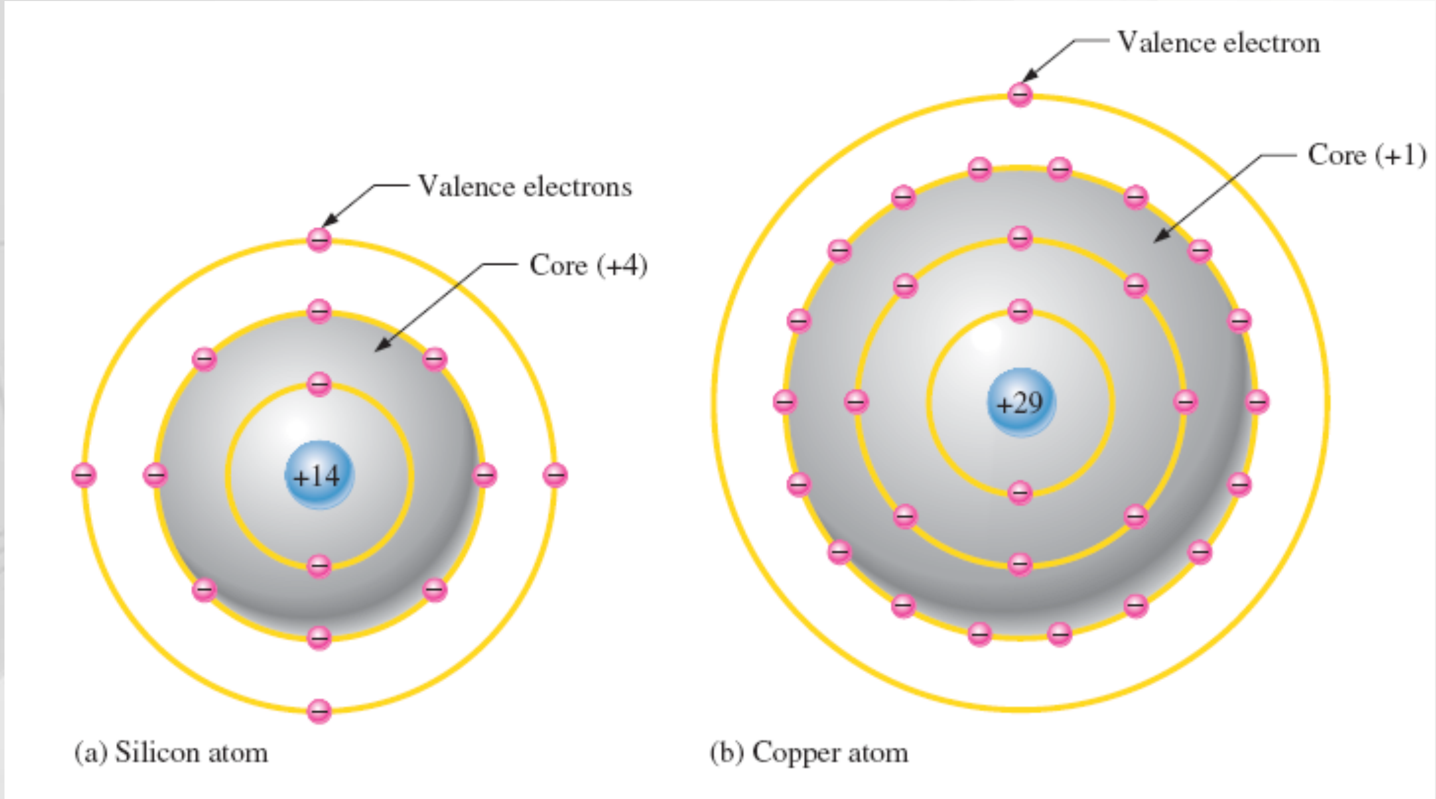
$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

At room temperature (300 K, 25°C) a large number of valence electrons have acquired sufficient energy to leave the valence band, cross the energy gap defined by *Eg in Fig. 1.8b and enter the* conduction band. For silicon *Eg is 1.1 eV, for germanium 0.67 eV, and for gallium* arsenide 1.41 eV.

Band Gap

- The difference in energy between the valence band and the conduction band is called an *energy gap or* ***band gap*****.**
- This is the amount of energy that a valence electron must have in order to jump from the valence band to the conduction band

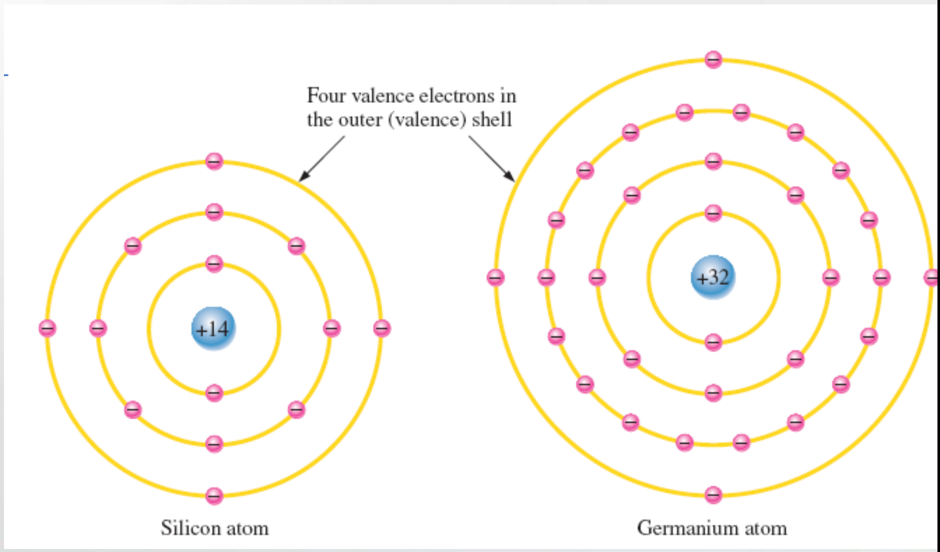
Comparison of a Semiconductor Atom to a Conductor Atom



Bohr diagrams of the silicon and copper atoms.

Silicon and Germanium

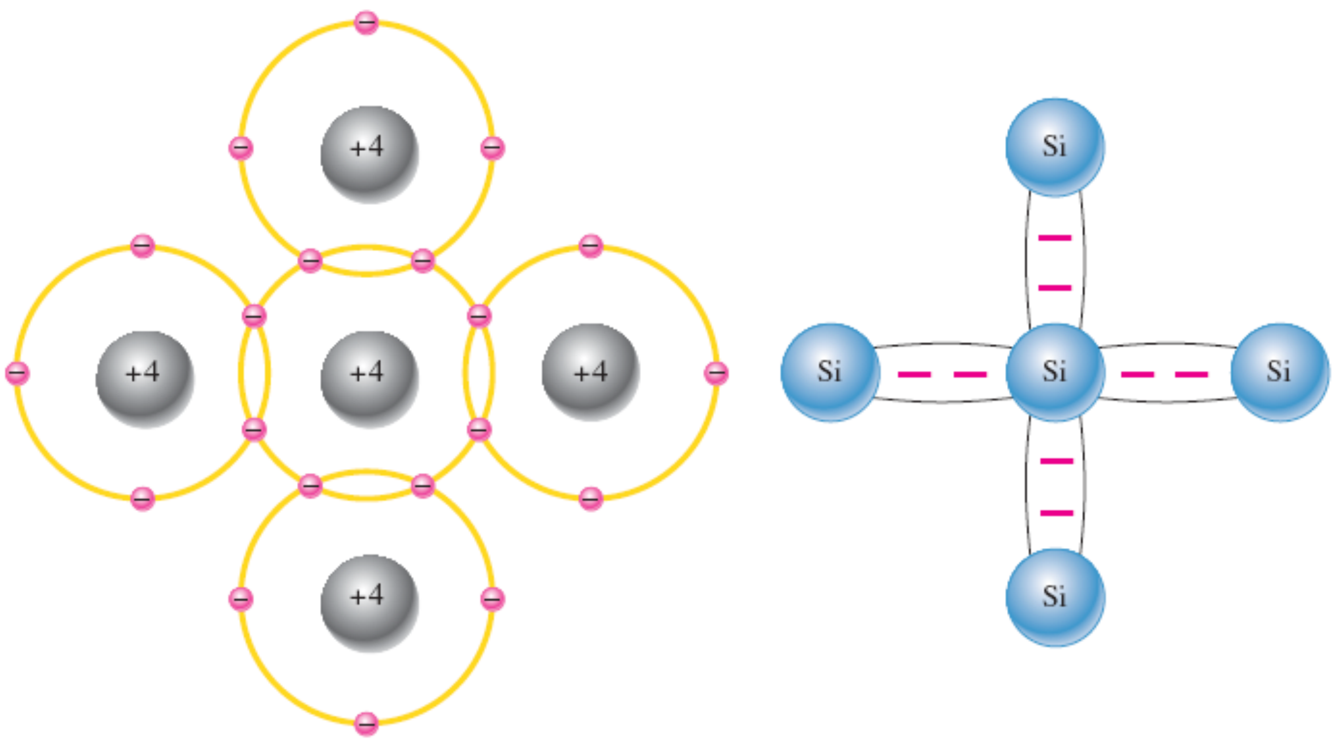
- **Silicon is** used in diodes, transistors, integrated circuits, and other semiconductor devices.
- Noticethat both silicon and **germanium have the characteristic four valence electrons.**



Silicon and Germanium

- The valence electrons in germanium are in the fourth shell while those in silicon are in the third shell, closer to the nucleus.
- This means that the germanium valence electrons are at higher energy levels than those in silicon and, therefore, require a smaller amount of additional energy to escape from the atom.
- This property " makes germanium more unstable at high temperatures" and results in excessive reverse current. This is why silicon is a more widely used semiconductive material.

Covalent Bonds

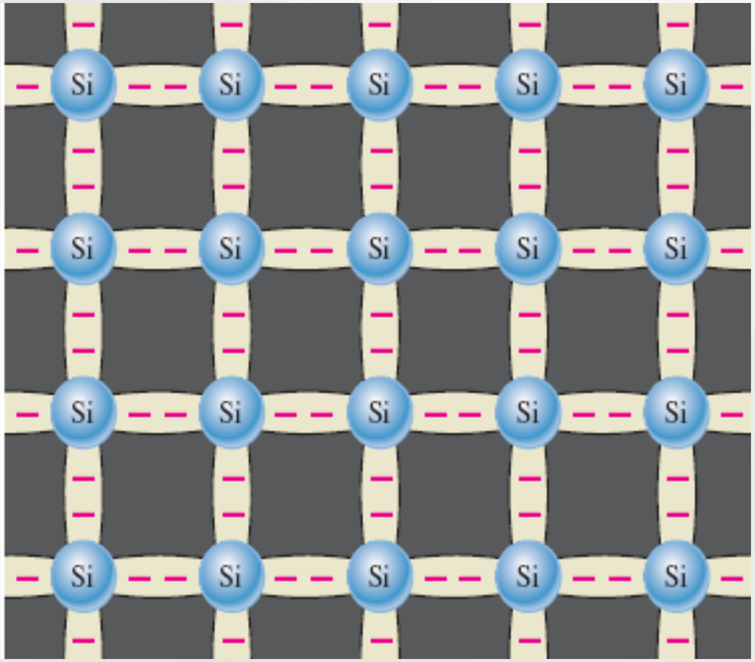


(a) The center silicon atom shares an electron with each of the four surrounding silicon atoms, creating a covalent bond with each. The surrounding atoms are in turn bonded to other atoms, and so on.

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

Covalent Bonds

- Covalent bonding in an intrinsic silicon crystal is shown in Fig. An **intrinsic crystal** is one that has no impurities.

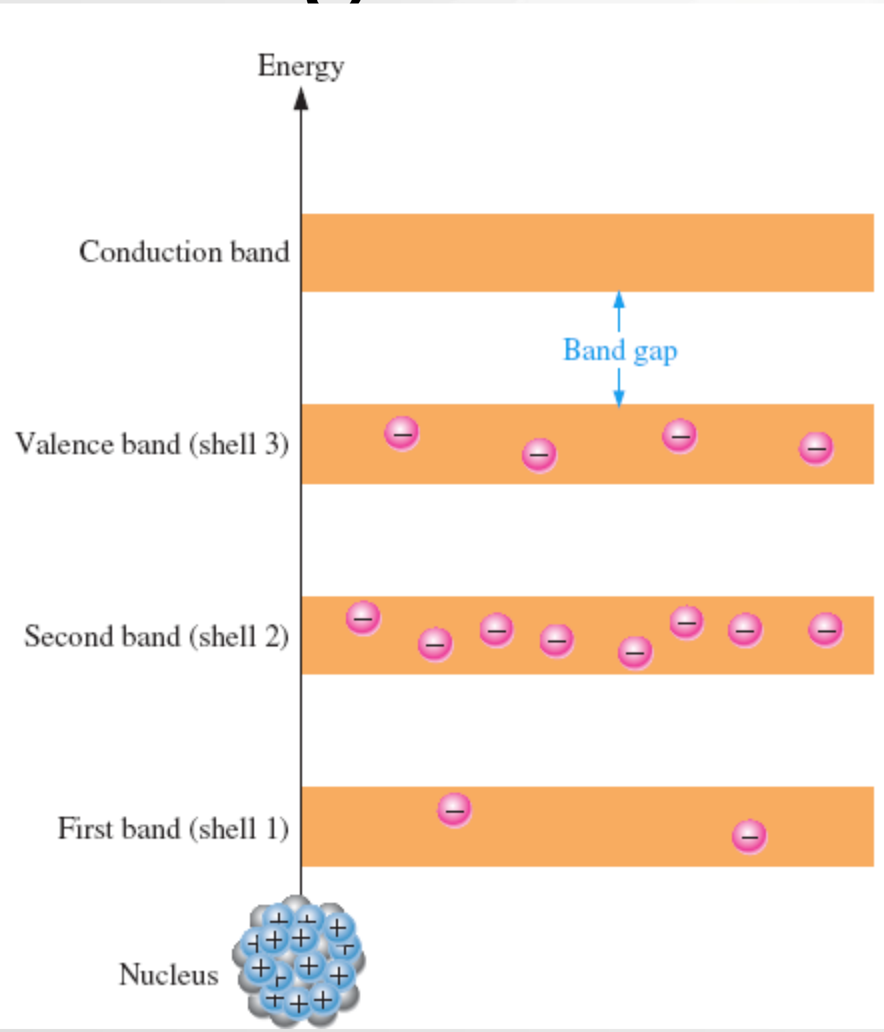


1–3 CURRENT IN SEMICONDUCTORS

- ❑ Describe how current is produced in a semiconductor
- ❑ Discuss conduction electrons and holes
  - ◆ Explain an electron-hole pair
  - ◆ Discuss recombination
- ❑ Explain electron and hole current

Energy Band Diagram

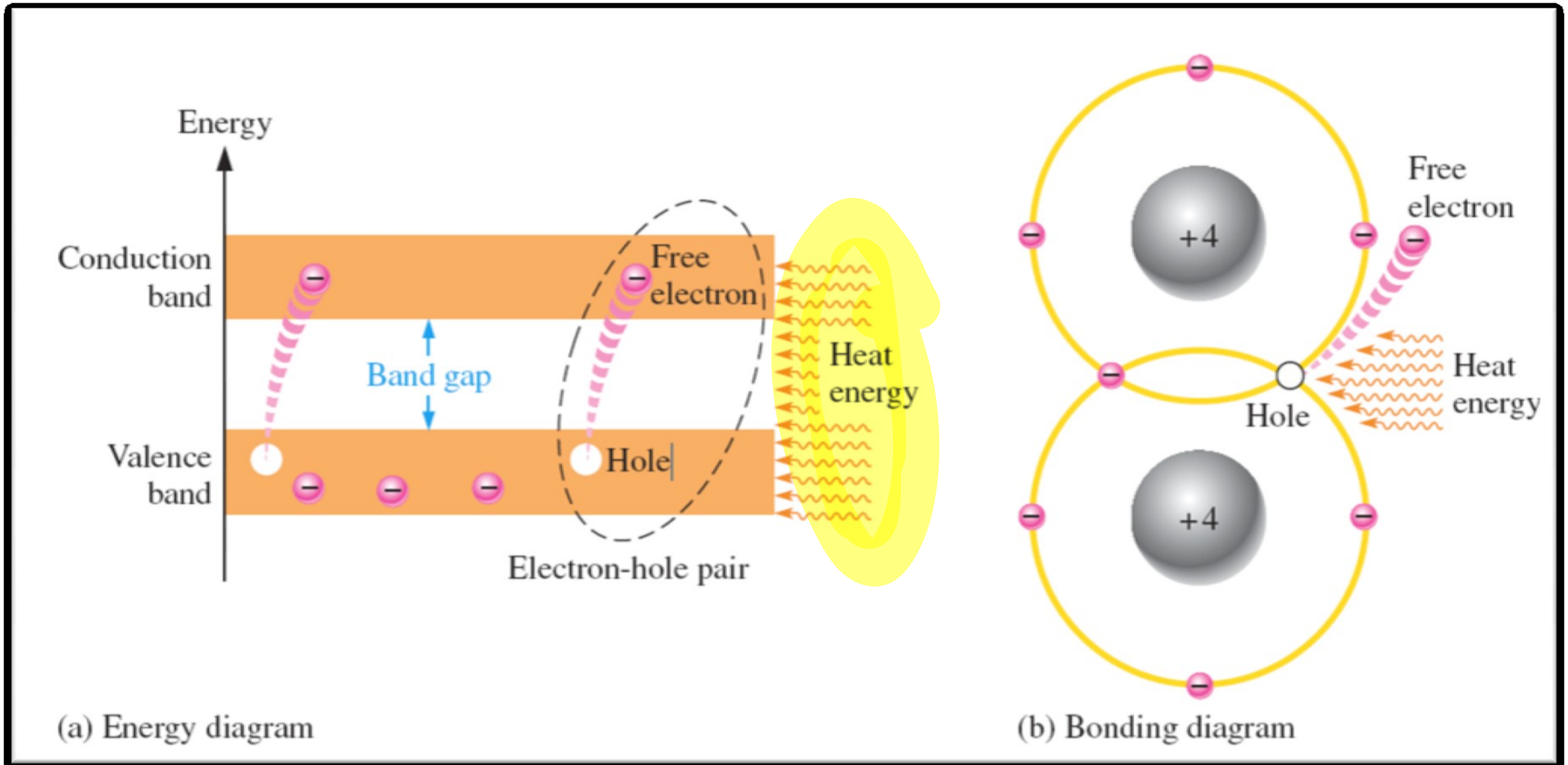
- Figure 1–12 shows the energy band diagram for an unexcited (no external energy such as heat) atom in a pure silicon crystal. This condition occurs *only at a temperature of absolute 0 Kelvin*.



Conduction Electrons and Holes

- An intrinsic (pure) silicon crystal **at room temperature** has sufficient heat (thermal) energy for some valence electrons to jump the gap from the valence band into the conduction band, becoming free electrons.
- Free electrons are also called **conduction electrons.**

Creation of electron-hole pairs

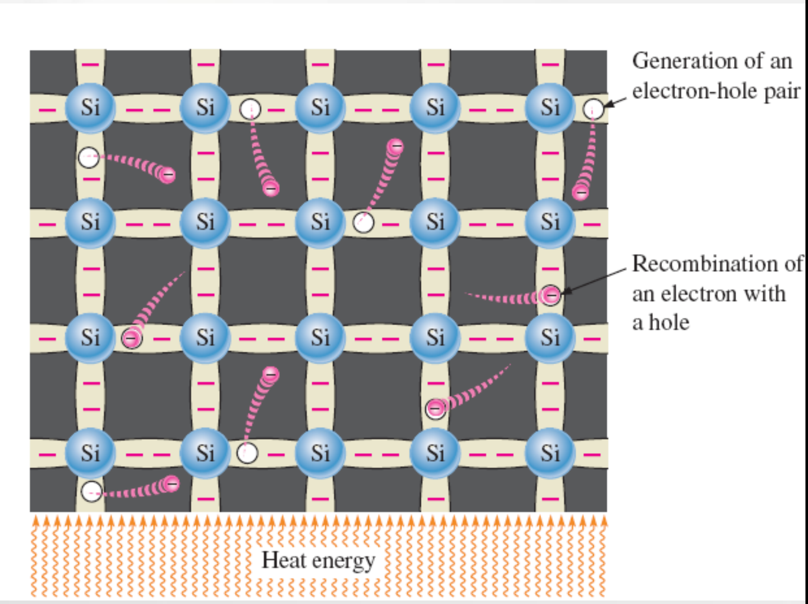


Creation of electron-hole pairs

- When an electron jumps to the conduction band, a vacancy is left in the valence band
- within the crystal. This vacancy is called a **hole.** For every electron raised to the conduction band by external energy, there is one hole left in the valence band, creating what is called an **electron-hole pair.**

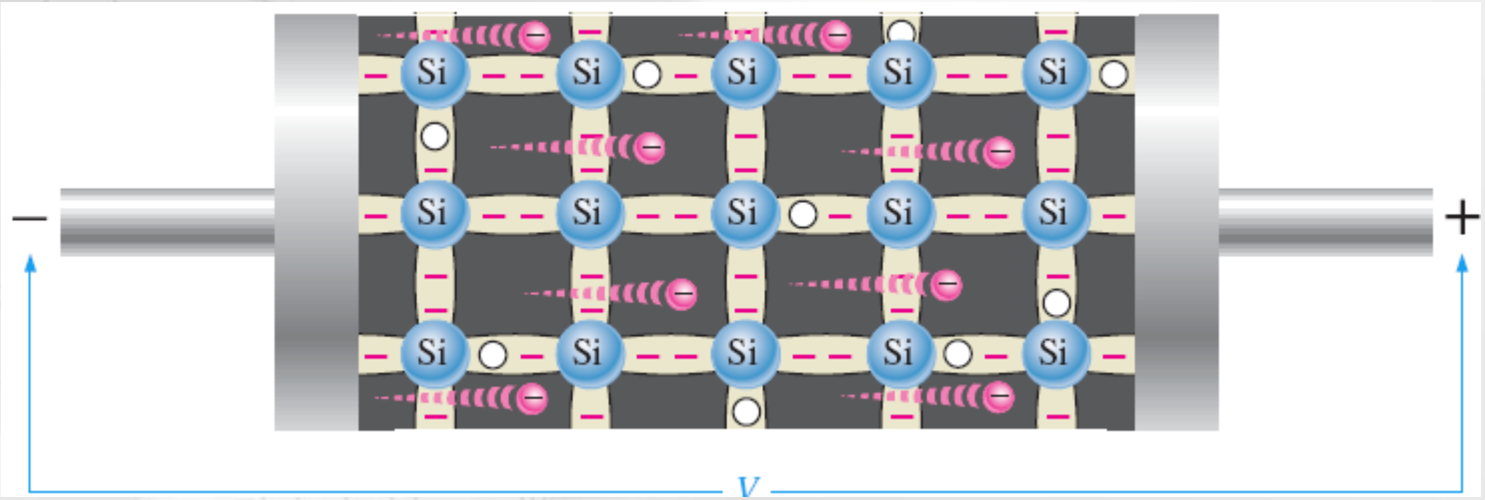
e^- ไปตกหลุมดำที่ว่าง.

- **Recombination** occurs when a conduction-band electron loses energy and falls back into a hole in the valence band



Electron and Hole Current

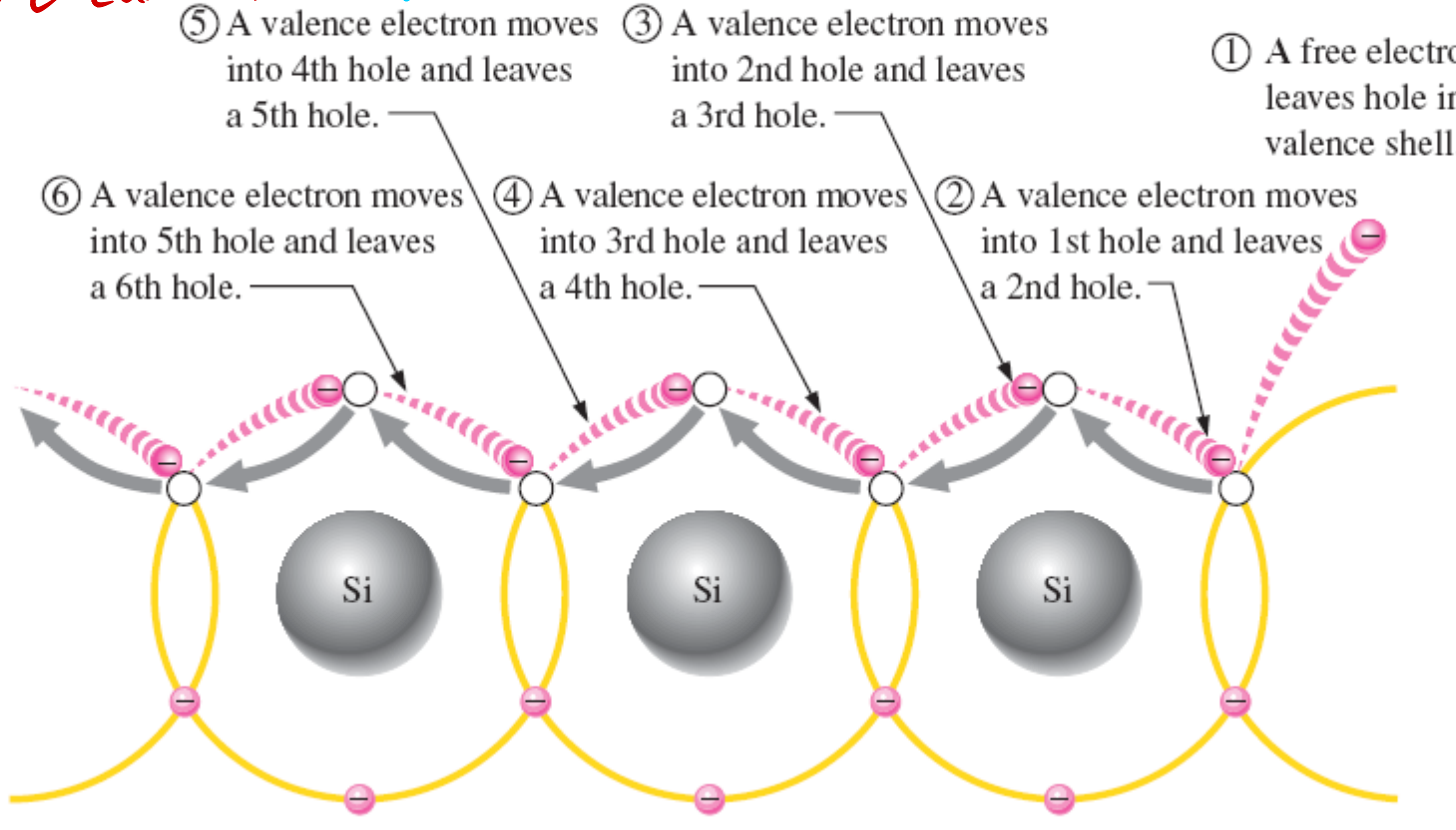
- The movement of free electrons is one type of **current in a semiconductive material and is called *electron current*.**



Electron and Hole Current

① hole current → + ไป -

② e^- current → กระแส - ไป +



When a valence electron moves left to right to fill a hole while leaving another hole behind, the hole has effectively moved from right to left. Gray arrows indicate effective movement of a hole.

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N-TYPE AND P-TYPE SEMICONDUCTORS

วิศวลาดกระบัง

ต้องเป็นหนึ่ง

และเป็นที่พึ่งของสังคม

1–4 N-TYPE AND P-TYPE SEMICONDUCTORS

สาร P.

สาร N.

After completing this section, you should be able to

- ❑ **Describe the properties of *n-type and p-type semiconductors***
  - ◆ Define *doping*

การ dop → เกิดสิ่งเจือปน

พาหะข้างมาก. สาร N/P พาหะข้างน้อย.

- ❑ Explain how *n-type semiconductors are formed*
  - ◆ Describe a majority carrier and minority carrier in *n-type material*
- ❑ Explain how *p-type semiconductors are formed*
  - ◆ Describe a majority carrier and minority carrier in *p-type material*

INTRINSIC SEMICONDUCTORS

(กึ่งตัวนำบริสุทธิ์)
ยังไม่ได้ dope.

การเจือ
ในสาร.

- Semiconductive materials do not conduct current well and are of limited value in their intrinsic state.
- Since semiconductors are generally poor conductors, their conductivity can be drastically increased by the controlled addition of impurities to the intrinsic (pure) semiconductive material.
- This process, called **doping, increases the number of current carriers (electrons** or holes). The two categories of impurities are *n-type and p-type*.

INTRINSIC SEMICONDUCTORS

- The free electrons in the material due only to natural causes are referred to as *intrinsic carriers*. At the same temperature, intrinsic germanium material will have approximately 2.5 x10^13 free carriers per cubic centimeter.

N-TYPE AND P-TYPE SEMICONDUCTORS

Intrinsic → valence e^- อยู่ 4 ตัว

1 left free e^- (เกิน 1)

Doping

V e^- 3 ตัว → เกิด hole e^- (หาย 1)

V 5 ตัว

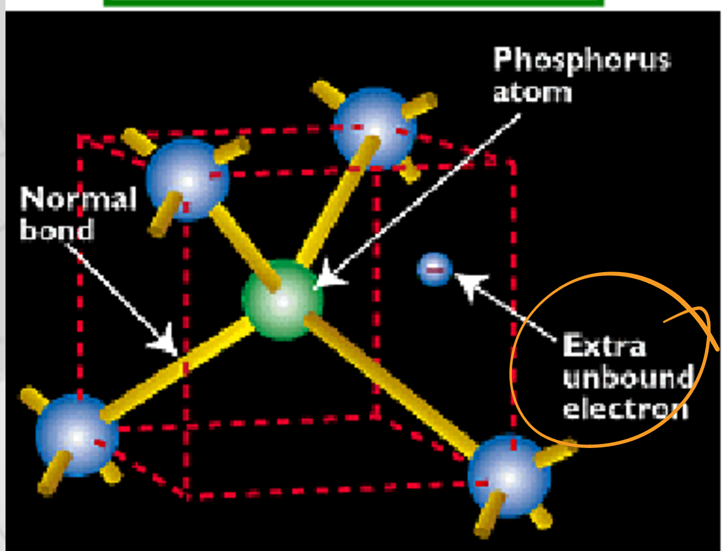
By substituting a Si atom with a special impurity atom (Column V or Column III element), a conduction electron or hole is created.

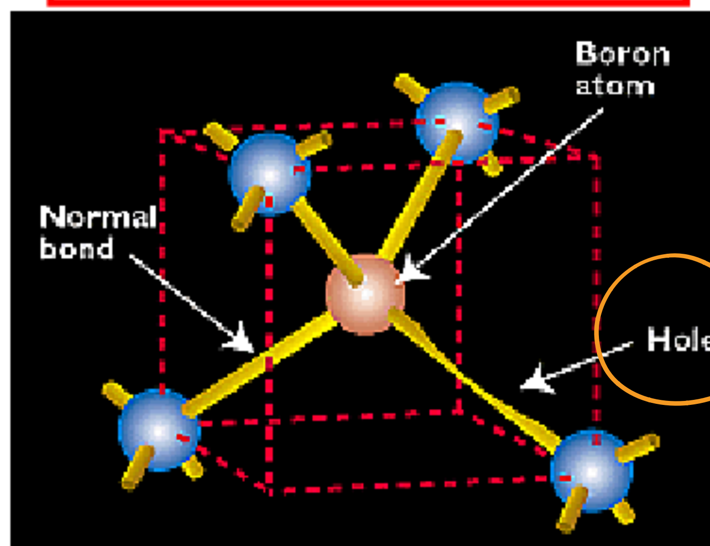
V e^- 5 ตัว

V e^- 3 ตัว

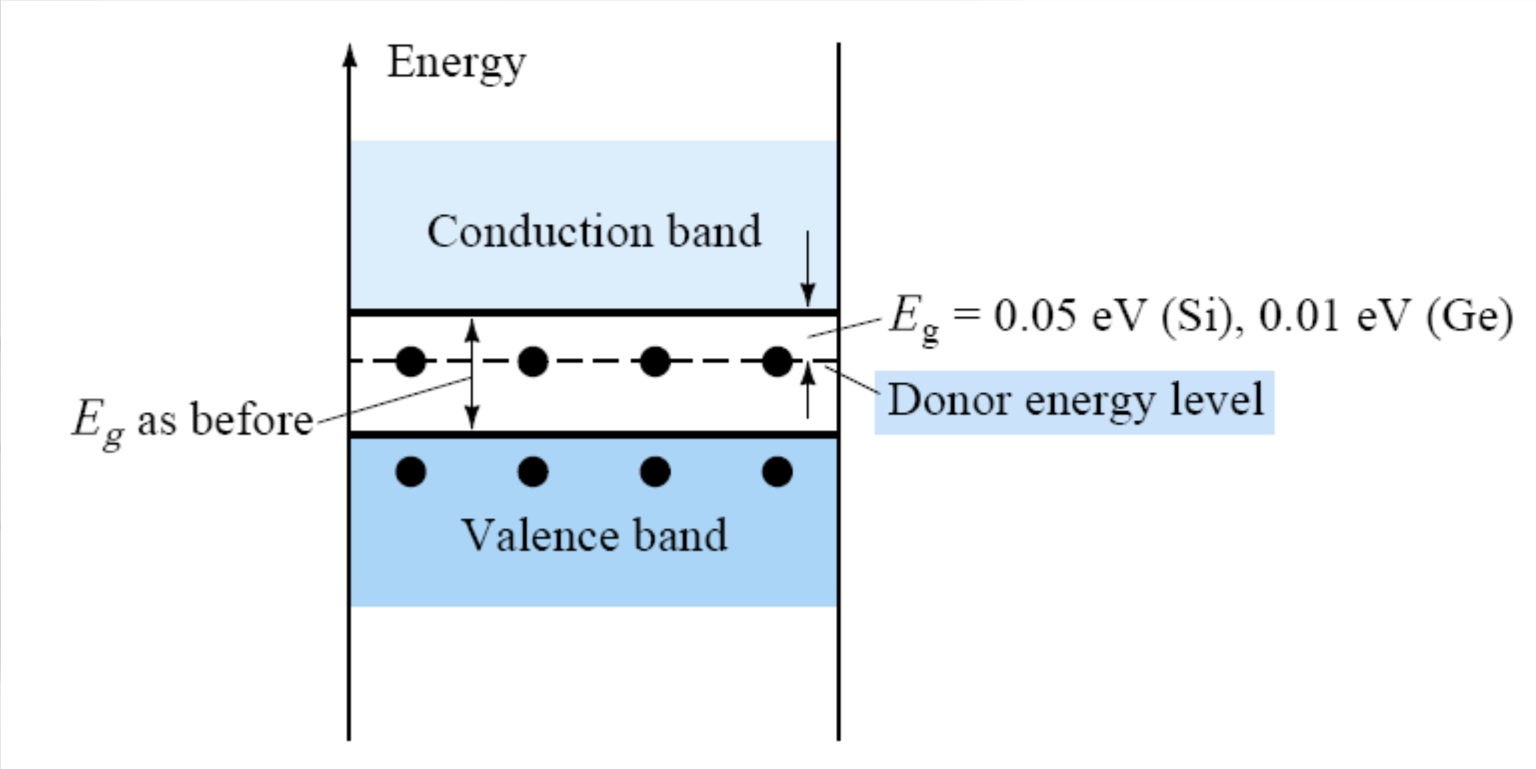
Donors: P, As, Sb

Acceptors: B, Al, Ga, In





Energy gap


Energy
Conduction band
E_g = 0.05 eV (Si), 0.01 eV (Ge)
Donor energy level
E_g as before
Valence band

Majority and Minority Carriers

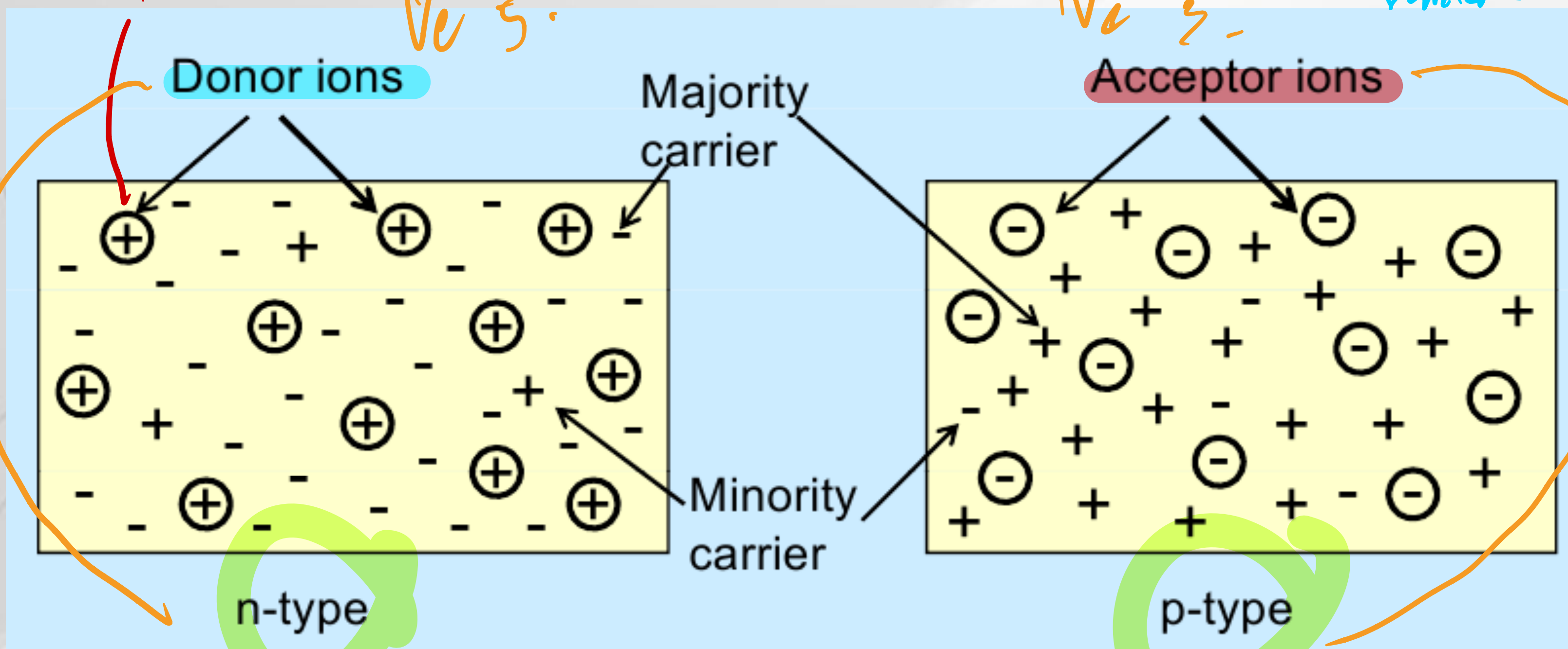
สาร P < major - hole, minor - e⁻

สาร N < major - e⁻, minor - hole

+ hole

Ve⁻ 5.

Ve⁻ 3.



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คณะวิศวกรรมศาสตร์ ลาดกระบัง

วิศวลาดกระบัง

ต้องเป็นหนึ่ง

และเป็นที่พึ่งของสังคม