



# ANALOG ELECTRONICS

*Medical Physics*

*Second Stage*

*Lecture 1*

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## **Definition of Electronics**

Electronics is a branch of physics and engineering concerned with the controlled motion of electric charges within electronic devices. It focuses on the behavior of electrons in active components such as diodes, transistors, and integrated circuits. Electronics differs from electrical engineering, which mainly deals with the generation, transmission, and distribution of electrical power.

Electronics studies the motion of electric charges in vacuum, gases, and, most importantly, semiconductors. The ability to control this motion precisely enables electronic circuits to perform specific functions such as amplification, oscillation, signal processing, and switching. Electronics forms the foundation of modern technology and is essential for communication systems, computing, medical devices, and energy systems.

## **Electronic Components**

Electronic systems are built from basic units called electronic components. These components are manufactured in discrete form or integrated into chips and are provided with metallic leads or pads for electrical connection. When connected together, they form an electronic circuit that performs a specific function.

Examples of electronic circuits include:

1. Amplifier
2. Radio receiver
3. Oscillator

## **Types of Components**

Electronic components can be classified into two main categories:

1. **Active components:** These are devices such as diodes and transistors that can control the flow of current and provide amplification or switching.
2. **Passive components:** These include resistors, capacitors, and inductors, which store or dissipate energy but do not control current directly.

## **Electronic Systems**

Complex electronic devices are composed of several interconnected subsystems or circuits. Each subsystem performs a specific function such as signal amplification, power supply regulation, or signal generation.

Examples of electronic systems include:

- Laptop computers
- DVD players
- iPods
- Mobile phones
- Personal Digital Assistants (PDAs)

## **Importance of Electronics**

Electronics is the backbone of modern technology. It enables the operation of systems ranging from simple household devices to advanced medical equipment and communication networks. Even everyday tools such as wristwatches and remote controls rely on small electronic circuits.

## Atomic Structure

All matter on Earth is composed of atoms, which may consist of single elements or combinations of elements. Each atom is made up of three fundamental particles: electrons, protons, and neutrons. The hydrogen atom in its normal form is an exception, as it contains no neutron.

### Definition of the Atom

An atom is the smallest particle of an element that retains the chemical and physical properties of that element. According to Bohr's model, the atom has a planetary structure consisting of a central nucleus containing protons and neutrons, with electrons orbiting around the nucleus in discrete energy levels.

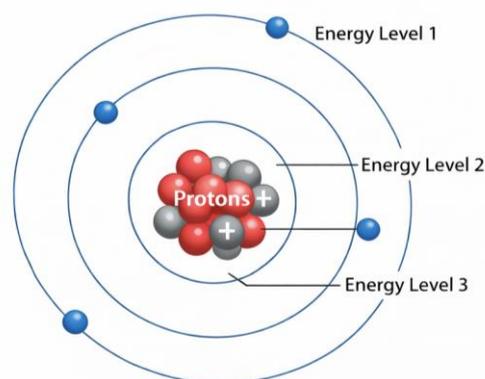


Figure 1: Atomic Structure

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**Electron** :An electron is a negatively charged particle that exists outside the nucleus of an atom.

Electrons are responsible for electric current and determine the electrical properties of materials.

**Proton** :A proton is a positively charged particle located in the nucleus of an atom.

The number of protons determines the atomic number of an element.

**Neutron** :A neutron is a particle with no electric charge, located in the nucleus of an atom.

Neutrons contribute to atomic mass and nuclear stability.

## Atomic Number and Energy Levels

Each type of atom is distinguished by its atomic number, which represents the number of protons in the nucleus. In a neutral atom, the number of electrons is equal to the number of protons.

Electrons occupy specific orbits known as energy levels or shells. Each shell corresponds to a definite energy value, and electrons cannot exist between shells. The maximum number of electrons that can occupy a shell is given by the relation:

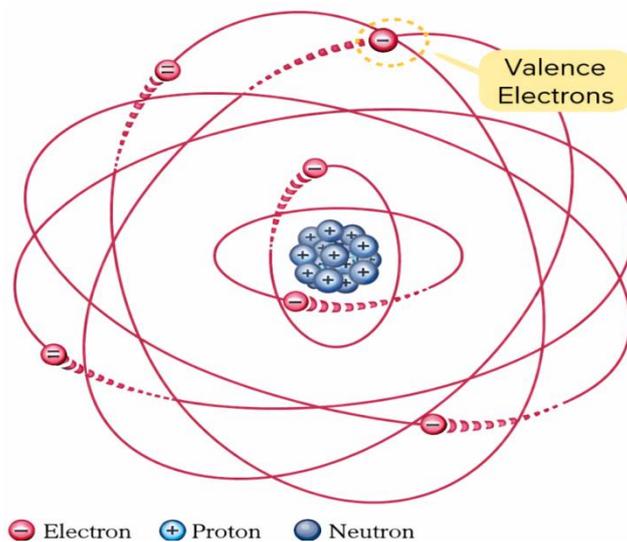
$$\text{Maximum number of electrons} = 2n^2$$

where  $n$  is the shell number.

## Valence Electrons

Electrons located in the outermost energy level of an atom are called valence electrons. These electrons possess higher energy and are less tightly bound to the nucleus compared to inner-shell electrons.

- Valence electrons determine:
  - Chemical bonding.
  - Electrical properties of the material.
  - Electrical conductivity.



**Figure 2: Valence Electrons in the Outermost Energy Shell**

### **Importance of Atomic Structure in Electronics**

- The arrangement of electrons in shells and the number of valence electrons explain why materials behave as conductors, insulators, or semiconductors.
- Understanding atomic structure is fundamental for analyzing and designing electronic devices.

## Classification of Materials

Materials can be classified according to their electrical properties into three main groups:

1. Insulators.
2. conductors.
3. semiconductors.

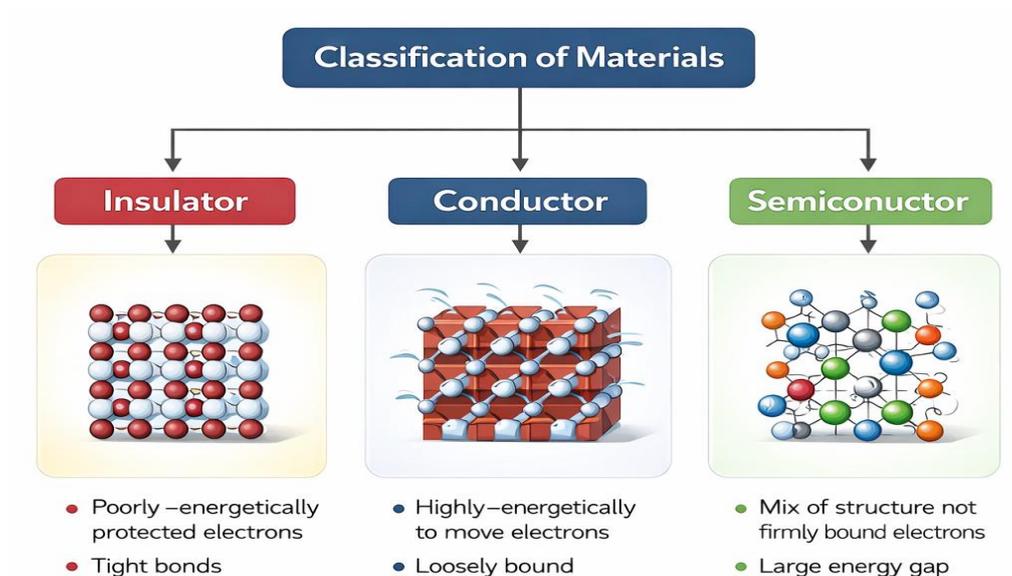


Figure 3: classification of materials

This classification depends on the number of free charge carriers available and the size of the energy gap between the valence band and the conduction band.

## **1. Insulators**

An insulator is a material that does not conduct electric current under normal conditions. In insulating materials, valence electrons are tightly bound to atoms, resulting in very few free electrons.

The energy gap in insulators is large, typically greater than or equal to 6 eV. A strong electric field is required for valence electrons to gain enough energy to move into the conduction band.

Examples of insulating materials include rubber, plastics, glass, mica, and quartz.

## **2. Conductors**

A conductor is a material that easily conducts electric current. Most metals are good conductors due to the presence of a large number of free electrons.

The best conductors are metals with one valence electron, such as copper, silver, gold, and aluminum, because their valence electrons are weakly bound to the nucleus.

In conductors, the valence band and the conduction band overlap, allowing electrons to move freely with very little applied energy.

Examples of conductors include copper, silver, gold, aluminum, iron, graphite, and salt water.

### 3. Semiconductors

A semiconductor is a material whose electrical conductivity lies between that of conductors and insulators.

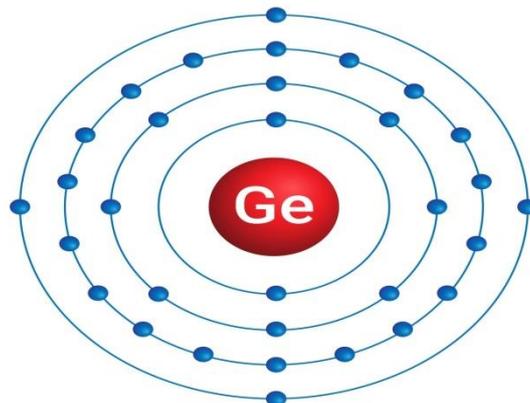
The conductivity of semiconductors can be controlled by temperature and by adding small amounts of impurities.

The most important elemental semiconductors are silicon (Si) and germanium (Ge), both of which belong to Group IV of the periodic table and have four valence electrons.

Silicon is the most widely used semiconductor material in modern electronics due to its thermal stability, abundance, and suitability for integrated circuits.

Semiconductors may be classified as intrinsic (pure) or extrinsic (doped).

Doping allows engineers to control the electrical behavior of materials and forms the basis of electronic devices studied in later lectures.



**Fig 4 :Atomic Structure and Covalent Bonding in Semiconductors**

## Silicon and Germanium

Silicon (Si) and Germanium (Ge) are two of the most important semiconductor materials. Both elements belong to Group IV of the periodic table and share similar atomic structures, which makes them suitable for electronic applications.

### Atomic Structure for silicon and germanium

- Both silicon and germanium atoms have **four valence electrons**.
- In silicon, the valence electrons are located in the **third shell**, closer to the nucleus.
- In germanium, the valence electrons are located in the **fourth shell**, farther from the nucleus.
- This difference means that germanium's valence electrons are at **higher energy levels** compared to silicon's.

### Electrical Properties

- Because germanium's valence electrons are less tightly bound, they require **less additional energy** to escape from the atom.
- This property makes germanium more sensitive to temperature changes.
- At high temperatures, germanium exhibits **excessive reverse current**, which reduces its stability.
- Silicon, on the other hand, is more stable under varying temperature conditions, making it more reliable for electronic devices.

### Note:

- Each silicon or germanium atom has **four valence electrons**.
- The atoms are bonded together by **covalent bonds**.
- Each covalent bond is formed by **two shared electrons** between two atoms.

Because of this atomic structure, a semiconductor is:

not a perfect insulator,

not a good conductor,

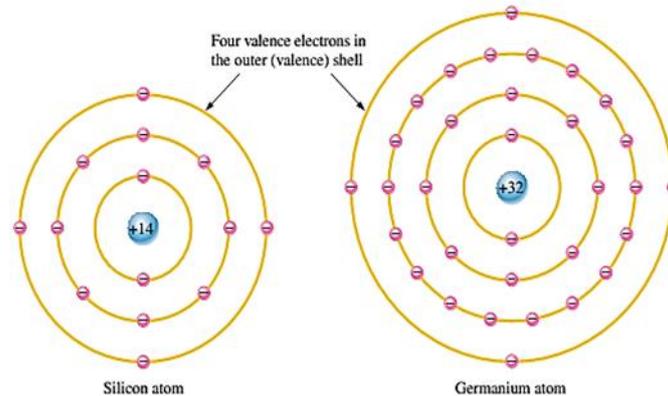
but its electrical behavior depends on energy, temperature, and impurities.

### Applications

- **Silicon** is the most widely used semiconductor material in modern electronics due to:
  - Its thermal stability.
  - Abundance in nature (found in sand and quartz).
  - Suitability for integrated circuits and microchips.
- **Germanium** was used in early transistors and diodes but has been largely replaced by silicon.

Today, germanium is still used in specialized applications such as high-speed devices and infrared optics.

Although both silicon and germanium are semiconductors with similar atomic structures, silicon's superior stability and availability make it the dominant material in the electronics industry. Germanium remains useful in niche applications but is less common in mainstream devices.



**Figure5: Atomic Structure of Silicon and Germanium Showing Valence Electrons**

## Comparison Between Silicon and Germanium

### Energy Band Structure

- Both silicon and germanium are semiconductors with four valence electrons.
- The **energy gap** (bandgap) in silicon is approximately **1.1 eV**, while in germanium it is **0.66 eV**.
- A smaller bandgap in germanium means electrons require less energy to move to the conduction band, making it more conductive at room temperature.

However, this also makes germanium more sensitive to temperature, leading to higher leakage currents.

### **Thermal Stability**

- **Silicon** has better thermal stability due to its stronger atomic bonding and lower leakage current.
- **Germanium** is more prone to reverse current and instability at elevated temperatures.

For this reason, silicon is preferred in environments with variable or high temperatures.

### **Manufacturing and Availability**

- Silicon is **abundant in nature**, primarily found in sand and quartz. It is easier and cheaper to purify and process for industrial use.
- Germanium is **less abundant** and more expensive to refine, limiting its widespread use.

Property	Silicon	Germanium
Bandgap	1.1 eV	0.66 eV
Thermal Stability	High	Moderate
Leakage Current	Low	High
Availability	Abundant	Limited
Cost	Lower	Higher
Common Uses	Microchips, solar cells, sensors	High-speed devices, IR optics

Table 1: Comparison Between Silicon and Germanium

**Semiconductors are classified into two main types:**

1. **Intrinsic Semiconductors**
2. **Extrinsic Semiconductors**

### *1) Intrinsic Semiconductors (Pure)*

**Intrinsic semiconductors are pure semiconductors without intentional impurities.**

**Examples include** pure silicon (Si) **and** pure germanium (Ge).

**Their conductivity is** relatively low at room temperature **and** increases with temperature.

## *2) Extrinsic Semiconductors (Doped)*

**Extrinsic semiconductors are semiconductors that have been doped with small amounts of impurities to increase conductivity.**

**Doping allows control of electrical properties and is the basis for many electronic devices.**

**Two types of extrinsic semiconductors:**

**1. n-type:**

Formed by doping with elements that have **five valence electrons** (such as phosphorus and arsenic).

The extra electrons increase the electrical conductivity.

**2. p-type:**

Formed by doping with elements that have **three valence electrons** (such as boron and gallium).

Doping creates **holes**, which act as positive charge carriers.

### **Importance**

Doping allows control of conductivity and is the basis of diodes, transistors, and integrated circuits.

## **PN Junction and Diodes (Introduction)**

When p-type and n-type semiconductors are joined together, a **PN junction** is formed.

This junction represents the fundamental building block of many semiconductor devices.

The structure, operation, and applications of PN junctions and diodes will be discussed in the next lecture.

### **Review Questions**

#### **Q1**

Electronics is a field concerned mainly with:

- A) Generation of electrical power
  - B) Transmission of electrical energy
  - C) Controlled motion of electric charges
- 

**Q2** -Which particle is directly responsible for electrical conduction in materials?

- A) Proton
  - B) Neutron
  - C) Electron
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**Q3** -The atomic number of an element is determined by the number of:

- A) Electrons
  - B) Neutrons
  - C) Protons
- 

**Q4** -Electrons located in the outermost energy level of an atom are called:

- A) Free electrons
- B) Core electrons
- C) Valence electron

**Q5-**Which type of material has a very large energy gap and does not conduct electricity under normal conditions?

- A) Conductor
  - B) Semiconductor
  - C) Insulator
- 

**Q6-**The approximate energy bandgap of silicon is:

- A) 0.66 eV
  - B) 1.1 eV
  - C) 2.5 eV
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H.W

Q1- Explain how the number of valence electrons in an atom affects the classification of materials into conductors, insulators, and semiconductors.

Q2-Explain the relationship between the energy gap (bandgap ) and the electrical behavior of materials, giving one example each for a conductor, an insulator, and a semiconductor.