

ELECTRICAL ENGINEERING MATERIALS

Unit I : Introduction to Materials

Topic: Classification of Materials, Atomic Structure, Energy Bands and Characteristics

Important Questions with Answers (3rd Semester, Electrical Engg.)

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Short Answer Questions

Q.1 Define conducting materials. Give two examples.

Ans. The materials which allow electric current to pass through them easily are called conducting materials or conductors. They have a large number of free electrons.

Examples: Copper, aluminium, silver, gold.

Uses: Copper is used for house wiring and for the windings of motors and transformers. Aluminium is used for overhead transmission lines.

Q.2 Define semiconductor. Write two applications.

Ans. A semiconductor is a material whose conductivity is more than that of an insulator but less than that of a conductor. Its conductivity can be changed by temperature and by adding a small amount of impurity.

Examples: Silicon and germanium.

Applications: (1) Diodes and transistors. (2) Integrated circuits (ICs) and solar cells.

Q.3 What are insulating materials? Give two examples.

Ans. The materials which do not allow electric current to pass through them under normal conditions are called insulating materials or insulators. They have very few free electrons.

Examples: Rubber, glass, PVC, porcelain, mica, dry paper.

Uses: PVC and rubber are used to cover wires and cables. Porcelain is used for insulators on poles and in switchgear.

Note: If the voltage applied is too high, even an insulator breaks down and current starts flowing through it.

Q.4 What are magnetic materials? Give two applications.

Ans. The materials which are strongly attracted by a magnet and can be easily magnetised are called magnetic materials.

Examples: Iron, nickel, cobalt, silicon steel, ferrites.

Applications: (1) Silicon steel is used for the cores of transformers, motors and generators.
(2) Hard magnetic materials such as Alnico are used for making permanent magnets.

Magnetic materials are of two types, soft and hard. They are studied in Unit IV.

Q.5 What are valence electrons?

Ans. The electrons present in the outermost shell of an atom are called valence electrons. The electrical behaviour of a material depends mainly on these electrons.

Remember: all valence electrons are not free electrons. See Q.6.

Q.6 Differentiate between valence electrons and free electrons.

Point	Valence electrons	Free electrons
Meaning	Electrons present in the outermost shell of an atom	Electrons which are free to move from atom to atom
Position	In the outermost shell, bound to the atom	Move through the material, not bound to any one atom
Role in conduction	Do not carry current unless they become free	Carry the electric current
Number	Fixed by the type of atom	Depends on the material and its temperature

Note: Free electrons come from valence electrons, but all valence electrons are not free. In a conductor many valence electrons become free. In an insulator they are tightly held, so they are not free.

Q.7 Describe the structure of an atom.

Ans. An atom is the smallest particle of an element. It has a nucleus at the centre and electrons revolving around the nucleus in fixed paths called shells.

Particle	Charge	Position
Proton	Positive (+)	Inside the nucleus
Neutron	No charge	Inside the nucleus
Electron	Negative (-)	Revolves around the nucleus in shells

1. The number of protons is equal to the number of electrons, so the atom is electrically neutral.
2. The number of protons in an atom is called its atomic number (Z).

3. The shells are named K, L, M, N and so on, starting from the nucleus. They can hold 2, 8, 18 and 32 electrons respectively.
4. The outermost shell can have at most 8 electrons. The electrons of this shell are the valence electrons.
5. The number of valence electrons decides the electrical behaviour of the material. Copper has 1 valence electron and silicon has 4.

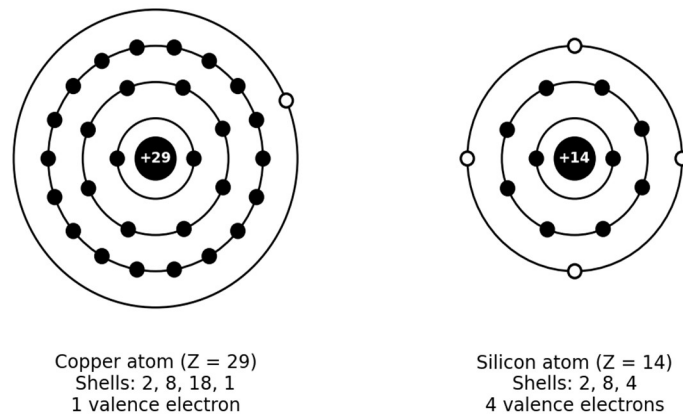


Fig. 1 Structure of copper and silicon atoms (black dots: inner-shell electrons, open circles: valence electrons)

Q.8 Define valence band, conduction band and forbidden energy gap.

Ans. These three terms are used in the energy band theory.

1. **Valence band:** The band of energy levels occupied by the valence electrons is called the valence band.
2. **Conduction band:** The band of energy levels above the valence band is called the conduction band. Electrons in this band are free to move and carry current.
3. **Forbidden energy gap:** The energy gap between the top of the valence band and the bottom of the conduction band is called the forbidden energy gap. No electron can stay in this gap. It is written as E_g and measured in electron volt (eV).

Material	Forbidden energy gap
Conductor	No gap (bands overlap), $E_g = 0$
Semiconductor	Small gap. Silicon about 1.1 eV, germanium about 0.67 eV
Insulator	Large gap, more than about 5 eV

Q.9 Define resistivity and conductivity. Write their units.

Ans. Resistivity (ρ) is the resistance of a conductor of unit length and unit cross-sectional area. For a conductor of length l and area of cross-section A , the resistance is $R = \rho l / A$, so $\rho = RA / l$.

Resistivity depends on the material and its temperature. It does not depend on the size of the conductor.

Conductivity (σ) is the reciprocal of resistivity, that is $\sigma = 1 / \rho$. It shows how easily a material allows current to flow.

Material	Resistivity	Conductivity
Conductor	Very low	Very high
Semiconductor	Medium	Medium
Insulator	Very high	Very low

Units: Resistivity is measured in ohm-metre ($\Omega \cdot m$). Conductivity is measured in siemens per metre (S/m).

Q.10 Explain the effect of temperature on the resistance of conductors, semiconductors and insulators.

Material	Effect of temperature on resistance	Reason
Conductor	Increases (positive temperature coefficient)	At higher temperature the atoms vibrate more and collide more with the free electrons, so the flow of current is opposed more.
Semiconductor	Decreases (negative temperature coefficient)	More bonds break and more electrons jump to the conduction band, so more current carriers are available.
Insulator	Generally decreases	At high temperature some electrons get enough energy to move, so the insulator becomes a poorer insulator.

Note: Carbon also has a negative temperature coefficient of resistance. Alloys like manganin have a temperature coefficient of resistance almost equal to zero, so their resistance remains almost constant when temperature changes.

Long Answer Questions

Q.11 Classify electrical engineering materials into conducting, semiconducting, insulating and magnetic materials. Give examples and applications.

Ans. Electrical engineering materials are divided into four groups according to their properties.

1. Conducting materials

These allow current to flow easily because they have many free electrons.

Examples: copper, aluminium, silver. **Uses:** wires, windings, transmission lines.

2. Semiconducting materials

Their conductivity is between that of conductors and insulators and it can be controlled.

Examples: silicon, germanium. **Uses:** diodes, transistors, ICs, solar cells.

3. Insulating materials

These do not allow current to flow under normal conditions.

Examples: rubber, glass, PVC, porcelain. **Uses:** covering of wires and cables, insulators, insulation in transformers.

4. Magnetic materials

These are attracted by magnets and are used where magnetic effects are needed.

Examples: iron, silicon steel, ferrites. **Uses:** cores of transformers, motors and generators, permanent magnets.

	Conducting	Semiconducting	Insulating	Magnetic
Behaviour	Pass current easily	Conductivity can be controlled	Do not pass current	Attracted by magnet
Examples	Copper, aluminium	Silicon, germanium	Rubber, glass, PVC	Iron, silicon steel
Uses	Wires, windings	Electronic devices	Insulation	Cores, magnets

Note: These groups can overlap. Iron, for example, is a good conductor and also a magnetic material.

Q.12 Explain the energy band theory of solids.

Ans. Energy band theory explains why some materials are conductors, some are semiconductors and some are insulators.

1. **Energy levels in an atom:** In an isolated atom, the electrons can have only certain fixed energies. These are called energy levels, and they correspond to the shells.

2. **Formation of bands:** In a solid, a very large number of atoms are very close to each other. Their energy levels affect each other, so each energy level spreads out into a band of many closely spaced levels (Fig. 2).
3. **Valence band:** The band of the outermost (valence) electrons.
4. **Conduction band:** The band above the valence band. Electrons in this band are free and carry current.
5. **Forbidden energy gap (E_g):** The gap between the valence band and the conduction band. No electron can stay here.
6. **Conduction of current:** For current to flow, electrons must be in the conduction band. An electron of the valence band can go to the conduction band only if it gets energy equal to or more than E_g . This energy can be supplied by heat, light or an electric field.

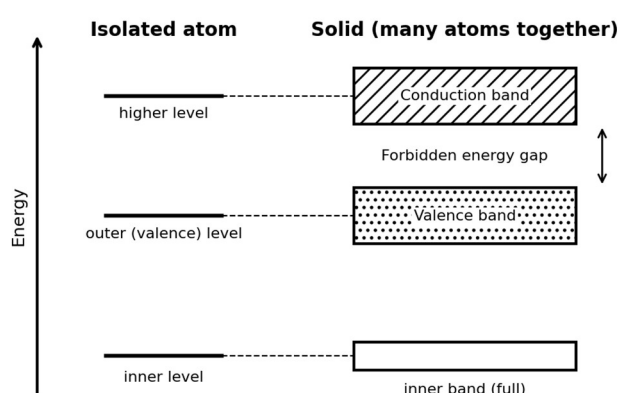


Fig. 2 Formation of energy bands in a solid

Result: In a conductor there is no forbidden gap. In a semiconductor the gap is small. In an insulator the gap is very large. See Q.13 for the diagrams.

Note: At absolute zero temperature (0 K) the valence band of a semiconductor is completely full and its conduction band is empty, so it behaves like an insulator.

Q.13 Differentiate between conductors, semiconductors and insulators on the basis of atomic structure and energy bands. Draw diagrams.

(a) On the basis of atomic structure

An atom has a nucleus (protons and neutrons) and electrons revolving around it in shells. The electrons of the outermost shell are the valence electrons. The number of valence electrons and how firmly they are held decide whether a material is a conductor, semiconductor or insulator.

Material	Valence electrons (generally)	Behaviour of electrons
Conductor	1 to 3	Loosely held. They easily become free, so current flows easily.

Semiconductor	4	Shared with neighbouring atoms by covalent bonds. At very low temperature there are almost no free electrons. At room temperature some bonds break and a few free electrons are available.
Insulator	5 to 8	Outer shell is nearly full and electrons are tightly held. Almost no free electrons.

Note: This is only a general rule. Lead has 4 valence electrons but is a conductor, and diamond has 4 but is an insulator. So, energy bands give a better explanation.

(b) On the basis of energy bands

In a solid, the energies of electrons are grouped in bands. The valence band contains the valence electrons. Electrons in the conduction band are free to move and carry current. The gap between the two bands is the forbidden energy gap (E_g).

1. Conductor: The valence band and conduction band overlap, so there is no gap. A large number of electrons are free to move even at normal temperature.

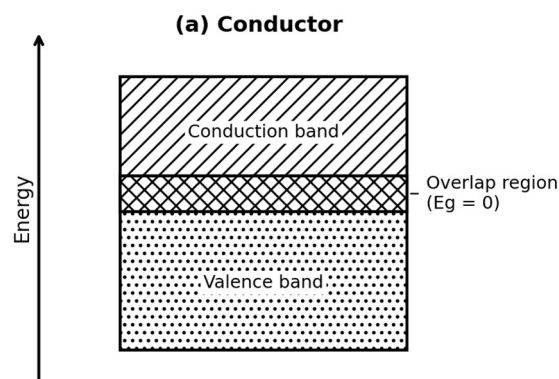


Fig. 3 Energy band diagram of a conductor

2. Semiconductor: The gap between the bands is small (about 1 eV). At low temperature the valence band is almost full and the conduction band is almost empty. At room temperature some electrons get enough energy to jump to the conduction band, so the material conducts a little.

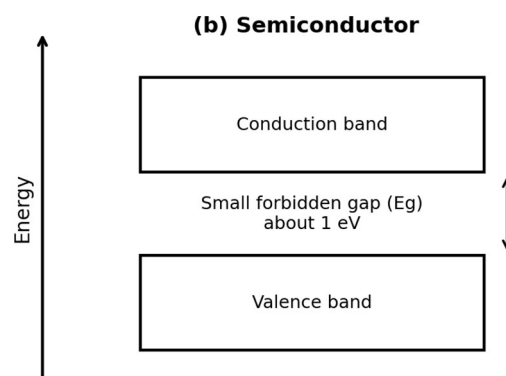


Fig. 4 Energy band diagram of a semiconductor

3. Insulator: The gap between the bands is very large (more than about 5 eV). Electrons cannot jump to the conduction band under normal conditions, so no current flows.

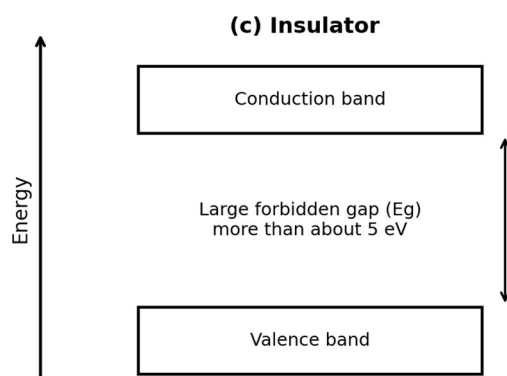


Fig. 5 Energy band diagram of an insulator

(c) Comparison

Point	Conductor	Semiconductor	Insulator
Valence electrons	1 to 3	4	5 to 8
Free electrons	Very many	Few	Almost none
Forbidden gap	Nil (bands overlap)	Small, about 1 eV	Large, above 5 eV
Conductivity	High	Medium	Very low
Resistivity	Very low	Medium	Very high
Effect of temperature on resistance	Increases	Decreases	Generally decreases
Examples	Copper, aluminium	Silicon, germanium	Rubber, glass

Points to Remember (for MCQ and True/False)

1. Forbidden energy gap is largest in insulators.
2. In an insulator the valence band and conduction band are separated by a large gap.
3. In a semiconductor the conduction band is almost empty and the valence band is almost full (at low temperature).
4. Forbidden gap of a conductor is zero. It is not 1 eV. (Statement "gap is 1 eV in conductors" is False.)
5. Electrons of the outermost orbit are valence electrons. All of them are not free electrons. (Statement "outermost electrons are known as free electrons" is False.)
6. Atomic number is the number of protons. Copper has 1 valence electron and silicon has 4.
7. Unit of resistivity is ohm-metre ($\Omega \cdot m$). Unit of conductivity is siemens per metre (S/m).

8. Resistance of conductors increases with temperature. Resistance of semiconductors and carbon decreases with temperature.
9. Manganin has almost zero temperature coefficient of resistance.
10. Air is an insulating material (True).
11. Silicon gap is about 1.1 eV and germanium gap is about 0.67 eV.