1

Classification of Materials

1·1. Introduction

Materials which are used in the field of Electrical Engineering are called Electrical Engineering Materials.

Selection of the right type of material for a particular engineering application and the proper use of these materials are the responsibilities of an engineer. To fulfil this requirement he should have a thorough understanding of the most important properties of the materials like mechanical, electrical, magnetic, thermal, chemical and physical. The properties of a material are its qualities which define its specific characteristics or behaviour. Those properties of a material which define its behaviour under applied forces of loads are called as mechanical properties. The strength of a material is its capacity to withstand a load. While in use a material may have to withstand tensile, compressive or shear forces. There are other factors also which must be considered in order to select the most suitable material and they are as under:

(*i*) **Cost.** The material should have a low cost so that it can easily be purchased and used. The cost should be low on account of economic considerations.

(*ii*) **Availability.** The material should be easily available in the market so that it can be purchased as and when required.

(*iii*) **Ease of manufacturing methods.** The material should have the quality of being manufactured easily and should not involve a complicated and time-consuming operations. This will avoid the unnecessary delays.

Irrespective of the function of the material to be selected is going to be, these factors must be taken into consideration. The study of electrical engineering materials is obligatory for an Electrical Engineer.

To understand how materials behave as conductor, semiconductor, insulator or magnetic, it is necessary to refer to atomic structure of materials. It is due to the internal bonding of atoms in a material which causes it to behave as ; conductor, semi-conductor or insulator.

1·2. Atomic Theory

All matter whether solid, liquid or gas is made up of minute particles called molecules which can further be sub-divided into atoms. Elements are composed of molecules containing atoms of one kind only. Compounds are composed of molecules containing atoms of different kinds.

An element is defined as a substance that can neither be broken up into other substances nor be created by ordinary chemical means. So far 105 elements have been discovered out of which 13 are man-made. The elements which are found in nature are gold, silver, copper, aluminium, mercury, hydrogen, oxygen etc. Examples of man-made elements are curium, Lawrencium etc.

Metals have a *microscopic grain structure* because their particles can be seen only through a microscope. On the other hand wood and concrete have *macroscopic grain structure* because their particles are visible to the unaided eye.

A substance that is composed of combination of elements is called a *compound e.g.* water is a compound having symbol H_2O which means it is composed of two elements namely hydrogen (2 parts) and oxygen (1 part).

According to modern atomic theory the central part of the atom is called "*nucleus*" and contains *protons* and *neutrons.* A proton is a positively charged particle and neutron has no charge. Thus, nucleus of an atom bears positive charge. The neutron is electrically neutral *i.e.* it carries no charge though it is as heavy as proton. The protons and neutrons are very closely held together with tremendous forces.

The nucleus is surrounded by a number of tiny particles called *electrons.* The electrons are spinning around themselves and also are revolving around the nucleus in orbits or shells. The electrons carry the smallest negative charge and have a negligible mass. The mass of electron is approximately $\frac{1}{1840}$ that of a proton, but is three times the diameter of the proton. The charge on each electron is $4 \cdot 8 \times 10^{10}$ e.s.u.

Under ordinary conditions the number of protons is equal to the number of electrons in an atom. Therefore, an atom is electrically neutral as a whole. This explains why a body does not exhibit any charge under ordinary conditions.

Electrons have negative charge exactly equal in magnitude to the positive charge of the protons. Electron is the lightest particle known. The radius of the atom is 10^{-8} cm, the radius of electron is 10^{-13} cm, whereas the radius of the nucleus is 10^{-12} cm.

The electrons are kept in the atom by the attraction exerted on them by the positive nucleus. In fact, the electrons can be regarded as arranged and revolving in successive orbits or levels around the nucleus. The electrons in each orbit or level are associated with a definite amount of energy. Thus the orbits are referred to as energy levels. The energy levels are denoted by the letters K, L, M, N, O, P etc. The K level is nearest to the nucleus.

To remove the electron from its orbit some definite amount of energy is required. To remove the electrons from the first orbit, the energy required is maximum and to remove the electrons from the outermost orbit the energy required is minimum.

The number of electrons that can be accommodated in any orbit or level is given by the formula $2N^2$, where N is the number of orbit or level.

Therefore, K level or first orbit has $2 \times 1^2 = 2$ electrons

L level or second orbit has $2 \times 2^2 = 8$ electrons

M level or third orbit has $2 \times 3^2 = 18$ electrons

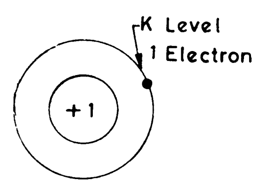
N level or fourth orbit has $2 \times 4^2 = 32$ electrons

and so on. But there is some limitation to the above formula that the outermost level or orbit of any atom cannot have more than 8 electrons and the last but one orbit of the atom cannot have more than 18 electrons.

It is the atom and its internal structure that help in determining the nature of each element.

1·3. Atomic Structures of Some Elements

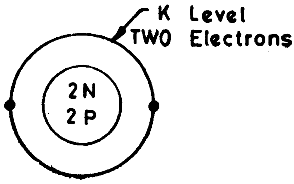
The atom, although extremely small, has a complex internal structure of its own. Scientists are not absolutely certain about the exact structure of the atom. However, some idea of the most widely accepted theory at present of the structure of the atom is given.



Hydrogen Atom
Fig. 1·1.

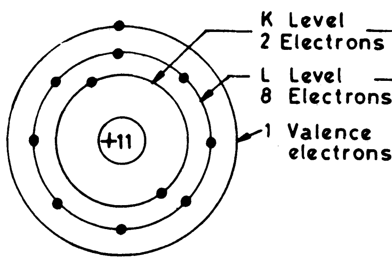
(*i*) **Structure of hydrogen atom.** Its atomic number is one, therefore, there is one electron revolving around its nucleus as shown in Fig. 1·1. The atomic weight of hydrogen is 1·008 which means that the nucleus of its atom consists of only one proton. Hydrogen atom does not contain any Neutrons in the nucleus.

(*ii*) **Structure of Helium Atom.** Its atomic number is 2 and so it has two planetary electrons and its nucleus contains 2 protons. Since its atomic weight is 4, it contains 2 neutrons. Refer to Fig. 1·2.

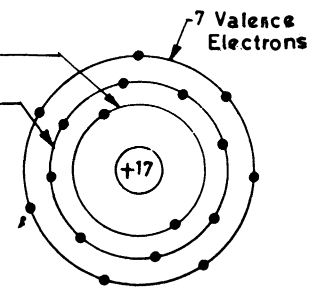


Helium Atom
At. No. = 2, At. wt. = 4
Fig. 1·2.

(*iii*) In Figs. 1·3 and 1·4 the atomic structures of Sodium and Chlorine atoms are shown respectively.

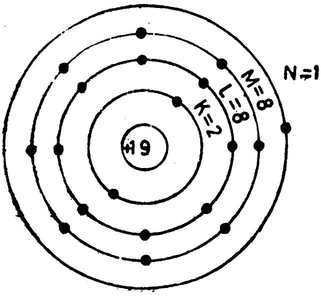


Sodium Atom
Fig. 1·3.

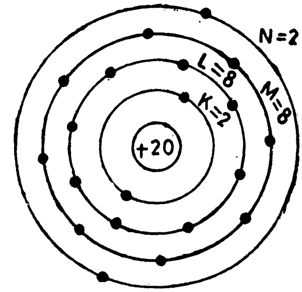


Chlorine Atom
Fig. 1·4.

(*iv*) **Structure of Potassium Atom.** It has 19 protons in the nucleus and, therefore, 19 electrons orbiting around. According to the formula $2N^2$, the number of electrons will be 2 in K level, 8 in L level leaving a balance of 9. The M level can accommodate 18 electrons and it would appear, therefore, that the balance 9 electrons will be accommodated in the M level. But the outermost orbit cannot have more than 8 electrons. Therefore, M level will have 8 electrons and the remaining 1 shall be accommodated in the next higher level *i.e.* the N level. This is shown in Fig. 1·5.



Potassium Atom
Fig. 1·5.



Calcium Atom
Fig. 1·6.

(*v*) **Structure of Calcium Atom.** The calcium atom has 20 protons in the nucleus and 2 electrons in K level, 8 electrons in L and M levels respectively and 2 electrons in N level as shown in Fig. 1·6.

1·4. Valence Electrons

The electrons in the outermost incomplete orbit, called the valence orbit or the valence ring, are called the *valence electrons.* The number of valence electrons is always less than 8. If electrons are added to the outermost orbit (called valence orbit) to bring the total to 8, the atom becomes stable. In the case of Helium, Neon, Argon and Radon the outermost orbit is complete and hence these atoms are stable and, therefore, inert.

It is the valence electrons that determine most of the properties of the elements and form bonds to hold the material together. The valence electrons are comparatively loosely bound to the rest of atom and may be removed by various means *e.g.* by applying electrical voltage to the material.

It is found that those substances whose atoms have their outermost orbits incomplete act as *good conductors* of electricity, *i.e.* they permit an easy detachment of their outermost electrons and offer very little hindrance to their flow through their atoms. Such substances are known as good conductors *e.g.* copper, aluminium, silver etc.

In substances whose electrons are rigidly held to their atoms are termed as *bad conductors* or *insulators.* In their case, a very large force (*i.e.* potential difference) is required to detach their electrons and even then the number of electrons detached and set drifting is comparatively small. Examples of insulators are wood, paper, cloth, rubber etc.

In other substances like germanium, selenium, uranium etc. if a potential difference is applied across the ends of the material, a

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* An atom is identified by its atomic number which indicates the number of protons in the nucleus (or the number of electrons in the orbits). An oxygen atom has eight protons and eight neutrons in the nucleus and eight orbital electrons, therefore, its atomic weight is 16 and its atomic number 8.

Atoms of the same element having same atomic number but different masses are known as isotopes and they have same chemical properties. The various isotopes of Uranium are ${}_{92}U^{234}$, ${}_{92}U^{235}$ and ${}_{92}U^{238}$ where 92 represents atomic number and 234, 235, 238 represent their atomic weights respectively.

Atoms having same mass but different atomic number are called isobars. They are atoms of different elements with different chemical and physical properties *e.g.*

${}_{13}Argon^{40}$ and ${}_{20}Calcium^{40}$ are isobars having different atomic number *i.e.* 13 and 20 respectively and the same atomic weights *i.e.* of 40.

partial flow of electrons takes place *i.e.* some of them can be detached from the atom and some of them cannot be detached and hence the conduction is partial. Such substances are known as *semi conductors*. Hence the properties of semi-conductors are in between those of conductors and insulators.

1·5. Classification of Electrical Engineering Materials

Electrical Engineering Materials can be classified into the following three categories;

(*i*) Conductors.

(*ii*) Semi-conductors.

(*iii*) Insulators.

Conductors. These are those materials which offer such a small resistance that they allow the electric current to flow through them easily. All metals and their alloys are good conductors of electricity. Carbon in solid form and powder form is also a good conductor. Pure water does not conduct electricity, but acidic water conducts electricity. When a charge is given to a conductor, it spreads all over the material.

Metals like silver, copper, aluminium, alloys like brass, bronze and carbon are the commonly used conducting materials. Silver is the best conductor of electricity, then copper and at third place is aluminium.

Silver being costly is rarely used for conductors. Copper and aluminium are used for making cables and wires. These days copper is being replaced by aluminium because it is cheap and available in plenty.

Semi conductors. They occupy an intermediate position between conductors and insulators *e.g.* Uranium, Germanium, Silicon, Thorium etc. These are commonly used for electronic devices. Semi-conductors are used in different fields of electrical engineering *e.g.* telecommunication and radio communication, electronics and power engineering. They also render their services as amplifiers, rectifiers, diodes, transistors etc.

Insulators. Those materials which offer such a high resistance that they do not allow current to pass through them. Their resistance is usually in $M\Omega$. If a charge is given to a point on an insulator, it does not spread over its body.

A few examples of insulating materials are rubber, cotton, silk, paper, mica, glass, porcelain, P.V.C., insulating varnish, mineral wax, synthetic wax, varnish, cloth, wood, bakelite, asbestos, marble, insulating oil such as transformer oil, air, nitrogen, freon etc. But there is no such material in this universe which is a perfect insulator.

The insulating materials may be of three types :

(*i*) Solid *e.g.* mica, rubber, glass etc.

(*ii*) Liquid *e.g.* insulating oil such as transformer oil.

(*iii*) Gaseous *e.g.* air, nitrogen, freon etc.

Details of Atomic Structures of Some Elements of the Periodic Table are given in Table 1·1

Table 1·1.

Atomic No.	*Element*	*Protons (+ve charges) in the nucleus*	*Electrons (–ve charges) per level*				
			K	*L*	*M*	*N*	*O*
(*1*)	(*2*)	(*3*)	(*4*)				
1	Hydrogen, *H*	1	1				
2	Helium, *He*	2	2				
3	Lithium, *Li*	3	2	1			
5	Boron, *B*	5	2	3			
6	Carbon, *C*	6	2	4			
7	Nitrogen, *N*	7	2	5			
8	Oxygen, *O*	8	2	6			
11	Sodium, *Na*	11	2	8	1		
12	Magnesium, *Mg*	12	2	8	2		
13	Aluminium, *Al*	13	2	8	3		
14	Silicon, *Si*	14	2	8	4		
15	Phosphorus, *P*	15	2	8	5		
16	Sulphur, *S*	16	2	8	6		
17	Chlorine, *Cl*	17	2	8	7		
18	Argon, *A*	18	2	8	8		
19	Potassium, *K*	19	2	8	8 1		
20	Calcium, *Ca*	20	2	8	8 2		
24	Chromium, *Cr*	24	2	8	13		1
25	Manganese, *Mn*	25	2	8	13		2
26	Iron, *Fe*	26	2	8	14		2
27	Cobalt, *Co*	27	2	8	15		2
28	Nickel, *Ni*	28	2	8	16		2
29	Copper, *Cu*	29	2	8	18		1
30	Zinc, *Zn*	30	2	8	18		2
32	Germanium, *Ge*	32	2	8	18		4

(1)	(2)	(3)	(4)					
33	Arsenic, *As*	33	2	8	18	5		
34	Selenium, *Se*	34	2	8	18	6		
47	Silver, *Ag*	47	2	8	18	18	1	
48	Cadmium, *Cd*	48	2	8	18	18	2	
50	Tin, *Sn*	50	2	8	18	18	4	
51	Antimony, *Sb*	51	2	8	18	18	5	
53	Iodine, *I*	53	2	8	18	18	7	
56	Barium, *Ba*	56	2	8	18	18	8	2
74	Tungsten, *W*	74	2	8	18	32	12	2
77	Iridium, *Ir*	77	2	8	18	32	15	2
78	Platinum, *Pt*	78	2	8	18	32	16	2
79	Gold, *Au*	79	2	8	18	32	18	1
80	Mercury, *Hg*	80	2	8	18	32	18	2
82	Lead, *Pb*	82	2	8	18	32	18	4
83	Bismuth, *Bi*	83	2	8	18	32	18	5

1·6. Inter Atomic Bonds

The bond between atoms make it possible to combine to form a solid. Inter atomic bonds are of three main types :

(*i*) Metallic Bond

(*ii*) Covalent Bond

(*iii*) Ionic Bond.

The attractive forces in all the three types of bonds are due to the valence electrons. The outermost orbit, which contains the valence electrons, is comparatively unstable. It can become stable either by acquiring more electrons to bring the total upto 8 or by losing all its electrons to another atom. This is how atomic bonds are formed.

(*i*) **Metallic Bond.** The outermost orbit should have eight electrons in order to be stable. Elements which have one, two or three valence electrons are very unstable. Atoms of such elements give up their valence electrons to form an electron cloud throughout the space occupied by the atoms. After giving up their valence electrons, positive ions are left. The material is now held together by the electrostatic force between the positive ions and electron cloud. This type of bond is found in elements having small number of valence electrons which are loosely held so that they can easily be released to join the common electron cloud. Solids which are held together by this type of bond have properties like ductility and good electrical conductivity *e.g.* silver, copper, aluminium.

If a potential difference is applied across such a material the electrons are easily attracted towards the positive terminal due to the following two reasons :

(*i*) Electrons are far removed from the positive ions.

(*ii*) Electrons are subjected to force of repulsion from other electrons.

The deficiency of the electrons thus created is made good by the inflow of the electrons through the negative terminal. The metallic bond acts between identical atoms, as in pure metals or between chemically similar atoms, as in alloys.

(*ii*) **Covalent Bond.** A covalent bond results from sharing of pairs of valence electrons by two or more atoms of the same element. The atoms of materials having 4 or more than 4 electrons

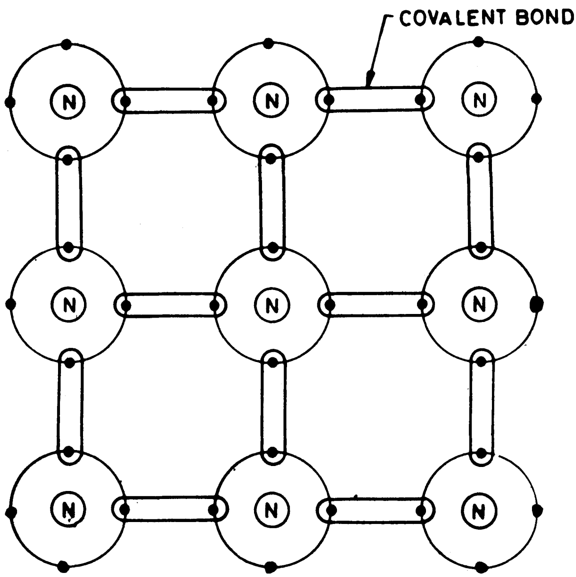

Fig. 1·7. Covalent bond of Germanium atoms.

revolving in their outermost orbits must share their electrons with the neighbouring atoms as shown in Fig. 1·7. This is because an atom must have at least 8 electrons in the outermost orbit in order to be stable.

In Fig. 1·7 the covalent bonding for Germanium atoms is shown. In this case the electrons revolve around the atoms in such a manner that each atom has alternately 8 and zero electrons instead of 4, in its outermost orbit. Therefore, each atom is charged alternatively positive and negative. Due to unlike charge the two atoms attract each other with an electrostatic force. The atoms of such materials behave as if they had full outer orbits. In this way each electron is locked in its place. This gives greater strength to such material and also provides very low electrical conductivity because no electrons are available for movement.

The electrons are so tightly bound in their orbits that a large amount of energy is required to remove them from covalent bonding. Such materials are, therefore, insulators in varying degrees. In an ideal insulator, all valence electrons are occupied in bond formation and none are available for conduction.

Certain materials normally behave as insulators but allow for more valence electrons to be made available by thermal energy. These elements are known a *semi-conductors* and have 4 valence electrons. Such elements include carbon, Silicon, Germanium etc. They are insulators at zero degree Kelvin (–273°C) but develop significant conductivity at room temperature.

Semi-conductors produced by thermal energy alone are called *Intrinsic semiconductors.* The conductivity of such elements is small due to relatively few free electrons at room temperature, but it increases exponentially with temperature.

The conductivity of semiconductor materials is considerably changed by adding impurities to them. If, for example, a few antimony atoms having 5 valence electrons are introduced into the structure of a semiconductor material like Germanium which has 4 valence electrons, there will be a local excess of electron in each covalent bond between Germanium and Antimony. One extra electron, not needed for bonding, is provided by each atom of Antimony. The extra electrons are free for movement and are, therefore, available for conduction.

Conduction resulting from addition of impurities to semiconductors are called *Extrinsic semiconductors.*

(iii) **Ionic Bond.** In ionic bond atoms of different elements (unlike covalent bonds which exist between atoms of the same element) transfer electrons from one to the other so that both have stable outermost orbits. At the same time both become ions, one positively and other negatively charged. The electrostatic force between the two gives rise to the bond.

For example, ionic bond exist between sodium (Na) and chlorine (Cl). In this case the sodium atom gives up its one valence electron and chlorine atom takes up this electron to complete its outer shell so that both become stable.

Materials behave as conductors, semiconductors or insulators depending on their internal structure. The order of the values of resistivity for these three types of materials are

Conducting Materials	:	10^{-8} to 10^{-6} ohm. m.
Semiconducting Materials	:	10^{0} to 10^{2} ohm. m.
Insulating Materials	:	10^{12} to 10^{18} ohm. m.

Table 1·2

Element	*Atomic No.*	*Atomic weight*
Aluminium (*Al*)	13	26·97
Argon (*A*)	18	39·944
Arsenic (*As*)	33	74·91
Boron (*B*)	5	10·82
Cadmium (*Cd*)	48	112·41
Calcium (*Ca*)	20	40·08
Carbon (*C*)	6	12·010
Cobalt (*Co*)	27	58·94
Copper (*Cu*)	29	63·54
Germanium (*Ge*)	32	72·6
Gold (*Au*)	79	197·2
Hydrogen (*H*)	1	1·0080
Iron (*Fe*)	26	55·85
Lead (*Pb*)	82	207·21
Mercury (*Hg*)	80	200·61
Nickel (*Ni*)	28	58·69
Nitrogen (*N*)	7	14·008
Oxygen (*O*)	8	16·00
Silicon (*Si*)	14	28·06
Silver (*Ag*)	47	107·80
Tungsten (*W*)	74	183·92
Uranium (*U*)	92	238·07

QUESTIONS

1·1. Name the three categories into which electrical engineering materials can be divided. Mention the range of resistivity for each category.

1·2. Explain how the materials can be classified into three groups on the basis of their atomic structure.

1·3. Explain how covalent bond results from sharing of valence electrons.

1·4. Explain how conduction takes place in conductors and semi-conductors.

1·5. What is an atom ? What are the fundamental components of the atom ?

1·6. Give the atomic structure of the following elements :

(*i*) Hydrogen (*iv*) Chlorine

(*ii*) Helium (*v*) Calcium.

(*iii*) Sodium

1·7. What is the importance of electrons in an atom ?

1·8. Define the following terms :

(*i*) Atomic number

(*ii*) Isotopes.

1·9. What properties of elements are determined by their valency electrons ?

1·10. "Knowledge of materials is back bond of Engineering". Discuss.

1·11. Which materials are classified as "semi-conductors" and on what basis are they classified as such ?

1·12. Distinguish between conductors and insulators.

1·13. Mention the difference between conductors, semi-conductors and insulators with reference to their atomic structure.

1·14. Name the three categories into which electrical engineering materials can be divided.

1·15. Indicate and explain what types of bonds will be present in the following components :

(*i*) H_2 (*ii*) CH_4 (*iii*) H_2O (*iv*) $AlCl_3$.

1·16. What are the forces acting between atoms and molecules ?

1·17. What are the destructive and non-destructive tests for material testing ?

MULTIPLE CHOICE TYPE QUESTIONS

1. When an electron is removed from an atom, it becomes

(*a*) a positive ion (*c*) an anode

(*b*) a negative ion (*d*) a cathode

2. A field of force can exist only between

(*a*) two molecules (*c*) two ions

(*b*) two atoms

3. The number of electrons in different orbits of an atom is governed by the formula (when n is the number of the orbit)

(*a*) n^2
(*c*) $3n$
(*b*) $2n^2$
(*d*) $4n$

4. The structures of the most common matals are
(*a*) linear
(*c*) hexagonal
(*b*) cubic

5. The lighest particle of an atom is
(*a*) electron
(*c*) proton
(*b*) neutron

6. Molecules of a substance having dissimilar atoms is called
(*a*) conductor
(*c*) compound
(*b*) semi-conductor

7. The diameter of the nucleus of an atom is
(*a*) 10^{-30} m
(*c*) 10^{-14} m
(*b*) 10^{20} m
(*d*) 10^{-25} m

8. The mass of proton is roughly heavier than the mass of electron by
(*a*) 184
(*c*) 18400
(*b*) 1840
(*d*) 184000

9. The coordination number of a cubic structure is
(*a*) 2
(*c*) 6
(*b*) 4
(*d*) 10

10. Metallic bonding is due to
(*a*) attraction between ions and electrons
(*b*) sharing of electrons between adjacent atoms
(*c*) none of the above

11. The formation of covalent bond is by
(*a*) sharing of electrons between atoms
(*b*) transfer of electrons between atoms
(*c*) none of the above

12. In solids, ionic bonding depends on
(*a*) sharing of electrons
(*c*) none of the above.
(*b*) transfer of electrons

13. The frequency of vibration of an atom in a crystal is determined by
(*a*) heat content of the crystal
(*b*) temperature of crystal
(*c*) the stiffness of bonds it makes with neighbours
(*d*) none of the above

14. The electrostatic nature of ionic bond makes it
(*a*) weak
(*c*) non-directional
(*b*) strong
(*d*) directional

15. Forbidden band is largest in
(*a*) insulator
(*b*) conductor
(*c*) semi-conductor

16. Fermi level is the highest available level at
(*a*) 0°C
(*b*) 0°F
(*c*) 0°K

17. Fermi energy is the amount of energy which
(*a*) must be given to a hole to move it to valence band
(*b*) a valence electron can have at room temperature
(*c*) must be given to an electron to move it to conduction band.

18. The kinetic energy of a bounded electron is less than that of an unbounded electron
(*a*) true
(*b*) false

19. The current due to flow of electrons in conduction band is more than the hole current in the valence band.
(*a*) true
(*b*) false

20. Solar cells are made of
(*a*) conducting materials
(*b*) semi conducting materials
(*c*) insulating materials.

21. Semi conducting material used in the construction of a solar cell is
(*a*) aluminium
(*b*) carbon
(*c*) phosphorus
(*d*) silicon and gallium.

22. Conductivity of semi-conducting materials increase with
(*a*) increase in temperature
(*b*) decrease in temperature
(*c*) temperature has no effect

23. The number of known elements on earth is about
(*a*) 20
(*b*) 80
(*c*) 100
(*d*) 125

24. The number of non-metals is about
(*a*) 20
(*b*) 60
(*c*) 80
(*d*) 100

25. The number of metals is approximately
(*a*) 100
(*b*) 80
(*c*) 60
(*d*) 20

26. Naturally occurring compounds of metals found from earth's crust are called
(*a*) elements
(*b*) compounds
(*c*) minerals

27. The outermost orbit of any atom cannot have more than
(*a*) 4 electrons
(*b*) 8 electrons
(*c*) 5 electrons

ANSWER KEY

1.	(*a*)	2.	(*c*)	3.	(*b*)	4.	(*b*)	5.	(*a*)
6.	(*c*)	7.	(*c*)	8.	(*b*)	9.	(*c*)	10.	(*a*)
11.	(*a*)	12.	(*b*)	13.	(*c*)	14.	(*c*)	15.	(*a*)
16.	(*c*)	17.	(*c*)	18.	(*a*)	19.	(*a*)	20.	(*b*)
21.	(*d*)	22.	(*a*)	23.	(*c*)	24.	(*a*)	25.	(*b*)
26.	(*c*)	27.	(*b*)						

FILL IN THE BLANKS

1. Hydrogen atom does not contain any _______ in the nucleus.
2. The _______ level is nearest to the nucleus.
3. The number of _______ electrons is always less than eight.
4. Elements which have one, two or three valence electrons are very _______.
5. _______ have a microscopic grain structure.
6. _______ is electrically neutral.
7. Hydrogen atom does not contain any _______ in the nucleus.
8. The conductivity of semi-conductor materials is considerably changed by adding _______.

ANSWERS

1. Neutrons	2. K	3. Valence
4. Unstable	5. Metals	6. Neutron
7. Neutrons	8. Impurities.	