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DEPARTMENT OF INFORMATION TECHNOLOGY

COURSE CODE: BBIT 1102

COURSE TITLE: BASIC ELECTRICITY AND OPTICS FOR BBIT

Instructional Material for BBIT- distance learning

COURSE OUTLINE

BIT 1101: BASIC ELECTRICITY AND OPTICS FOR BIT

Contact Hours: 42

Pre-requisite: None

Purpose: To understand electronics, magnetic and optical business information technologies and devices.

Objectives: By the end of the course units, the learner will be able to:

- i) Describe the properties of materials in terms of conductivity
- ii) Describe the basic properties of magnets, optics and electricity and their uses.
- iii) Solve basic problems of magnetism, optics and electricity.
- iv) Describe the application of optical and electrical devices in information technology

Course Content

Physics

Introduction to Electricity and Magnetism; Atomic structure: Bonding, Crystals and Crystallography Conductors, Insulators and semi-conductors, Magnetism : Electromagnetic induction. Mains Electricity, Current Electricity and Resistance, Electrostatics and capacitors.

Electronics: Introduction, Diodes, Rectifiers, Transistors.

Optics: Light and its properties, Thin lenses, Total internal Reflection, Fibre optics.

Electromagnetic Radiation: Photoelectric Effect, Laser, Holography and Colour.

Assessments

A learner is assessed through ; Continuous Assessment Tests (CATs) - (30%); End of semester examination (70%)

Required text books

- i) Kuhn K.F. 1996, Basic Physics: A self – Teaching Guide), Wiley
- ii) Hewitt P.G. 2001., Conceptual Physics: with practicing physics workbook, Addison Wiley, 9th Edition,
- iii) Wildi T(1995), Basic Electricity for Industry, Pearson Education
- iv) Gussow M. Schaum's, (1993), Outline of Basic Electricity, McGraw – Hill
- v) Hewitt R.B. & Margenau it (1981), Foundations of physics, Bow Press

TABLE OF CONTENTS

COURSE OUTLINE	1
COURSE OUTLINE	2
1.0 ELECTRICITY AND ATOMIC STRUCTURE.....	7
1.1 INTRODUCTION	7
1.2 ELECTRICITY	7
1.3 BASIC STRUCTURE OF MATTER	7
1.4 ATOMIC STRUCTURE.....	8
1.5 RUTHERFORD'S EXPERIMENT	9
1.6 BONDING	11
1.7 COVALENT BONDING.....	13
1.8 METALLIC BONDING.....	14
CHAPTER REVIEW QUESTIONS	15
SUGGESTED REFERENCES	15
2.0 CRYSTALS AND CRYSTALLOGRAPHY.....	16
2.1 CRYSTALS.....	16
2.2 CRYSTALLOGRAPHY	18
2.3 CRYSTALLOGRAPHY IN MATERIALS ENGINEERING	19
CHAPTER REVIEW QUESTIONS	20
SUGGESTED REFERENCES	21
3.0 MAGNETISM	22
CHAPTER REVIEW QUESTIONS	24
SUGGESTED REFERENCES	24
4.0 CURRENT AND RESISTANCE.....	25
4.1 PARALLEL AND SERIES CONNECTIONS TOGETHER (EQUIVALENT CIRCUITS)	
30	
CHAPTER REVIEW QUESTIONS	32
SUGGESTED REFERENCES	32
5.0 MAINS ELECTRICITY	33
CHAPTER REVIEW QUESTIONS	36
SUGGESTED REFERENCES	36
6.0 ELECTROMAGNETIC INDUCTION.....	37
6.1 THE TRANSFORMER.	38
6.1.1 TRANSFORMER EQUATION.	38

6.2	TRANSMISSION OF MAINS ELECTRICITY.....	39
6.2.1	ENERGY LOSS DURING POWER TRANSMISSION.....	39
	CHAPTER REVIEW QUESTIONS	40
4.	WHAT IS THE TRANSFORMER?.....	40
7.0	ELECTROSTATICS.....	41
7.1	ELECTROSTATIC CHARGE	41
7.2	ATTRACTION AND REPULSION.....	41
7.3	GOLD LEAF ELECTROSCOPE.....	42
7.4	ELECTROSTATIC SHOCK.....	43
7.5	DANGERS OF ELECTROSTATIC CHARGES.....	43
7.6	USES OF ELECTROSTATIC CHARGES.....	44
7.6.1	INKJET PRINTER.....	44
7.6.2	PHOTOCOPIER.....	45
7.7	ELECTRIC CHARGES.....	45
7.8	POSITIVE AND NEGATIVE, ATTRACTIVE AND REPULSIVE.....	45
7.9	CONSERVATION OF CHARGE.....	46
7.10	CONDUCTORS AND INSULATORS.....	46
7.11	CHARGING A BODY.....	46
	CHAPTER REVIEW QUESTIONS	47
	SUGGESTED REFERENCES	47
8.0	CAPACITORS	48
8.1	CAPACITORS IN A CIRCUIT.....	49
8.1.1	SERIES CONNECTION OF CAPACITORS	49
8.2	PARALLEL CONNECTION OF CAPACITORS.....	50
	CHAPTER REVIEW QUESTIONS	51
	SUGGESTED REFERENCES	51
9.0	ELECTRONICS	51
9.1	DIODES.....	53
9.2	FUNCTIONS OF A DIODE.....	53
9.3	FORWARD VOLTAGE DROP	53
9.4	REVERSE VOLTAGE.....	53
9.5	CONNECTING AND SOLDERING	54
9.6	TESTING DIODES.....	54

9.7	SIGNAL DIODES (SMALL CURRENT).....	54
9.7	PROTECTION DIODES FOR RELAYS	55
9.8	RECTIFIER DIODES (LARGE CURRENT).....	55
9.9	BRIDGE RECTIFIERS.....	55
9.10	TRANSISTORS.....	56
9.10.2	TESTING A TRANSISTOR.....	57
9.10.3	TESTING WITH A MULTIMETER	57
	CHAPTER REVIEW QUESTIONS	57
	SUGGESTED REFERENCES	58
10.0	OPTICS.....	59
10.1	VELOCITY OF LIGHT AND REFRACTIVE INDEX.....	60
10.2	REFLECTION AND REFRACTION OF LIGHT	61
10.3	DISPERSION OF LIGHT	62
10.4	ABSORPTION OF LIGHT	63
10.5	POLARIZATION OF LIGHT	64
	CHAPTER REVIEW QUESTIONS	65
	SUGGESTED REFERENCES	66
11.0	THIN LENSES	67
11.1	CONVERGENT LENS	67
11.2	DIVERGENT LENS	68
11.3	TOTAL INTERNAL REFLECTION (T.I.R.).....	69
11.4	OPTICAL FIBRE	71
11.4.1	HOW AN OPTICAL FIBER TRANSMITS LIGHT	72
	CHAPTER REVIEW QUESTIONS	74
	SUGGESTED REFERENCES	74
12.0	ELECTROMAGNETIC RADIATION	75
12.1	LIGHT AS AN EM RADIATION	77
12.2	RADIO WAVES	78
12.3	THE PHOTOELECTRIC EFFECT	78
	CHAPTER REVIEW QUESTIONS	80
	SUGGESTED REFERENCES	80
13.0	LASER.....	81
13.1	USES OF LASER	81

13.2	ATOM-LIGHT INTERACTIONS	81
13.3	LAPTOP SCREENS	83
	CHAPTER REVIEW QUESTIONS	83
14.0	HOLOGRAPHY AND COLOUR.	84
14.1	HOLOGRAPHY	84
14.2	TECHNICAL DESCRIPTION.....	85
14.3	HOLOGRAPHIC RECORDING PROCESS.....	86
14.4	HOLOGRAPHIC RECORDING.....	86
14.5	HOLOGRAPHIC RECONSTRUCTION PROCESS.....	86
14.6	MASS REPLICATION.....	88
14.7	DYNAMIC HOLOGRAPHY	89
14.8	HOLOGRAPHIC DATA STORAGE.....	89
14.9	DIGITAL HOLOGRAPHY	90
14.9	HOLOGRAPHY IN ART	90
	CHAPTER REVIEW QUESTIONS	91
	SUGGESTED REFERENCES	91

1.0 ELECTRICITY AND ATOMIC STRUCTURE

Learning Objectives

By the end of this section, the learner should be able to:-

- i. Define source of electricity
- ii. Explain the structure of an atom
- iv. Describe Rutherford's experiment
- v. Explain Bonding of atoms

1.1 Introduction

1.2 Electricity

Electricity is a naturally occurring force that exists all around us. Humans have been aware of this force for many centuries. Ancient man believed that electricity was some form of magic because they did not understand it. Greek philosophers noticed that when a piece of amber was rubbed with cloth, it would attract pieces of straw. They recorded the first references to electrical effects, such as static electricity and lightning, over 2,500 years ago.

It was not until 1600 that a man named Dr. William Gilbert coined the term “*electricus*,” a Latin word which describes the static charge that develops when certain materials are rubbed against amber. This is probably the source of the word “electricity.” Electricity and magnetism are natural forces that are very closely related to one another. You will learn a little about magnetism in this section, but there is a whole section on magnetism if you want to learn more.

In order to really understand electricity, we need to look closely at the very small components that compose all matter.

1.3 Basic Structure of Matter

The Atom

All matter such as solids, liquids, and gases, is composed of **atoms**. Therefore, the atom is considered to be the basic building block of matter. However, atoms are almost always grouped together with other atoms to form what is called a molecule. Only a few gases such as helium are composed of individual atoms.

Atoms are extremely small. The radius of a typical atom is on the order of 0.00000000001 meter and cannot be studied without very powerful microscopes. Electron microscope can be used to magnify things until very small details appear relatively big.

1.4 Atomic structure

All normal matter consists of atoms, which are often joined together to form molecules.

All atoms are made of three types of particle:

- Positively charged protons
- Uncharged neutrons
- Negatively charged electrons

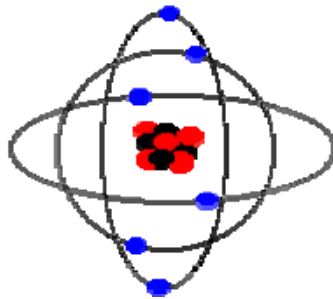


Diagram 1: Atomic Structure.

The protons and neutrons contain 99% of the mass of the atom. They form the nucleus at the centre of the atom. The electrons orbit the *nucleus* like planets orbiting a sun. The nucleus is where most of the mass of the atom is concentrated.

The drawing shown is not to scale. In fact, if an atom were enlarged to the size of a football Stadium, the nucleus would still only be the size of a pea! This means all atoms, and all matter made from them, is 99% empty space.

You may have met the following law about electrostatic forces when you studied physics: Opposite charges (positive and negative) *attract*. Like charges (positive and positive, or negative and negative) *repel*. This is called the basic law of electrostatics. This means that the negative electrons orbiting around the positive nucleus are attracted to it, and it is this attraction which keeps them in orbit, and stops them from flying off into the void. Their orbital speed (which is high!) and various quantum effects (don't ask!) stop them falling in towards the nucleus and crashing into it. If the nucleus contains positively charged protons, and like charges repel each other, why don't the

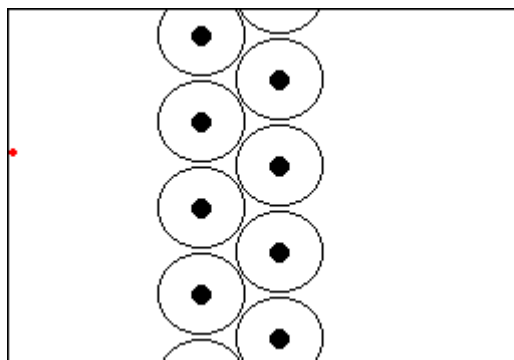
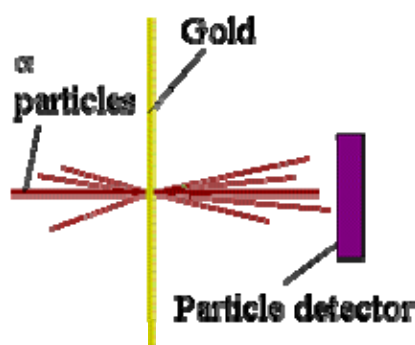
protons repel each other and blow the nucleus apart? Although the positive charges on the protons do indeed tend to push them apart, there is another force at work that is even stronger! It is called the *Strong Nuclear Force* and it only operates over very small distances - about 10^{-15} metres, which is about the size of the atomic nucleus. When protons are roughly this distance apart, the Strong Nuclear Force takes over and pulls the protons (and neutrons, if there are any) together and holds them tightly. The mass and charge of these particles are normally quoted in 'mass units' and 'charge units'. Protons and neutrons have just about the same mass, one unit, which is approx. 1.7×10^{-24} grammes. Electrons have virtually no mass, about 0.0005 of a proton's mass.

	Proton	Neutron	Electron
Mass	1 unit	1 unit	almost 0
Charge	+1 unit	0	-1 unit

Protons have a positive charge of 1 unit (about 1.6×10^{-19} Coulombs). Neutrons are neutral (hence the name) - they have no charge and are just 'dead weight'. Electrons have exactly the same charge as protons except negative. Protons and electrons have opposite charges so they are attracted to each other. This attraction keeps electrons orbiting the nucleus.

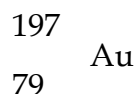
1.5 Rutherford's Experiment

We know all this due to experiments performed by scientists such as Ernest Rutherford at the end of the nineteenth and beginning of the twentieth century. In 1910, Rutherford did an experiment to determine what atoms were like. He fired a beam of a *particles* (*alpha* particles) (which had recently been discovered) at a thin gold foil, tracking them using a detector. To his surprise he discovered that most of the particles went straight through the foil, but some were deflected at an angle and some even bounced straight back! This showed that most of the particles passed through empty space but that some were being deflected by a small point charge. *Alpha* particles were known to be positive so they must be bouncing off the positive nucleus.



Atomic Number and Relative Atomic Mass

The symbol of the atom often has two figures next to it. The top figure is the Relative Atomic Mass. It shows how many protons and neutrons there are altogether in the atom, and tells you how much heavier than a hydrogen atom (1 lone proton) the atom is.

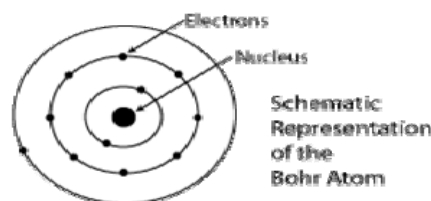


The example that you see above is the symbol for Gold (Au). It is 197 times as heavy as a hydrogen atom, i.e. its Relative Atomic Mass (R.A.M.) is 197. The bottom number (the Atomic Number) tells you how many protons there are in the atom. It also marks the atom's position in the Periodic Table, since they are arranged in the order of their proton count. You can work out how many neutrons there are in the atom by subtracting the bottom number from the top. The example shows us that gold is element number 79 in the table, and therefore each atom of gold has 79 protons in it. The number of neutrons in a gold atom is $197 - 79 = 118$.

To find the number of neutrons, subtract the atomic number from the relative atomic mass. If you look at the periodic table, you will find that the elements all have relative atomic masses which are decimal values. How can you have a fraction of a neutron? Well, clearly atoms don't contain parts of neutrons. The effect occurs because each element consists of a number of *isotopes*. In practice, most relative atomic masses are so close to whole numbers that we tend to round them. For instance, the relative atomic mass of Chromium is 51.996, so we tend to use the value 52 as the relative atomic mass.

1.6 Bonding

From elementary chemistry we know that the atomic structure of any element is made up of a positively charged nucleus surrounded by electrons revolving around it. An element's atomic number indicates the number of positively charged protons in the nucleus. The atomic weight of an atom indicates how many protons and neutrons in the nucleus. To determine the number of neutrons in an atom, the atomic number is simply subtracted from the atomic weight.



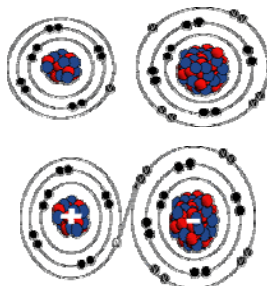
The Nucleus contains Protons and Neutrons.

Atoms like to have a balanced electrical charge. Therefore, they usually have negatively charged electrons surrounding the nucleus in numbers equal to the number of protons. It is also known that electrons are present with different energies and it is convenient to consider these electrons surrounding the nucleus in energy “shells.” For example, magnesium, with an atomic number of 12, has two electrons in the inner shell, eight in the second shell and two in the outer shell.

All chemical bonds involve electrons. Atoms will stay close together if they have a shared interest in one or more electrons. Atoms are at their most stable when they have no partially-filled electron shells. If an atom has only a few electrons in a shell, it will tend to lose them to empty the shell. These elements are metals. When metal atoms bond, a metallic bond occurs. When an atom has a nearly full electron shell, it will try to find electrons from another atom so that it can fill its outer shell. These elements are usually described as nonmetals. The bond between two nonmetal atoms is usually a covalent bond. Where metal and nonmetal atom come together an ionic bond occurs. There are also other, less common, types of bond but the details are beyond the scope of this material. On the next few pages, the Metallic, Covalent and Ionic bonds will be covered in more detail.

Ionic bonding occurs between charged particles. These may be atoms or groups of atoms, but this discussion will be conducted in terms of single atoms. Ionic bonding occurs between metal atoms and nonmetal atoms. Metals usually have 1, 2, or 3 electrons in their outermost shell. Nonmetals have 5, 6, or 7 electrons in their outer shell. Atoms with outer shells that are only partially filled are unstable. To become stable, the metal

atom wants to get rid of one or more electrons in its outer shell. Losing electrons will either result in an empty outer shell or get it closer to having an empty outer shell. It would like to have an empty outer shell because the next lower energy shell is a stable shell with eight electrons.



Since electrons have a negative charge, the atom that gains electrons becomes a negatively charged ions (also known as anion) because it now has more electrons than protons. Alternately, an atom that loses electrons becomes a positively charged ion (also known as cations). The particles in an ionic compound are held together because there are oppositely charged particles that are attracted to one another.

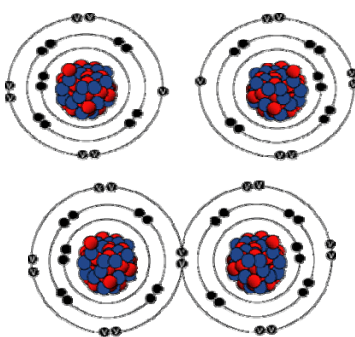
The images schematically show the process that takes place during the formation of an ionic bond between sodium and chlorine atoms. Note that sodium has one valence electron that it would like to give up so that it would become stable with a full outer shell of eight. Also note that chlorine has seven valence electrons and it would like to gain an electron in order to have a full shell of eight. The transfer of the electron causes the previously neutral sodium atom to become a positively charged ion (cation), and the previously neutral chlorine atom to become a negatively charged ion (anion). The attraction for the cation and the anion is called the ionic bond.

Generally, *solid materials* with ionic bonds:

- are hard because particles cannot easily slide past one another.
- are good insulators because there are no free electrons or ions (unless dissolved or melted).
- are transparent because their electrons are not moving from atom to atom and less likely to interact with light photons.
- are brittle and tend to cleave rather than deform because bonds are strong.
- have high melting point because ionic bonds are relatively strong.

1.7 Covalent Bonding

Where a compound only contains nonmetal atoms, a covalent bond is formed by atoms sharing two or more electrons. Nonmetals have 4 or more electrons in their outer shells (except boron). With this many electrons in the outer shell, it would require more energy to remove the electrons than would be gained by making new bonds. Therefore, both the atoms involved share a pair of electrons. Each atom gives one of its outer electrons to the electron pair, which then spends some time with each atom. Consequently, both atoms are held near each other since both atoms have a share in the electrons.



More than one electron pair can be formed with half of the electrons coming from one atom and the rest from the other atom. An important feature of this bond is that the electrons are tightly held and equally shared by the participating atoms. The atoms can be of the same element or different elements. In each molecule, the bonds between the atoms are strong but the bonds between molecules are usually weak. This makes many solid materials with covalent bonds brittle. Many ceramic materials have covalent bonds.

Compounds with covalent bonds may be solid, liquid or gas at room temperature depending on the number of atoms in the compound. The more atoms in each molecule, the higher a compound's melting and boiling temperature will be. Since most covalent compounds contain only a few atoms and the forces between molecules are weak, most covalent compounds have low melting and boiling points. However, some, like carbon compounds, can be very large. An example is the diamond in which carbon atoms each share four electrons to form giant lattices.

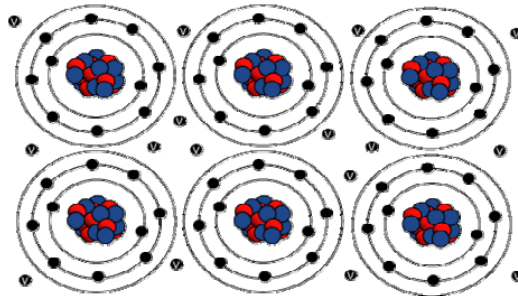
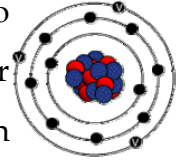
Some Common Features of Materials with Covalent Bonds:

- Hard

- Good insulators
- Transparent
- Brittle or cleave rather than deform

1.8 Metallic Bonding

A common characteristic of metallic elements is they contain only one to three electrons in the outer shell. When an element has only one, two or three valence electrons (i.e. electrons in the outer shell), the bond between these electrons and the nucleus is relatively weak. So, for example, when aluminum atoms are grouped together in a block of metal, the outer electrons leave individual atoms to become part of common “electron cloud.” In this arrangement, the valence electrons have considerable mobility and are able to conduct heat and electricity easily. Also, the delocalized nature of the bonds, make it possible for the atoms to slide past each other when the metal is deformed instead of fracturing like glass or other brittle material.



Since the aluminum atoms lose two electrons, they end up having a positive charge and are designated Al^{3+} ions (cations). These ions repel each other but are held together in the block because the negative electrons are attracted to the positively charged ions. A result of the sharing of electrons is the cations arrange themselves in a regular pattern. This regular pattern of atoms is the crystalline structure of metals. In the crystal lattice, atoms are packed closely together to maximize the strength of the bonds. An actual piece of metal consists of many tiny crystals called grains that touch at grain boundaries.

Some Common Features of Materials with Metallic Bonds:-

- Good electrical and thermal conductors due to their free valence electrons
- Opaque
- Relatively ductile

Chapter Review Questions

1. Define the Atom
2. The atom consists of three components. Name them
3. State the basic law of electrostatics
4. Describe the contribution of Rutherford's experiment
5. Define Relative Atomic Mass of an atom
6. Define the Atomic Number of an atom
7. State three types of atomic bonds
8. Name the common characteristics of *solid materials* with ionic bonds
9. Name Common Features of Materials with Covalent Bonds
10. Name Common Features of Materials with Metallic Bonds

Suggested References

- i. Electricity and Magnetism (Hardcover) by Seema Singh Publisher: Campus Books International (2009)
- ii. Electricity And Magnetism: Berkeley Physics ,Edward M. Purcell , Tata Mgraw Hill (2007)
- iii. Electricity and Magnetism: Berkeley Physics 2004, Author: Edward M. Purcell
- iv. Free online books on http://web.mit.edu/6.013_book/www/book.html

2.0 CRYSTALS AND CRYSTALLOGRAPHY

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Describe the structure and formation of a Crystal
- ii). Explain the Concept of Crystallography
- iii). Discuss crystallography in Materials Engineering

2.1 Crystals

Introduction

A **crystal** or **crystalline solid** is a solid material, whose constituent atoms, molecules, or ions are arranged in an orderly repeating pattern extending in all three spatial dimensions. The scientific study of crystals and crystal formation is crystallography. The process of crystal formation via mechanisms of crystal growth is called crystallization or solidification. The word *crystal* is derived from the Ancient Greek word (*krustallos*), meaning "rock-crystal" but also "ice", from (*kruos*), "icy cold, frost" The word once referred particularly to quartz, or "rock crystal".

Most metals encountered in everyday life are polycrystals. Crystals are often symmetrically intergrown to form crystal twins.



Halite (sodium chloride) - a single, large crystal.

The process of forming a crystalline structure from a fluid or from materials dissolved in the fluid is often referred to as crystallization. In the old example referenced by the root meaning of the word crystal, water being cooled undergoes a phase change from liquid to solid beginning with small ice crystals that grow until they fuse, forming a polycrystalline structure. The physical properties of the ice depend on the size and arrangement of the individual crystals, or grains, and the same may be said of metals solidifying from a molten state.

Which crystal structure the fluid will form depends on the chemistry of the fluid, the conditions under which it is being solidified, and also on the ambient pressure. While the cooling process usually results in the generation of a crystalline material, under certain conditions, the fluid may be frozen in a noncrystalline state. In most cases, this involves cooling the fluid so rapidly that atoms cannot travel to their lattice sites before they lose mobility. A noncrystalline material, which has no long-range order, is called an amorphous, vitreous, or glassy material. It is also often referred to as an amorphous solid, although there are distinct differences between crystalline solids and amorphous solids: most notably, the process of forming a glass does not release the latent heat of fusion.

Crystalline structures occur in all classes of materials, with all types of chemical bonds. Almost all metal exists in a polycrystalline state; amorphous or single-crystal metals must be produced synthetically, often with great difficulty. Ionically bonded crystals can form upon solidification of salts, either from a molten fluid or upon crystallization from a solution. Covalently bonded crystals are also very common, notable examples being diamond, silica, and graphite. Polymer materials generally will form crystalline regions, but the lengths of the molecules usually prevent complete crystallization. Weak van der Waals forces can also play a role in a crystal structure; for example, this type of bonding loosely holds together the hexagonal-patterned sheets in graphite.

Most crystalline materials have a variety of crystallographic defects. The types and structures of these defects can contain a profound effect on the properties of the materials. Since the initial discovery of crystal-like individual arrays of atoms that are not regularly repeated, made in 1982 by Dan Shechtman, the acceptance of the concept and the word quasicrystal have led the International Union of Crystallography to redefine the term crystal to mean "any solid having an essentially discrete diffraction diagram", thereby shifting the essential attribute of crystallinity from position space to Fourier space. Within the family of crystals one distinguishes between traditional crystals, which are periodic, or repeating, at the atomic scale, and a periodic (incommensurate) crystals which are not. This broader definition adopted in 1996 reflects the current understanding that microscopic periodicity is a sufficient but not a necessary condition for crystals.

While the term "crystal" has a precise meaning within materials science and solid-state physics, colloquially "crystal" refers to solid objects that exhibit well-defined and often pleasing geometric shapes. In this sense of the word, many types of crystals are found in nature. The shape of these crystals is dependent on the types of molecular bonds between the atoms to determine the structure, as well as on the conditions under which they formed. Snowflakes, diamonds, and table salt are common examples of crystals.

Some crystalline materials may exhibit special electrical properties such as the ferroelectric effect or the piezoelectric effect. Additionally, light passing through a crystal is often refracted or bent in different directions, producing an array of colors; crystal optics is the study of these effects. In periodic dielectric structures a range of unique optical properties can be expected as seen in photonic crystals.

The shapes of crystals depend on both the internal symmetry of the material and on the relative growth rate of the faces. In general, the faces of the crystal that grow most rapidly are those to which the crystallizing particles are bound most securely. These rapidly growing faces are usually the smaller, less well developed faces. The larger faces are usually associated with directions in the crystal where there are only weak intermolecular interactions.

All crystallization methods change the physical state of a material by transforming the system from some non-equilibrium state toward an equilibrium state. Crystallization methods may be separated into two broad categories based upon how the system performs this transformation. Concentration gradient methods typically involve concentrating the sample by either removal of solvent or transport of the material to another solvent system in which the material is less soluble. Thermal gradient methods rely upon the fact that crystals form when a material is cooled.

The choice of crystallization method for a particular sample depends greatly upon the physical and chemical properties of the sample. Properly choosing the best solvents, crystallizing agents, and temperatures is essential to producing top quality crystals.

2.2 Crystallography

Crystallography is the experimental science of determining the arrangement of atoms in solids. The word "crystallography" is derived from the Greek words *crystallon* = cold

drop / frozen drop, with its meaning extending to all solids with some degree of transparency, and *grapho* = write. Before the development of X-ray diffraction crystallography, the study of crystals was based on the geometry of the crystals. This involves measuring the angles of crystal faces relative to theoretical reference axes (crystallographic axes), and establishing the symmetry of the crystal in question. The former is carried out using a goniometer. The position in 3D space of each crystal face is plotted on a stereographic net, e.g. Wulff net or Lambert net. In fact, the pole to each face is plotted on the net. Each point is labelled with its Miller index. The final plot allows the symmetry of the crystal to be established.

Crystallographic methods now depend on the analysis of the diffraction patterns that emerge from a sample that is targeted by a beam of some type. The beam is not always electromagnetic radiation, even though X-rays are the most common choice. For some purposes electrons or neutrons are used, which is possible due to the wave properties of the particles. Crystallographers often explicitly state the type of illumination used when referring to a method, as with the terms *X-ray diffraction*, *neutron diffraction* and *electron diffraction*.

These three types of radiation interact with the specimen in different ways. X-rays interact with the spatial distribution of the valence electrons, while electrons are charged particles and therefore feel the total charge distribution of both the atomic nuclei and the surrounding electrons. Neutrons are scattered by the atomic nuclei through the strong nuclear forces, but in addition, the magnetic moment of neutrons is non-zero. They are therefore also scattered by magnetic fields. When neutrons are scattered from hydrogen-containing materials, they produce diffraction patterns with high noise levels. However, the material can sometimes be treated to substitute hydrogen for deuterium. Because of these different forms of interaction, the three types of radiation are suitable for different crystallographic studies.

2.3 Crystallography in Materials Engineering

Crystallography is a tool that is often employed by materials scientists. In single crystals, the effects of the crystalline arrangement of atoms is often easy to see macroscopically, because the natural shapes of crystals reflect the atomic structure. In addition, physical properties are often controlled by crystalline defects. The

understanding of crystal structures is an important prerequisite for understanding crystallographic defects. Mostly, materials do not occur in a single crystalline, but polycrystalline form, such that the powder diffraction method plays a most important role in structural determination.

A number of other physical properties are linked to crystallography. For example, the minerals in clay form small, flat, plate like structures. Clay can be easily deformed because the plate like particles can slip along each other in the plane of the plates, yet remain strongly connected in the direction perpendicular to the plates. Such mechanisms can be studied by crystallographic texture measurements.

In another example, iron transforms from a body-centered cubic (bcc) structure to a face-centered cubic (fcc) structure called austenite when it is heated. The fcc structure is a close-packed structure, and the bcc structure is not, which explains why the volume of the iron decreases when this transformation occurs.

Crystallography is useful in phase identification. When performing any process on a material, it may be desired to find out what compounds and what phases are present in the material. Each phase has a characteristic arrangement of atoms. Techniques like X-ray diffraction can be used to identify which patterns are present in the material, and thus which compounds are present (note: the determination of the "phases" within a material should not be confused with the more general problem of "phase determination," which refers to the phase of waves as they diffract from planes within a crystal, and which is a necessary step in the interpretation of complicated diffraction patterns).

Crystallography covers the enumeration of the symmetry patterns which can be formed by atoms in a crystal and for this reason has a relation to group theory and geometry.

Chapter Review Questions

1. Define a **crystal** or **crystalline solid**
2. What do you understand by the term crystallography?
3. What is crystallization?
4. What is an amorphous, vitreous, or glassy material?
5. Give two examples of Covalently bonded crystals

Suggested References

- i. Crystallography: A Treatise On The Morphology Of Crystals (1895)
Author: Nevil Story-Maskelyne 2008 Publisher: Kessinger Publishing

3.0 MAGNETISM

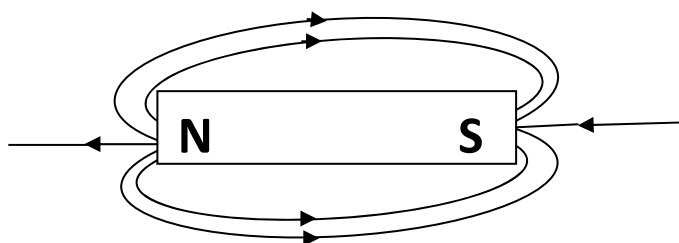
Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Describe the concept of Magnetism
- ii). Explain the polarity of a magnet
- iii). Draw magnetic field lines for magnets

Introduction

A magnet has two poles, called North and South. A magnetic field is a region around the magnet where magnet materials experience a force.



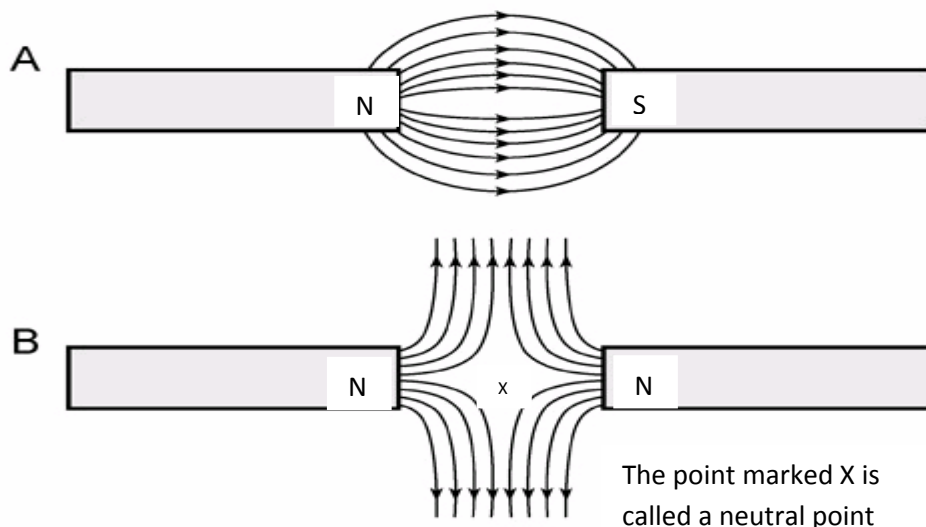
There are mainly three magnetic elements, iron, nickel and cobalt. In practice you will only use iron, or steel which is an alloy of iron. The shape of the magnetic field around the magnet is shown by lines. Arrows on the lines point away from North and towards South to show the direction of the magnetic field. The lines of magnetic force do not cross each other. The closer together the lines are, the stronger the field is. You need to know the shape of the magnetic field for a bar magnet, poles which attract and poles which repel. The magnetic field can be seen by placing the magnet under a piece of paper with small iron filings on top. The filings line up in the shape of the field. The direction of the arrows can be seen by placing a compass in the field. The compass points in the direction of the arrows, away from North and towards South. This means that when a compass points to the Earth's North Pole, there must be a magnetic South Pole up there.

Magnetic Poles.

The forces between North and South poles are similar to the forces between electrostatic charges. Unlike poles attract (pull towards each other), Like poles repel (push away from each other). This means that two North poles will repel each other, two South poles will repel each other, one North pole and one South pole will attract each other.

This is the basic law of magnetism. The further apart the poles, the weaker the forces between them. You need to know the shape of the magnetic field for poles which attract and poles which repel. Notice that the lines of magnetic force between the poles are parallel.

Two like poles will repel each other. These may be two North poles or two South poles, they will both have the same magnetic field shape. The region in the centre of the poles shown by the X has no magnetic field, as the two opposing fields cancel each other out.



When a current flows through a conductor, it produces a magnetic field. The shape of the magnetic field depends on the shape of the conductor. You need to know the shape of the magnetic field for a straight wire and a coil. Other arrangements have been left as an assignment for the learner.

The magnetic field around a straight wire is circular, at right angles to the wire. You can work out the direction of the field using your right clenched fist. Point your thumb upwards in the same direction as the current. The direction of the field is the same direction in which your fingers curl. Reversing the direction of the current will reverse the magnetic field direction.



Chapter Review Questions

1. Draw the magnetic field lines around the following the arrangement below.
2. Name the three main magnetic elements?
3. State the basic law of magnetism

Suggested References

- i. Electricity And Magnetism Author: Mahajan : 1988 Publisher: Tata Mgraw Hill
- ii. Electricity and Magnetism (Hardcover) by Seema Singh Publisher: Campus Books International (2009)
- iii. Free online books on http://web.mit.edu/6.013_book/www/book.html

4.0 CURRENT AND RESISTANCE

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). State ohm's law
- ii). Describe the relationship between Current and Resistance
- iii). Calculate combined resistance in Parallel and Series Connections of resistors

Ohm's Law

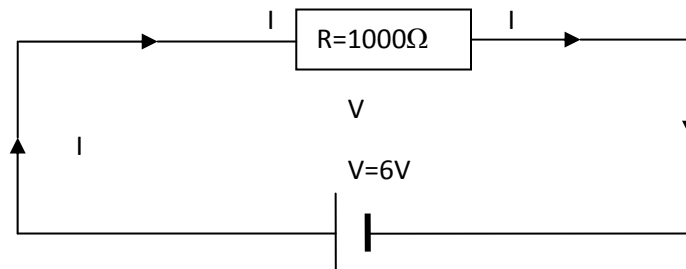


Figure 1

One thing we need to be able to do when we see a schematic circuit diagram is to perform mathematical calculations to define the precise behavior of the circuit. All information required to perform such calculations should be included on the schematic diagram itself. That way the information is all in one place, and any required detail can be determined readily.

Consider the basic circuit shown in figure 1. We know immediately that the battery voltage is 6 volts and that the resistor is rated at 1000Ω . Now, how can we determine how much current is flowing through this circuit?

The relationship between voltage V , current I , and resistance R is given as $V = I \times R$.

Using basic algebra we can also rewrite this as:

$$R = V \div I \text{ and also } I = V \div R$$

These three equations describe *Ohm's Law*, which defines this relationship. *Ohm's law* states that *provided physical quantities like temperature are kept constant, the current flowing through a conductor is directly proportional to voltage drop across it*. The ratio $\frac{V}{I}$ is

the resistance R of the conductor. Resistance is measured in Ohms Ω . (from Ohm's law), voltage is measured in Volts, V and current is measured in Amperes, A .

In the circuit in figure 1, we see that $V = 6$ volts and $R = 1000 \Omega$. To find the current flowing in this circuit, we must select the equation that solves for I . Using that equation, we note that:

$$I = V \div R$$

$$I = 6v \div 1000\Omega$$

$$I = 0.006 \text{ ampere (A)} = 6 \text{ milliamperes (mA)}$$

All calculations involving Ohm's Law are handled in exactly the same way. If the circuit gets complex, the calculations must be tailored to match. However, each calculation is still just this simple.

Demonstrations: Light bulbs in series and parallel connection.

Perform this demonstration.

Connect two light bulbs and two cells as shown. First connect the two bulbs in series as shown in the diagram (figure 2).

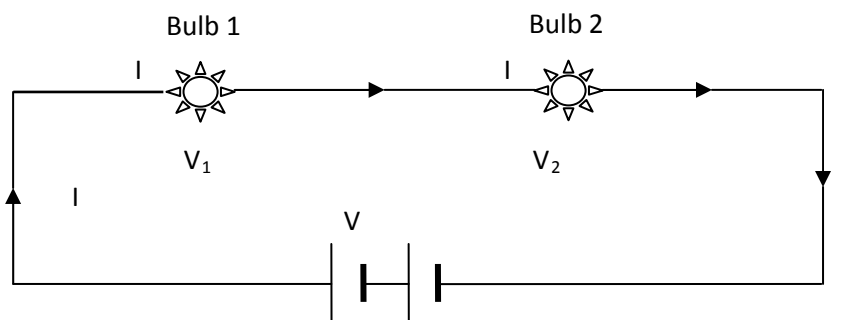


Figure 2. Bulbs connected in series

Notice the brightness of the bulbs. Now connect the same bulbs with the same dry cells in parallel as in figure 3.

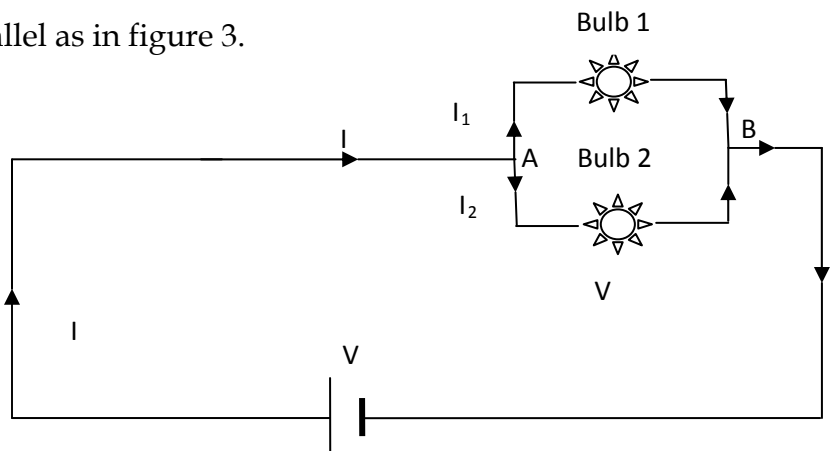


Fig 3. Bulbs connected in parallel.

Notice the brightness of the bulbs. You have noticed that when bulbs are connected in series, they have less brightness as compared to when they are connected in parallel. The bulbs can be taken as resistors. When resistors are connected in series, the total resistance for the combination is more than the resistance of any one of the individual resistors. The high resistance resists the flow of current in the bulbs, hence the less brightness.

In the parallel connection, you have noted that the same bulbs light brightly. This is because in parallel connection, the total resistance is less than the resistance of the individual resistors. The less resistance allows more current to flow through the bulbs hence the bulbs light brightly.

Using the examples of the bulbs, we can now see how we add resistance in series and in parallel.

We've looked at Ohm's Law for a circuit containing a single resistor, and found it to be quite simple. But what happens if we have multiple resistors in the circuit? How can we deal with that, and still perform accurate calculations on the overall circuits?

On this section, we'll consider a circuit using three resistors, connected so that the same current flows through all of them, and the three resistors must share the applied voltage. This is known as a *series* connection.

Series connection of resistors.

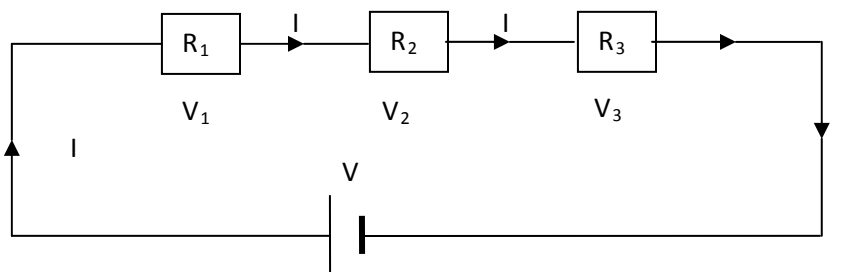


Figure 1.1: Resistors R_1 , R_2 and R_3 in a Series Connection.

In a series connection, resistors are connected in a straight line and have the same current through them.

Look at the three resistors in series. The current going through each resistor is the same so,

$V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$. But the cell is producing a voltage V . thus,

$$V=V_1+V_2+V_3 \text{ which means that}$$

$$V=IR_1+IR_2+IR_3 \text{ and since } I \text{ is common, it implies that}$$

$V=I(R_1+R_2+R_3)$ but $V=IR$ (from Ohms law), meaning that the total resistance R_T for a series combination of resistors is given by $R_T=R_1+R_2+R_3$. The equation holds for n resistors. Thus $R_T=R_1+R_2+R_3+\dots\dots R_n$

Example1 : (a) What is the current flowing through a 3Ω , 6Ω , and 9Ω resistor in series when connected to a 12 V battery? (b) What is the voltage drop across each resistor?

$$(a) V = I(R_1 + R_2 + R_3) = I(18\Omega)$$

$$I = V/(18 \Omega) = 12V/18\Omega = 0.67 \text{ Amps}$$

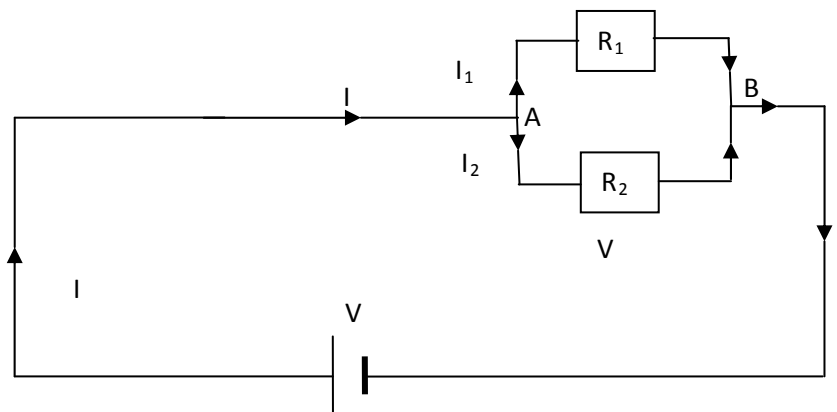
The equivalent resistance is 18Ω which is *greater* than the resistance of any single resistor. We draw *equivalent* circuits with fewer resistors.

(b) Since $V = IR$ and the current is the same for each one, the voltage drop across each resistor is given as: $V_1 = IR_1 = (0.67A)(3\Omega) = 2 \text{ V}$, $V_2 = IR_2 = (0.67A)(6\Omega) = 4 \text{ V}$, $V_3 = IR_3 = (0.67A)(9\Omega) = 6 \text{ V}$

Note how $V_1 + V_2 + V_3 = 12 \text{ V}$ which is the voltage across the battery.

Parallel Wiring

In a parallel circuit the voltage drop across each resistor is the same, Consider the parallel combination of two resistors R_1 and R_2 below.

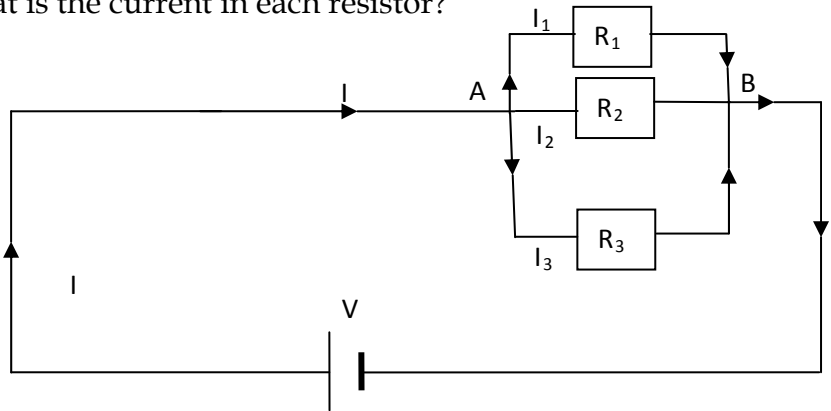


So, at the junction A, current I subdivides into I_1 through resistor R_1 and I_2 through resistor R_2 . Since the two resistors are in parallel, they have equal voltage drop, V . this means that the total current $I = I_1 + I_2$, $I = V/R_1 + V/R_2$ from Ohm's law, $V=IR$, $I=V(1/R_1 + 1/R_2)$, $I= V(1/R_T)$

In general, $1/R_T = 1/R_1 + 1/R_2 + \dots 1/R_n$ for n resistors in parallel

Example2: (a) consider the resistors in example 1. What is the total current in the circuit if a 3Ω , 6Ω , and 9Ω resistor are all connected in parallel to a 12 V battery?

(b) What is the current in each resistor?



$$(a) \frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{3\Omega} + \frac{1}{6\Omega} + \frac{1}{9\Omega}$$

$$\frac{1}{R_p} = \frac{11}{18\Omega}$$

$$R_p = \frac{18}{11} \Omega = 1.6 \Omega$$

Note how the resistance of resistors in parallel is *less* than the resistance of any single resistor.

$$I = V/(1.6 \Omega) = 12\text{V}/1.6\Omega = 7.3 \text{ A}$$

(b) For each resistor $V = IR$, and V is 12 V , so:

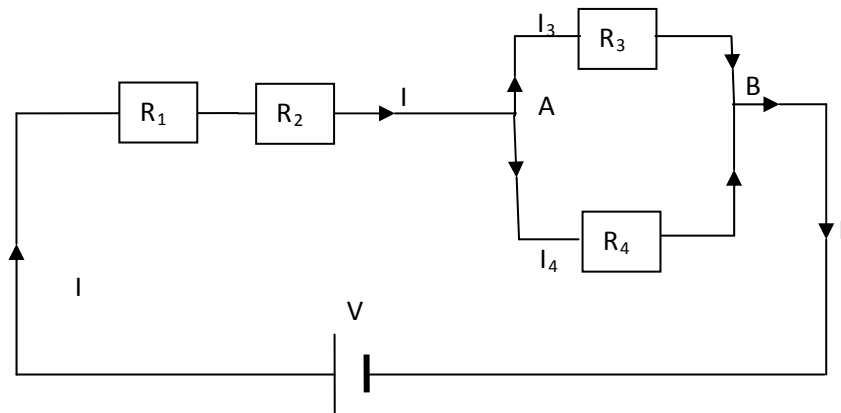
$$I_1 = V/R_1 = 12\text{V}/3\Omega = 4 \text{ A}$$

$$I_2 = V/R_2 = 12\text{V}/6\Omega = 2 \text{ A}$$

$$I_3 = V/R_3 = 12\text{V}/8\Omega = 1.3 \text{ A}$$

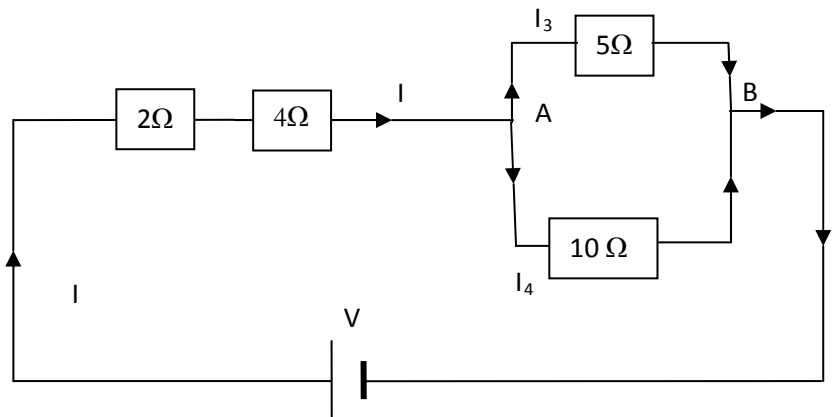
Note how $I_1 + I_2 + I_3 = 7.3 \text{ Amps}$, which is the total current.

4.1 Parallel and Series Connections Together (Equivalent Circuits)



If we have many resistors in parallel and in series, then we take a step-by-step process to reduce this to an equivalent circuit.

EXAMPLE3: What is the equivalent resistance of this circuit?

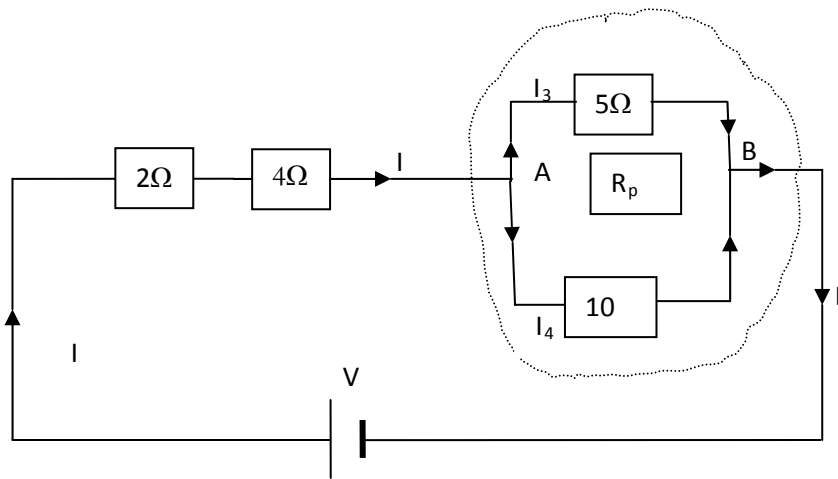


$$\begin{aligned} R_1 &= 2\Omega & R_2 &= 4\Omega \\ R_3 &= 5\Omega & R_4 &= 10\Omega \end{aligned}$$

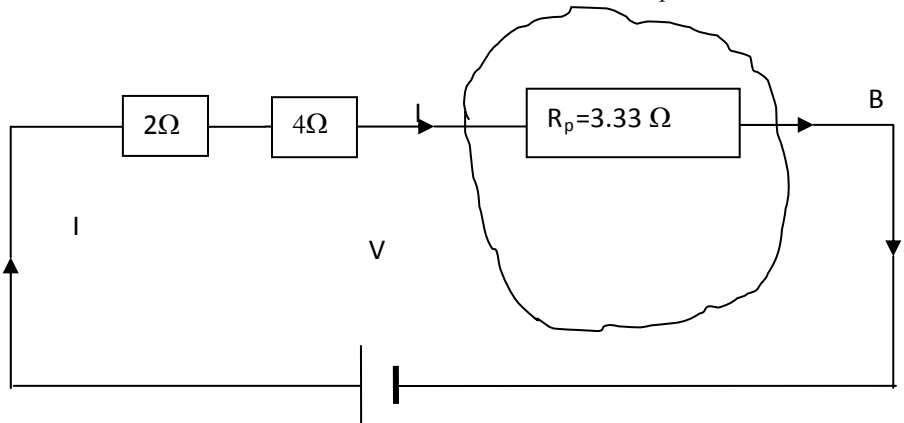
First look at R_3 and R_4 . These two resistors are in parallel because any current flow has a choice of which resistor to go through. Thus,

$$\frac{1}{R_p} = \frac{1}{R_3} + \frac{1}{R_4} = \frac{1}{5} + \frac{1}{10} = \frac{2+1}{10} \Omega = \frac{3}{10}. \text{ This implies that } \frac{1}{R_p} = \frac{3}{10} \Omega \text{ and thus } R_p = \frac{10}{3} \Omega$$

And we have that the starting circuit is equivalent to one that looks like the following.



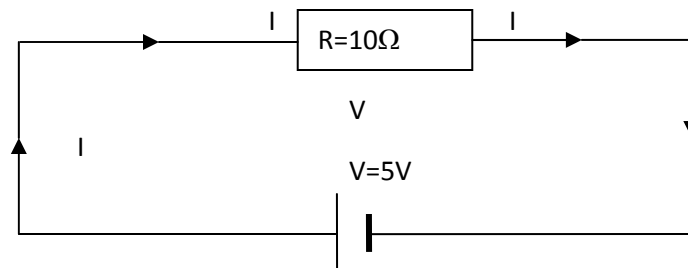
The combined resistance for R_3 and R_4 is now R_p as shown below.



Now we can easily see that R_1 , R_2 , and R_p are in series because any current must flow through each resistor (or resistor branch).

$$R_T = 2 + 4 + 3.33 = 9\Omega$$

We can put many resistors together and often still reduce them to a single equivalent resistor.



Chapter Review Questions

1. State ohm's law
2. Describe the formula that defines the relationship between Current and Resistance
3. Find the current flowing through the circuit below.

Suggested References

- i. Electricity And Magnetism Author: Mahajan : 1988 Publisher: Tata Mgraw Hill
- ii. Electricity and Magnetism (Hardcover) by Seema Singh Publisher: Campus Books International (2009)
- iii. Free online books on http://web.mit.edu/6.013_book/www/book.html

5.0 MAINS ELECTRICITY

Learning Objectives.

By the end of this section, the learner should be able to:-

- iv). Explain the source of Mains Electricity
- v). Explain the transmission of Mains Electricity
- vi). Explain the Electromagnetic induction

Introduction

The electricity which comes into your house through the wall sockets (called Mains Electricity) is different from the electricity which comes from cells in two important ways.

1. It is an alternating current (a.c.)
2. It is at a much higher voltage (it can kill you!).

Mains electricity in the UK is supplied at 240 Volts, in the USA it is 110 Volts and in Kenya it is supplied at 240volts. A cell or battery is typically 1.5 to 12 Volts, which is much less dangerous. We are familiar with direct current circuits where the electrons flow from one side of the cell, through all the components and return to the other side of the cell. With alternating current (symbol a.c.) the electrons first start to flow in one direction until the current reaches a maximum value, then the current slows down and stops. The electrons then start to flow in the opposite direction until the current reaches the same maximum value (but it is now given a minus sign to show it is in the opposite direction), then the current again slows down and stops. This whole cycle then repeats itself over and over again. The number of cycles in one second (called the frequency) is given in a unit called Hertz (symbol Hz) where 1 Hz = 1 cycle per second. Mains electricity in the Kenya is supplied at 50Hz (50 cycles per second).

If an alternating current supply is connected to a cathode ray oscilloscope (called a CRO), the display shows a wave as the current changes from maximum positive to maximum negative. Two complete cycles of the wave are shown on the CRO. Where the wave goes above the zero line, the current flows forwards, where the wave goes below the zero line the current flows backwards. If a direct current supply is connected to the CRO, the display shows a single straight line which represents a constant current in one direction only. There are a large number of appliances which use mains

electricity. An appliance is a useful arrangement of electrical components. These include cookers, heaters, lighting, TV, radio, hi-fi and computers.

The first two, cookers and heaters, can use other types of energy, for example gas. Lighting today is almost entirely powered by electricity but in the past, gas lamps and candles were used. The alternating current of mains electricity can be used directly to power cookers, heaters and lighting, since they all depend on the heating effect of current passing through a wire. The last four, TV, radio, hi-fi and computers, must use direct current electricity. The alternating current of mains electricity must first be turned into direct current by using an arrangement of diodes, which allow electric current to flow in one direction only. The voltage is usually stepped down to 12 volts or less by using a suitable transformer.

The Live wire is connected directly to the generators of the electricity supply company. NEVER touch this wire, it can kill you!! The Neutral wire returns the electricity to the generator after it has passed through the appliance, to complete the circuit. NEVER touch this wire!! In a complete circuit, it carries the same electricity as the Live wire. The Earth wire usually carries no electricity, it is there as a safety device. If something in the appliance goes wrong, or it is wired incorrectly, then the Earth wire carries the same electricity as the Live wire. To be completely safe, NEVER touch this wire either!!

Each wire has its own coloured insulation, to show if it is Live, Neutral or Earth. The wire inside is made of copper, which is an excellent conductor. The copper wire is held inside the brass pin of the plug by a small screw. Mains electricity is safe to use if we avoid touching a Live conductor, and the current is kept down to a safe level.

Safety measures include

- i). Insulation
- ii). Double Insulation
- iii). Earthing
- iv). Fuses
- v). Circuit Breakers

Any metal is a conductor of electricity. Any non-metal is an insulator, with the exception of graphite which conducts electricity because of its unusual molecular structure. The wires which we use to conduct electricity are made of a high purity

copper metal, which is an excellent conductor. The insulator which covers the wires is a polymer called PVC (often just called "plastic"). It is an excellent insulator, flexible enough to bend around corners and cheap to make. Insulation can become unsafe if it is damaged or wet because impure water will conduct electricity.

Some appliances are double insulated.

An appliance which is double insulated has the whole of the inside contained in plastic, underneath an outer casing. If anything goes wrong with the appliance, no Live conductor can touch the outer casing because of the insulating plastic.

Appliances which are double insulated include electric drills and hairdryers. The Earth wire usually carries no electricity, it is connected to the metal case on the inside of the appliance. If something goes wrong inside the appliance and the Live wire touches the metal case, then the Earth wire acts like a Neutral wire and completes the circuit for the electricity. A very large current suddenly flows because the metal case has little resistance. This large current blows the fuse in the plug and disconnects the appliance from the power supply.

The Live wire is always connected to the Live pin of the plug by a fuse. The fuse has a rating printed on the outside in amps. If the current going through the fuse rises above its rated value, then the fuse "blows" (it melts) which turns off the appliance. For example, if the fuse says 5 amps, then a current greater than 5 amps will blow the fuse. Fuses are given different colours for different ratings. This is called colour coding.

A 2 amp fuse is blue, 3 amp is red, 5 amp is black (or very dark blue), 13 amp is brown. A fuse has its own circuit symbol. To understand how a fuse works in more detail, we must look at the Heating Effect of Current. From Ohm's Law, it was mentioned that a component usually gets hotter when a current flows through it.

The wires which link the components of a circuit also get hotter with increasing current. The more current passing through the wire, the hotter it gets. A very hot wire might melt or set fire to the insulation which covers it. A fuse is a thin piece of wire which is manufactured to melt when a certain current (called its rating) passes through it.

In this way the fuse protects the rest of the circuit from the damage caused by too high a current. To find the reason why current has a heating effect, we must look at the resistance of the wire itself.

Chapter Review Questions

1. Explain the sources of Mains Electricity in Kenya
2. Explain the Electromagnetic induction
3. Describe Safety measures include in mains electricity
4. What is a fuse?
5. Why are fuses connected to the live wire?

Suggested References

- i. Free online books on http://web.mit.edu/6.013_book/www/book.html
- ii. College physics fifth edition by serway and faughn, 1999, saunders college publishing

6.0 ELECTROMAGNETIC INDUCTION

Learning Objectives

By the end of this section, the learner should be able to:-

Explain the Electromagnetic induction

- i). Describe the working principle of a transformer
- ii). Use the transformer equation to solve problems
- iii). Describe the transmission of mains electricity

Introduction

The term electromagnetic suggest the existence of electric and magnetic properties of a conductor. Induction comes from the word induce. In electromagnetic induction, we will deal with electricity that results from induction of current due to magnetic field around the conductor or coil.

Electromagnetic Coil.

The magnetic field around a straight wire is not very strong. A strong field can be made by coiling the wire around a piece of soft iron. This electromagnet is sometimes called a solenoid. The shape of the magnetic field is the same as a bar magnet. The soft iron inside the coil makes the magnetic field stronger because it becomes a magnet itself when the current is flowing. Soft iron is used because it loses its magnetism as soon as the current stops flowing. Soft iron is said to form a temporary magnet. In this way, the electromagnet can be switched on and off by turning the electricity on and off.

Steel forms a permanent magnet. If steel was used inside the coil, it would continue as a magnet after the electricity was switched off. It would not be useful as an electromagnet. Permanent magnets are needed for electric motors, generators, loudspeakers and microphones.

The strength of the magnetic field around the coil can be increased by:-

- 1. Using a soft iron core (core means middle bit).
- 2. Using more turns of wire on the coil.
- 3. Using a bigger current.

Reversing the direction of the current will reverse the magnetic field direction. An electromagnet is used in the electric bell, relay, circuit breaker, loudspeaker and microphone.

6.1 The Transformer.

A transformer is made from two coils, one on each side of a soft iron core. It can decrease the voltage (called a step down transformer) or increase the voltage called a step up transformer. Alternating current is passed through the primary coil (the input) which creates a changing magnetic field in the iron core. The changing magnetic field then induces alternating current of the same frequency in the secondary coil (the output). A step up transformer has more turns of wire on the secondary coil, which makes a larger induced voltage in the secondary coil. It is called a step up transformer because the voltage output is larger than the voltage input. If the secondary coil has twice as many turns of wire then the output voltage will be twice the input voltage.

6.1.1 Transformer Equation.

This equation is important! The transformer equation relates the number of turns of wire to the difference in voltage between the primary and secondary coils.

$$V_P / V_S = N_P / N_S$$

Where V_P is the voltage in the primary coil. V_S is the voltage in the secondary coil. N_P is the number of turns of wire on the primary coil. N_S is the number of turns of wire on the secondary coil.

There are two vital points to remember.

1. Transformers only work with alternating current. Using direct current will create a magnetic field in the core but it will not be a changing magnetic field and so no voltage will be induced in the secondary coil.
2. Using a step up transformer to increase the voltage does not give you something for nothing.

As the voltage goes up, the current goes down by the same proportion. The power equation shows that the overall power remains the same,

$$P = V \times I \quad \text{Power} = \text{Voltage} \times \text{Current}.$$

In reality, the power output is always less than the power input because the changing magnetic field in the core creates currents (called eddy currents) which heat the core. This heat is then lost to the environment, it is wasted energy.

A step down transformer has less turns of wire on the secondary coil, which makes a smaller induced voltage in the secondary coil. It is called a step down transformer because the voltage output is smaller than the voltage input. If the secondary coil has half as many turns of wire then the output voltage will be half the input voltage. Decreasing the voltage does not decrease the power. As the voltage goes down, the current goes up.

6.2 Transmission of Mains Electricity

Electricity is generated on a large scale at power stations and then transmitted through cables (called the National Grid) to factories and homes. Copper cables carrying the electricity are buried in the ground or aluminium cables are suspended from pylons. Aluminium is used because it has a low density and can safely be suspended from inexpensive thin pylons. Pylons have the disadvantage that they look ugly on the landscape but have the advantage of easy access to the cables for maintenance and repair. Transmission using pylons is cheaper than burying cables underground. Transformers are used to produce a very high voltage for the transmission of electricity, to minimize energy loss.

6.2.1 Energy Loss during Power Transmission

A generator at a power station might produce electricity with a voltage of 25,000V and a current of 8,000A. Such a large current would cause the cables of the National Grid to get hot because of the heating effect of current. Energy would then be lost as heat to the atmosphere and by the time that the electricity had traveled from the power station through the cables to the towns and factories. Much of the original energy would be lost as heat. To reduce the energy loss, a step up transformer at the power station is used to raise the voltage to 400,000V. This is 16 times the input voltage of 25,000V.

The power equation tells us that if the voltage has gone up by 16 times, then the current must be reduced by 16 times. The original current of 8,000A is reduced to $8000 \div 16 = 500\text{A}$. This current is still high but the thickness of the cables means that the heating

effect is minimal. At factories, a step down transformer reduces the voltage to 33,000V. For houses, a step down transformer reduces the voltage to 240V.

The electricity produced by power stations is alternating current because

1. It is easy to generate alternating current.
2. Transformers will not work with direct current.

Chapter Review Questions

1. Why is Steel not suitable for use in an electromagnet
2. How can the strength of an electromagnet be increased?
3. State two uses of an electromagnet
4. What is The Transformer?
5. What is the difference between a step up and a step down transformer?
6. Why is Aluminum is used in power cables?
7. Why is very high voltage used for transmission of electricity?

Suggested References

- i. College physics fifth edition by serway and faughn, 1999, saunders college publishing
- ii. Free online books on http://web.mit.edu/6.013_book/www/book.html

7.0 ELECTROSTATICS

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Discuss the concept of Electrostatics and Electrostatic Charge
- ii). Describe the behavior of Positive and Negative charges
- iii). Describe a Capacitor
- iv). Calculate combined capacitance in more than one capacitor

Introduction

7.1 Electrostatic Charge

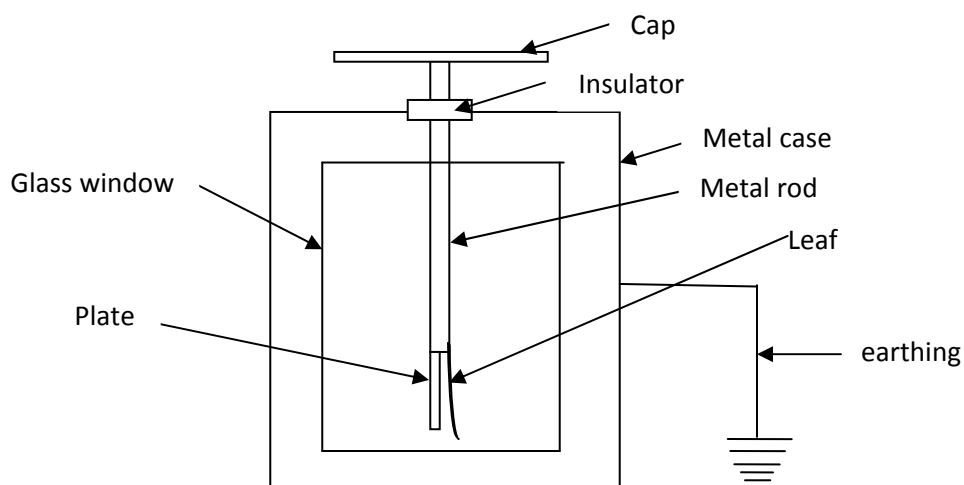
We are familiar with charge flowing through conductors, which we usually just call "electricity". Charge can also be present on insulators and because these materials do not allow the charge to flow, this is called electrostatic charge (static meaning it "stays still"). Materials which are insulators can be charged by friction. Insulators can transfer charge by friction. When the surface of one insulator rubs against another, electrons can be transferred. The insulator which gains electrons will get a negative charge, the insulator which loses electrons will get a positive charge. It is most important to know that it is only the negative electrons which can move. Positive charges (protons) cannot move because they are stuck inside the nuclei of the atoms of the material. For example, if polythene (a type of plastic) is rubbed with a dry cloth, electrons are transferred from the cloth to the polythene. The polythene gains electrons and becomes negatively charged, the cloth loses electrons and becomes positively charged. It is not possible to predict in advance which way the electrons will go for a certain material. The same cloth, when rubbed against acetate (a different type of plastic) will gain electrons and become negatively charged, leaving the acetate with a positive charge.

7.2 Attraction and Repulsion.

Opposite charges attract (pull towards each other), Like charges repel (push away from each other). This means that two positively charged things will repel each other, two negatively charged things will repel each other. One positively charged thing and one negatively charged thing will attract each other. The further apart the charged things are, the weaker the forces of attraction and repulsion are. You can show whether something is charged or not by using a gold leaf electroscope.

7.3 Gold Leaf Electroscope.

The electroscope is a very thin piece of gold foil (called gold leaf) fixed at the top to a piece of copper. The copper has a large round top, called the cap. The whole thing is put inside a glass case, to stop air blowing the delicate gold leaf around. The piece of copper goes through insulation in the top of the glass case, so that any charge on the gold leaf cannot escape.



Charge can be transferred to the electroscope by wiping the charged object across the cap. The charge flows over the conducting copper and gold, and the gold leaf rises as it is repelled by having the same charge as the copper.

Neutral Objects.

We know that like charges repel and unlike charges attract but what about neutral (uncharged) objects? It is found that a charged object (whether positive or negative) may attract uncharged objects, for example a charged plastic comb will pick up small pieces of paper. You can try this yourself. Just charge the comb by combing your hair! (hair is a good insulator). What is happening? It is thought that when a negatively charged object gets close to an uncharged one, electrons in the uncharged object are repelled, leaving the positive charges behind. These positive charges are then attracted to the negatively charged object. If the rod was positively charged, then it would attract electrons in the neutral object and so the two would still attract each other. The small number of charges shown is an over-simplification since in reality there are millions and millions of atoms in a tiny piece of paper, each with its own electrons and protons.

When we draw the rod with a few negative charges, it means that the rod has a few more negative than positive charges.

7.4 Electrostatic Shock.

If a high amount of charge builds up on an insulator, it can escape through a small distance in air to a neutral or oppositely charged object. You may have noticed that pulling off a jumper or shirt over your head can cause crackling. If the clothing is made from a synthetic fibre (a plastic material which is a good insulator) then charge is transferred as it rubs against your hair (also a good insulator). The crackling is the sound made by the charge jumping between the clothing and your hair through the air. Touching a car door or a radiator can sometimes give you a shock. If both the car seat and your clothing are made from a synthetic fibre, then one rubs against the other transferring charge as you step out of the car. The charge then jumps the small air gap between your finger and the car as you go to close the car door. This can feel unpleasant. Similarly, if both the carpet and your shoes are made from synthetic materials, then charge is transferred as you walk around. Touching a radiator will cause the charge to jump the small air gap between your finger and the radiator. If your clothing, carpet, shoes etc. are made from natural fibres then you are much less likely to get a shock. Natural fibres such as wool and cotton attract a small amount of moisture (water) to their surface and this moisture allows the material to conduct a little so the charge escapes before it can build up enough to jump through air. If the air itself is moist, the charge will also escape and no shock will occur. When charge jumps across a small air gap it causes a spark which can be dangerous. Lightning is a natural example of a huge charge jumping across a very large air gap, and we know how dangerous lightning can be.

7.5 Dangers of Electrostatic Charges.

When charge jumps across an airgap it causes a spark. The spark can ignite (set fire to) flammable liquid vapours and powders in pipes. Care must be taken to avoid sparks when putting fuel in cars or aircraft. The fuel itself is an insulator (a hydrocarbon) and charge can be transferred as it flows through a pipe if the pipe is also an insulator. This happens because there is friction between the fuel and the pipe. As the nozzle (the end)

of the pipe is brought close to the fuel tank, a spark can jump between the two igniting the fuel. This can cause a serious explosion, particularly with aircraft which are filled at very high speed. The spark can be avoided if the pipe nozzle is made to conduct by connecting an earthing strap to it and so any charge can be safely conducted away. An earthing strap connects the pipe to the ground (the Earth). In addition, a cable can connect the pipe to the fuel tank, so that there can be no difference in charge between them.

There is a very similar situation with powders in pipes. If the powder is an insulator then charge is transferred in the same way as fuel in pipes. A spark can ignite a powder and cause an explosion just like a flammable liquid vapour. The solution is the same. Use earthing straps between the pipe and earth.

7.6 Uses of Electrostatic Charges.

Electrostatic charge is used in paint spraying, inkjet printers, photocopiers, and the removal of pollution from industrial chimneys. Millions of cars are made each year and the car bodies must all be painted to prevent them from going rusty. The paint is sprayed onto the car bodies and the process is made more efficient by using electrostatic charge. The paint spray goes past a high voltage positive needle as it leaves the spray gun and the tiny droplets of paint pick up a positive charge. Remember, they do this by losing negative electrons. It is only the electrons which can move. The car body is then given a high voltage negative charge which attracts the positively charged paint droplets. This is good for two reasons. Firstly, the paint droplets spread out more as they leave the gun. This happens because they all get the same positive charge and so they all repel each other. This is better than coming straight out of the gun as the paint will cover a wider area more evenly. Secondly, the paint droplets are attracted to the negative metal car body, and so less paint will be wasted on the floor or the walls of the paint shop.

7.6.1 Inkjet Printer.

An inkjet printer uses electrostatic charge to direct the ink to the correct place on the page. Coloured ink is passed through a very small hole (called a nozzle) which separates the ink into many tiny droplets. The tiny droplets are given an electrostatic

charge. The direction in which the charged ink droplets move can be controlled by electrically charged metal plates. A voltage on the plates means that the charged ink droplets will be attracted to one plate and repelled by the other. This is very similar to an "electron gun" or "cathode ray oscilloscope" where an electron beam is directed to a particular place on a screen. The ink droplets have a positive charge. They are attracted to the negative plate and repelled by the positive plate. By controlling the voltage on the plates a particular ink drop can be precisely positioned on the paper. There are many nozzles, and the final picture is made up from a very large number of coloured ink drops, each in exactly the right place for the image.

7.6.2 Photocopier.

A photocopier uses electrostatic charge to produce a copy. The original (the page you want copied) is placed onto a sheet of glass. An image of this page is projected onto a positively charged drum. The drum has a coating which conducts electricity when light falls on it. The parts of the drum which are lit by the projected image lose their electrostatic charge when they start to conduct. A black powder (called toner) is negatively charged. The toner is attracted to the positively charged parts of the drum. The drum rotates and rolls against a piece of copier paper. The toner is transferred from the drum to the paper making a black and white image of the original. Finally, the paper is heated which makes the toner stick to it. This is called "fixing" the image. When you use a photocopier you can feel that the copier paper is still warm.

7.7 Electric Charges

The Greek philosopher Thales observed that if a person rubbed amber (a petrified tree resin) with wool or fur, then the amber would attract small pieces of leaf or cloth. Our word "electricity" comes from the Greek *elektron* - which means "amber."

Characteristics

7.8 Positive and Negative, Attractive and Repulsive

There are two kinds of charge. Benjamin Franklin named them positive and negative and defined the charge on the rubbed glass rod to be positive.

Like Charges Repel and Unlike Charges Attract. This is one case where the phrase "Opposites Attract" is absolutely true. When two things are attracted this could occur for

one of two reasons. Either they are of different charges, or one is charged and the other is attracted to it due to an **induced polarization** of the charge. Induced polarization is when the charge within an object separates, so part of the object is slightly positively charged and some of the object is slightly negatively charged, even though the whole object has no net charge.

7.9 Conservation of Charge

We don't create or destroy charge, just transfer it. In accelerators it can be created in pairs so that the total charge is always the same. During any process, the net electric charge of an isolated system remains constant. So if a charged object touches an uncharged object, some of the extra charge from the charged object transfers to the uncharged object. But the total charge stays the same. If the two objects are identical in composition, size, and shape, then after touching each other they will both have exactly the same amount of charge on them.

Charges that we can observe are due to atomic electrons and protons. Electrons are negatively charged and protons are positively charged. Electrons can move from one atom to another, so a negative charge means an excess of electrons and a positive charge is a deficiency of electrons. Ions are produced when an atom loses or gains electron (s). The value of quantized charge is very small since $e = 1.60 \times 10^{-19}$ C. All charges come in integral multiples of e . We measure charge using the unit (SI) of Coulombs (C). An electron has a charge of $e = 1.60 \times 10^{-19}$ C, so there are $(1.60 \times 10^{-19} \text{ C})^{-1} = 6.25 \times 10^{18}$ electrons per Coulomb. Charge is usually measured in millicoulombs (mC) 1×10^{-3} or in microcoulombs (μC) 1×10^{-6} .

7.10 Conductors and Insulators

Why don't you stand outside during an electrical storm hold a long tall metal object? Conductors easily conduct electric charge. Insulators do not easily conduct electric charge. Metals are usually good conductors. Plastics, rubber and wood are usually insulators. Electrical cords illustrate this well. The metal inside is a good conductor. The rubber on the outside is a good insulator.

7.11 Charging a Body

What happens to multiple conductors and insulators next to each other? When they touch, charge is transferred from one object to the other so that if the objects are the

same shape and size, their charges equal each other. When they are brought near, their charge moves within the object so the object becomes electrically polarized, but charge does not transfer from one object to another. Consider an uncharged sphere. It is neutral thus has equal number of positive and negative charges. The charges are well distributed within the sphere. (Figure 1(a))

Figure 1(a) An Uncharged Sphere.

Charging a Sphere by Contact Method

Just as the word suggests, the contact method of charging a sphere involves touching an uncharged sphere with a negatively (-vely) charged rod. What happens is that the negative charges in the negatively charged rod neutralizes the positive charges in the uncharged sphere.

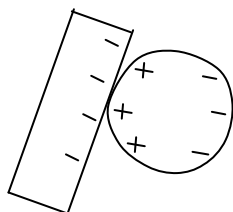
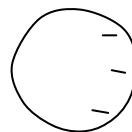


Figure (a)



(b)



(c)

The charges are then distributed within the conductor after the charging rod has been withdrawn. Charging a conductor by induction has been deliberately left as a task for the learner.

Chapter Review Questions

1. Draw and name the major features of a gold leaf electroscope
2. Electrostatic Shock.
3. Give some uses of electrostatic charges.
4. Differentiate between Conductors and Insulators
5. Charging a Sphere by Contact Method using a positively charged rod

Suggested References

- i. Ferroelectric Phenomena In Crystals: Physical Foundations Author: Strukov B. A. 1998
- ii. Understanding Physics Electricity & Magnetism, D C Pandey, 2009

8.0 CAPACITORS

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Describe a Capacitor
- ii). Calculate combined capacitance in more than one capacitor
- iii). Explain the types and uses of dielectrics used in capacitors

Introduction

In October 1745, Ewald Georg von Kleist of Pomerania in Germany found that charge could be stored by connecting a high voltage electrostatic generator by a wire to a volume of water in a hand-held glass jar. Von Kleist's hand and the water acted as conductors and the jar as a dielectric (although details of the mechanism were incorrectly identified at the time). Von Kleist found, after removing the generator, that touching the wire resulted in a painful spark. In a letter describing the experiment, he said "I would not take a second shock for the kingdom of France." The following year, the Dutch physicist Pieter van Musschenbroek invented a similar capacitor, which was named the Leyden jar, after the University of Leiden where he worked. Daniel Gralath was the first to combine several jars in parallel into a "battery" to increase the charge storage capacity. Benjamin Franklin investigated the Leyden jar and "proved" that the charge was stored on the glass, not in the water as others had assumed. He also adopted the term "battery". (denoting the increasing of power with a row of similar units as in a battery of cannon), subsequently applied to clusters of electrochemical cells. Leyden jars were later made by coating the inside and outside of jars with metal foil, leaving a space at the mouth to prevent arcing between the foils. The earliest unit of capacitance was the 'jar', equivalent to about 1nanofarad.

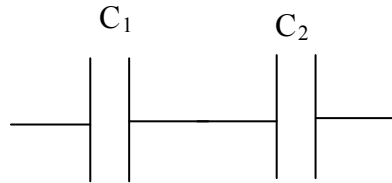
A capacitor consists of two conductors separated by a non-conductive region called the dielectric medium though it may be a vacuum or a semiconductor depletion region chemically identical to the conductors. A capacitor is assumed to be self-contained and isolated, with no net electric charge and no influence from any external electric field. The conductors thus hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field. In SI units, a capacitance of one farad means that one coulomb of charge on each conductor causes a voltage of one volt across the device.

Capacitors follow the same law using the reciprocals. The total capacitance of capacitors in series is equal to the reciprocal of the sum of the reciprocals of their individual capacitances:

8.1 Capacitors in a Circuit

8.1.1 Series Connection of Capacitors

When capacitors are in series, the charge on each one is the same, so...



$$V = \frac{Q}{C_1} + \frac{Q}{C_2} = Q(1/C_1 + 1/C_2) = QC_T \quad \text{so} \quad 1/C_T = 1/C_1 + 1/C_2 + \dots$$

So, equivalent circuits with capacitors are done the same as for resistors, except that they combine differently.

$$\frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}.$$

The working voltage of a series combination of identical capacitors is equal to the sum of voltage ratings of individual capacitors. This simple relationship only applies if the voltage ratings are equal as well as the capacitances. However, the division of DC voltage between the capacitors is dominated by the leakage resistance of the capacitors, rather than their capacitances, and this has considerable variation. To counter this equalising resistors may be placed in parallel with each capacitor which effectively add to the leakage current. The value of resistor chosen (perhaps a few megohms) is as large as possible, but low enough to ensure that the capacitor leakage current is insignificant compared to the current through the resistor. At DC, the circuit appears as a chain of series identical resistors and equal voltage division between the capacitors is ensured. In high-voltage circuits, the resistors serve an additional function as bleeder resistors

A **dielectric** is an electrical insulator that may be polarized by an applied electric field. When a dielectric is placed in an electric field, electric charges do not flow through the material, as in a conductor, but only slightly shift from their average equilibrium

positions causing **dielectric polarization**. Because of dielectric polarization, positive charges are displaced toward the field and negative charges shift in the opposite direction. This creates an internal electric field that partly compensates the external field inside the dielectric. If a dielectric is composed of weakly bonded molecules, those molecules not only become polarized, but also reorient so that their symmetry axis aligns to the field.

Although the term "insulator" refers to a low degree of electrical conduction, the term "dielectric" is typically used to describe materials with a high polarizability. The latter is expressed by a number called the dielectric constant. A common, yet notable example of a dielectric is the electrically insulating material between the metallic plates of a capacitor. The polarization of the dielectric by the applied electric field increases the capacitor's capacitance.

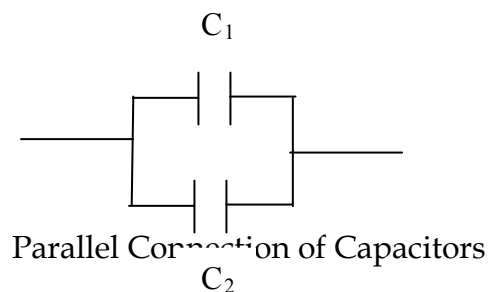
The study of dielectric properties is concerned with the storage and dissipation of electric and magnetic energy in materials. It is important to explain various phenomena in electronics, optics, and solid-state physics.

The term "dielectric" was coined by William Whewell (from "dia-electric") in response to a request from Michael Faraday. The capacitor is a reasonably general model for electric fields within electric circuits. An ideal capacitor is wholly characterized by a constant capacitance C , defined as the ratio of charge $\pm Q$ on each conductor to the voltage V between them:

$$C = \frac{Q}{V}$$

8.2 Parallel Connection of Capacitors

When capacitors are in parallel, the total charge is the sum of the charge on each one,



The total charge on both capacitors is $\approx Q_1 + Q_2$ the sum of the charges on each capacitors, thus

$$= C_1 V + C_2 V \text{ (from } Q=CV \text{)}$$

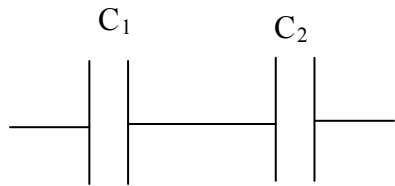
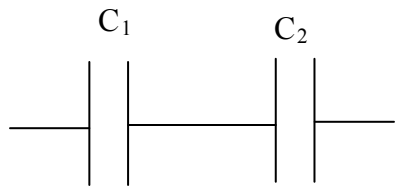
$$= V(C_1 + C_2) = C_P V$$

$$\text{so } C_T = C_1 + C_2 + \dots$$

So the total capacitance for several capacitors connected in parallel is given as:-

$$C_{\text{total}} = C_1 + C_2 + \dots + C_n.$$

The working voltage of a parallel combination of capacitors is always limited by the smallest working voltage of an individual capacitor.



Chapter Review Questions

1. What is a capacitor?
2. Given that C_1 and C_2 are $2\mu\text{F}$ and $3\mu\text{F}$ respectively, calculate the combined capacitance in the arrangement below.
3. Define a **dielectric**
4. Given that C_1 and C_2 are $2\mu\text{F}$ and $3\mu\text{F}$ respectively, calculate the combined capacitance in the arrangement below.

Suggested References

- i. Electronic Projects For Model Aircraft **Author:** Ken Ginn 2001, Nexus Special Interests
- ii. Understanding Physics Electricity & Magnetism, D C Pandey, 2009
- iii. College physics fifth edition by serway and faughn, 1999, saunders college publishing

9.0 ELECTRONICS

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Describe the use of semi-conductors in electronics
- ii). Discuss the working principles of Diodes
- iii). Describe the Rectifier diodes
- iv). Explain the Bridge rectifiers circuits
- v). Describe the working principles of Transistors

Introduction

Semiconductors are materials which have a conductivity between conductors (generally metals) and nonconductors or insulators (such as most ceramics). Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide. In a process called doping, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material.

Due to their role in the fabrication of electronic devices, semiconductors are an important part of our lives. Imagine life without electronic devices. There would be no radios, no TV's, no computers, no video games, and poor medical diagnostic equipment. Although many electronic devices could be made using vacuum tube technology, the developments in semiconductor technology during the past 50 years have made electronic devices smaller, faster, and more reliable. Think for a minute of all the encounters you have with electronic devices. How many of the following have you seen or used in the last twenty-four hours? Each has important components that have been manufactured with electronic materials.

microwave oven	electronic balance	video games
Radio	television	VCR
Watch	CD player	Stereo
Computer	lights	air conditioner
Calculator	telephone	musical greeting cards
diagnostic equipment	clock	Refrigerator
Car	security devices	Stove

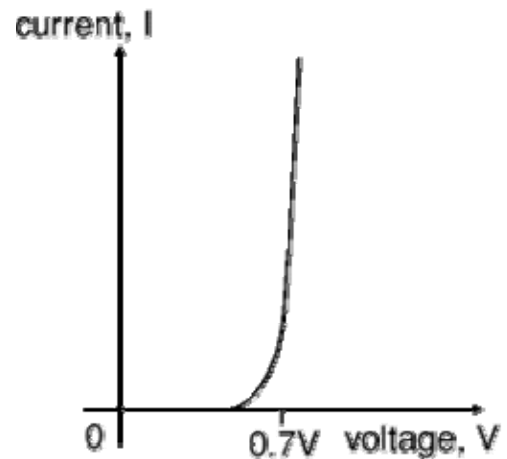
Advances in the field of electronics can continue to improve our lives. Learning about electronic materials can help us understand and be able to participate in the fields of communication, computers, medicine, the basic sciences and engineering. All of these fields use electronics extensively. Use of semi conductors is discussed further in the section on electronics.

9.1 Diodes

Example:  Circuit symbol: 

9.2 Functions of a Diode

Diodes are electrical devices that allow electricity to flow in only one direction. The arrow of the circuit symbol shows the direction in which the current can flow. Diodes are the electrical version of a valve and early diodes were actually called valves.



Characteristic of a Silicon Diode

9.3 Forward Voltage Drop

Electricity uses up a little energy pushing its way through the diode, rather like a person pushing through a door with a spring. This means that there is a small voltage across a conducting diode, it is called the **forward voltage drop** and is about 0.7V for all normal diodes which are made from silicon. The forward voltage drop of a diode is almost constant whatever the current passing through the diode so they have a very steep characteristic (current-voltage graph).

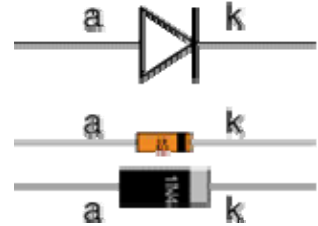
9.4 Reverse Voltage

When a reverse voltage is applied a perfect diode does not conduct, but all real diodes leak a very tiny current of a few μA or less. This can be ignored in most circuits because it will be very much smaller than the current flowing in the forward direction. However, all diodes have a **maximum reverse voltage** (usually 50V or more) and if this is exceeded the diode will fail and pass a large current in the reverse direction, this is called **breakdown**.

Ordinary diodes can be split into two types: Signal diodes which pass small currents of 100mA or less and Rectifier diodes which can pass large currents. In addition there are LEDs (which have their own page) and Zener diodes.

9.5 Connecting and Soldering

Diodes must be connected the correct way round, the diagram may be labelled **a** or **+** for anode and **k** or **-** for cathode (yes, it really is k, not c, for cathode!). The cathode is marked by a line painted on the body. Diodes are labelled with their code in small print, you may need a magnifying glass to read this on small signal diodes!



Small **signal diodes** can be damaged by heat when soldering, but the risk is small unless you are using a **germanium diode** (codes beginning OA...) in which case you should use a heat sink clipped to the lead between the joint and the diode body. A standard crocodile clip can be used as a heat sink.

Rectifier diodes are quite robust and no special precautions are needed for soldering them.

9.6 Testing Diodes

You can use a multimeter or a simple tester (battery, resistor and LED) to check that a diode conducts in one direction but not the other. A lamp may be used to test a rectifier diode, but do NOT use a lamp to test a signal diode because the large current passed by the lamp will destroy the diode!

9.7 Signal diodes (small current)

Signal diodes are used to process information (electrical signals) in circuits, so they are only required to pass small currents of up to 100mA.

General purpose signal diodes such as the 1N4148 are made from silicon and have a forward voltage drop of 0.7V.

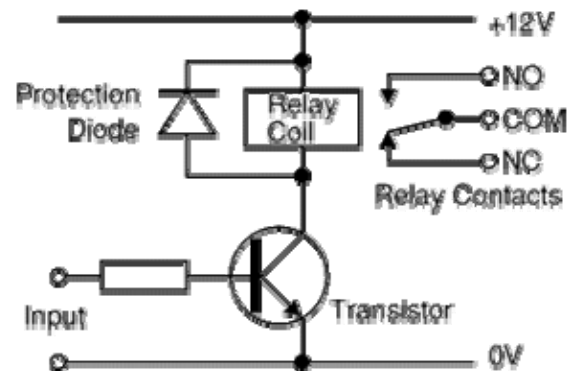
Germanium diodes such as the OA90 have a lower forward voltage drop of 0.2V and this makes them suitable to use in radio circuits as detectors which extract the audio signal from the weak radio signal.

For general use, where the size of the forward voltage drop is less important, silicon diodes are better because they are less easily damaged by heat when soldering, they have a lower resistance when conducting, and they have very low leakage currents when a reverse voltage is applied.

9.7 Protection diodes for relays

Signal diodes are also used to protect transistors and ICs from the brief high voltage produced when a relay coil is switched off. The diagram shows how a protection diode is connected 'backwards' across the relay coil.

Current flowing through a relay coil creates a magnetic field which collapses suddenly when the current is switched off. The sudden collapse of the magnetic field induces a brief high voltage across the relay coil which is very likely to damage transistors and ICs. The protection diode allows the induced voltage to drive a brief current through the coil (and diode) so the magnetic field dies away quickly rather than instantly. This prevents the induced voltage becoming high enough to cause damage to transistors and ICs.



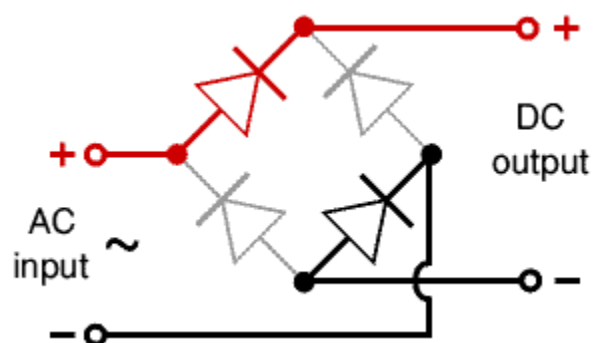
9.8 Rectifier Diodes (Large Current)

Rectifier diodes are used in power supplies to convert alternating current (AC) to direct current (DC), a process called rectification. They are also used elsewhere in circuits where a large current must pass through the diode.

All rectifier diodes are made from silicon and therefore have a forward voltage drop of 0.7V. The table shows maximum current and maximum reverse voltage for some popular rectifier diodes. The 1N4001 is suitable for most low voltage circuits with a current of less than 1A.

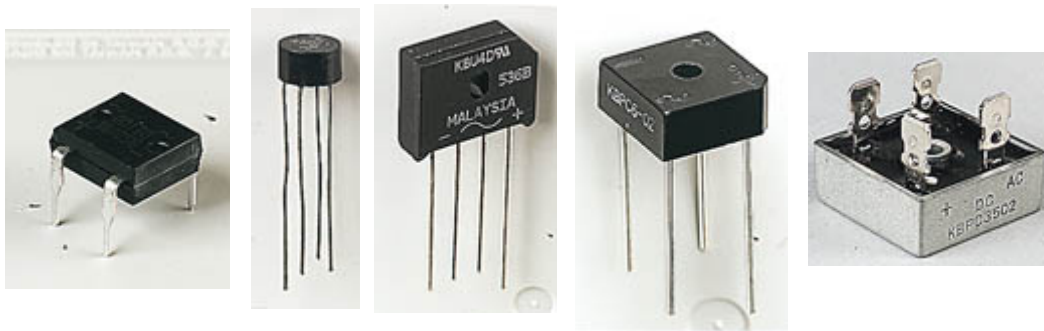
9.9 Bridge Rectifiers

There are several ways of connecting diodes to make a rectifier to convert AC to DC. The



bridge rectifier is one of them and it is available in special packages containing the four diodes required. Bridge rectifiers are rated by their maximum current and maximum reverse voltage. They have four leads or terminals: the two DC outputs are labelled + and -, the two AC inputs are labelled $\sim$.

The diagram shows the operation of a bridge rectifier as it converts AC to DC. Notice how alternate pairs of diodes conduct.



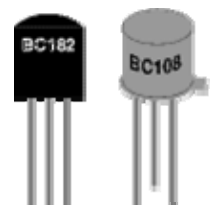
Various types of Bridge Rectifiers

Note that some have a hole through their centre for attaching to a heat sink

9.10 Transistors

Function

Transistors **amplify current**, for example they can be used to amplify the small output current from a logic IC so that it can operate a lamp, relay or other high current device. In many circuits a resistor is used to convert the changing current to a changing voltage, so the transistor is being used to **amplify voltage**.

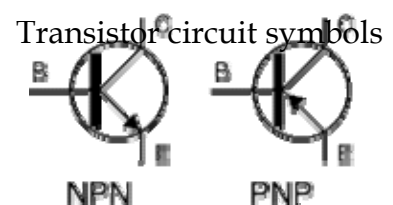


A transistor may be used as a **switch** (either fully on with maximum current, or fully off with no current) and as an **amplifier** (always partly on).

The amount of current amplification is called the **current gain**, symbol h_{FE} .

9.10.1 Types of Transistor

There are two types of standard transistors, **NPN** and **PNP**, with different circuit symbols. The letters refer to the layers of semiconductor material used to make the transistor. Most transistors used today are NPN because this is the easiest



type to make from silicon. If you are new to electronics it is best to start by learning how to use NPN transistors.

The leads are labelled **base** (B), **collector** (C) and **emitter** (E).

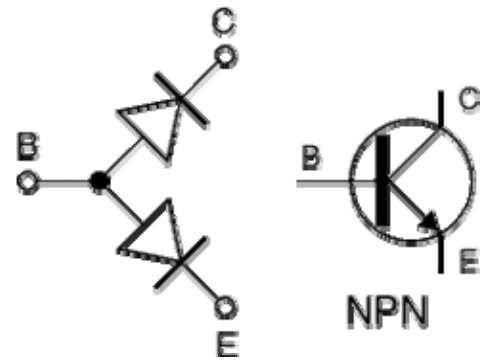
These terms refer to the internal operation of a transistor but they are not much help in understanding how a transistor is used, so just treat them as labels!

9.10.2 Testing a transistor

Transistors can be damaged by heat when soldering or by misuse in a circuit. If you suspect that a transistor may be damaged there are two easy ways to test it:

9.10.3 Testing with a Multimeter

Use a multimeter or a simple tester (battery, resistor and LED) to check each pair of leads for conduction. Set a digital multimeter to diode test and an analogue multimeter to a low resistance range.



Test each pair of leads both ways (six tests in total):

- The **base-emitter (BE)** junction should behave like a diode and conduct one way only.
- The **base-collector (BC)** junction should behave like a diode and conduct one way only.
- The **collector-emitter (CE)** should not conduct either way.

Testing an NPN transistor

The diagram shows how the junctions behave in an NPN transistor. The diodes are reversed in a PNP transistor but the same test procedure can be used.

Chapter Review Questions

1. What are Semiconductors
2. Name two Semiconductors
3. Define doping
4. Define a Diodes
5. Draw the circuit symbol for a diode
6. Give some uses of diodes
7. Name the two Types of Transistors

8. Draw the symbol for each transistor

Suggested References

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- ii. Understanding Physics Electricity & Magnetism, D C Pandey, 2009
- iii. College physics fifth edition by serway and faughn, 1999, saunders college publishing

10.0 OPTICS

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Define behavior of light
- ii). Discuss the relationship between Velocity of Light and Refractive Index
- iii). Describe the properties of white Light

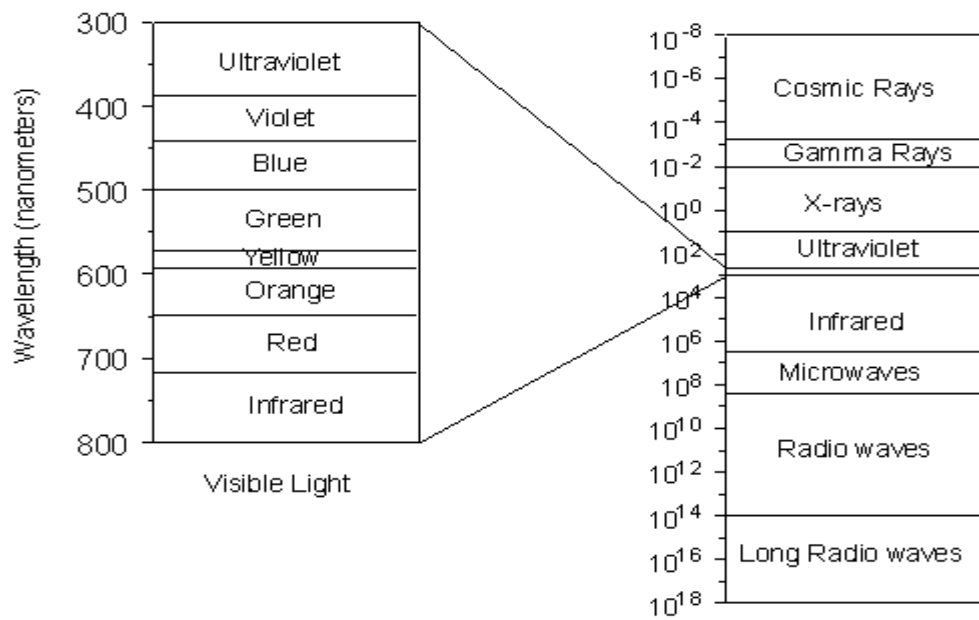
Introduction

Properties of Light: Reflection, Refraction, Dispersion, and Refractive Indices

The optical properties of crystals are, next to x-ray diffraction and direct chemical analyses, the most reliable properties available to distinguish and identify minerals. The optical properties depend on the manner that visible light is transmitted through the crystal, and thus are dependent on crystal structure, crystal symmetry, and chemical composition of the mineral. In order to understand the optical properties of crystals we must first understand something about light and how it interacts with matter.

Light

Light is an electromagnetic radiation that has properties of waves. The electromagnetic spectrum can be divided into several bands based on the wavelength of the light waves. As we have discussed before, visible light represents a narrow group of wavelengths between about 380 nm ($1 \text{ nm} = 10^{-9} \text{ m}$) and 730 nm.



Our eyes interpret these wavelengths as different colors. If only a single wavelength or limited range of wavelengths are present and enter our eyes, they are interpreted as a certain color. If a single wavelength is present we say that we have *monochromatic light*. If all wavelengths of visible light are present, our eyes interpret this as white light. If no wavelengths in the visible range are present, we interpret this as dark.

10.1 Velocity of Light and Refractive Index

The energy of light is related to its frequency and velocity as follows:

$$E = hf = hc/\lambda$$

where E = energy

h = Planck's constant, 6.62517×10^{-34} JS

f = frequency

C = velocity of light = 3.0×10^8 m/s

λ = wavelength

The velocity of light, C , in a vacuum is 3.0×10^8 m/s. Light cannot travel faster than this, but if it travels through a substance, its velocity will decrease. Note that from the equation given above-

$$C = f\lambda$$

The frequency of vibration, f , remains constant when the light passes through a substance. Thus, if the velocity, C , is reduced on passage through a substance, the wavelength, λ , must also decrease. We here define *refractive index*, n , of a material or substance as the ratio of the speed of light in a vacuum, C , to the speed of light in a material through which it passes, C_m .

$$n = C/C_m$$

Note that the value of refractive index will always be greater than 1.0, since C_m can never be greater than C . In general, C_m depends on the density of the material, with C_m decreasing with increasing density. Thus, higher density materials will have higher refractive indices.

The refractive index of any material depends on the wavelength of light because different wavelengths are interfered with and bend to different extents according to the atoms that make up the material. In general refractive index varies linearly with wavelength.

Materials can be divided into 2 classes based on how the velocity of light of a particular wavelength varies in the material.

1. Materials whose refractive index does not depend on the direction that the light travels are called *isotropic* materials. In these materials the velocity of light does not depend on the direction that the light travels. Isotropic materials have a single, constant refractive index for each wavelength. Minerals that crystallize in the isometric system, by virtue of their symmetry, are isotropic. Similarly, glass, gases, most liquids and amorphous solids are isotropic.
2. Materials whose refractive index does depend on the direction that the light travels are called *anisotropic* materials. These types of materials will have a range of refractive indices between two extreme values for each wavelength. Anisotropic materials can be further divided into two subclasses, although the reasoning behind these subdivisions will become clear in a later lecture.
 - a. Minerals that crystallize in the tetragonal and hexagonal crystal systems (as well as some plastics) are *uniaxial* and are characterized by 2 extreme refractive indices for each wavelength.
 - b. Minerals that crystallize in the triclinic, monoclinic, and orthorhombic crystal systems are *biaxial* and are characterized by 3 refractive indices, one of which is intermediate between the other two.

Air, since it is a gas, is isotropic. The refractive index of air is usually taken as 1.0, although its true value is 1.0003.

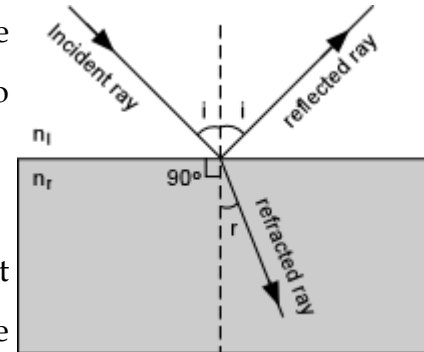
10.2 Reflection and Refraction of Light

When light strikes an interface between two substances with different refractive indices, two things occur. An incident ray of light striking the interface at an angle, i , measured between a line perpendicular to the interface and the propagation direction of the incident ray, will be reflected off the interface at the same angle, i . In other words the angle of reflection is equal to the angle of incidence.

If the second substance is transparent to light, then a ray of light will enter the substance with different refractive index, and will be refracted, or bent, at an angle r , the angle of refraction. The angle of refraction is dependent on the angle of incidence and the refractive index of the materials on either side of the interface according to *Snell's Law*:

$$n_i \sin(i) = n_r \sin(r)$$

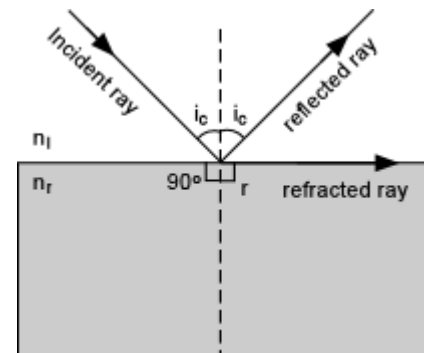
Note that if the angle of incidence is 0° (i.e. the light enters perpendicular to the interface) that some of the light will be reflected directly back, and the refracted ray will continue along the same path. This can be seen from Snell's law, since $\sin(0^\circ) = 0$, making $\sin(r) = 0$, and resulting in $r = 0$.



There is also an angle, i_c , called the *critical angle for total internal reflection* where the refracted ray travels along the interface between the two substances.

This occurs when the angle $r = 90^\circ$. In this case, applying Snell's law: $n_i \sin(i_c) = n_r \sin(90^\circ) = n_r$ [since $\sin(90^\circ) = 1$]

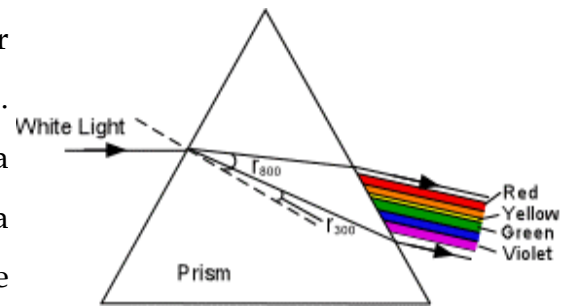
$$\sin(i_c) = n_r / n_i$$



10.3 Dispersion of Light

The fact that refractive indices differ for each wavelength of light produces an effect called *dispersion*. This can be seen by shining a beam of white light into a triangular prism made of glass. White light entering such a prism will be refracted in the prism by different angles depending on the wavelength of the light.

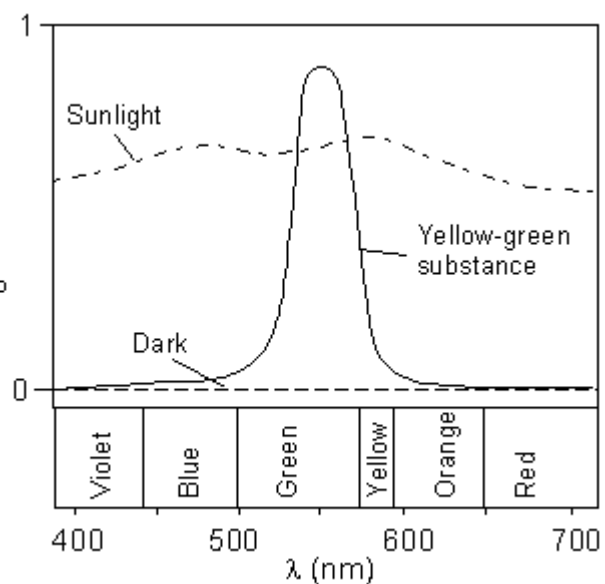
The refractive index for longer wavelengths (red) are lower than those for shorter wavelengths (violet). This results in the a greater angle of refraction for the longer wavelengths than for the shorter wavelengths. (Shown here are the paths taken for a wavelength of 800 nm, angle r_{800} and for a wavelength of 300 nm, angle r_{300}). When the light exits from the other side of the prism, we see the different wavelengths dispersed to show the different colors of the spectrum.



10.4 Absorption of Light

When light enters a transparent material some of its energy is dissipated as heat energy, and it thus loses some of its intensity. When this absorption of energy occurs selectively for different wavelengths of light, the light that gets transmitted through the material will show only those wavelengths of light that are not absorbed. The transmitted wavelengths will then be seen as color, called the **absorption color** of the material.

For example, if we measure the intensity of light, I_0 , for each wavelength before it is transmitted through a material, and measure the intensity, I , for each wavelength after it has passed through the material, and plot I/I_0 versus λ , we obtain the absorption curve for that material as shown here. The absorption curve (continuous line) for the material in this example shows that the light exiting the material will have a yellow-green color, called the



absorption color. An opaque substance would have an absorption curve such as that labeled "Dark", i.e. no wavelengths would be transmitted.

Sunlight, on passing through the atmosphere has absorption curve as shown, thus we see it as white light, since all wavelengths are present.

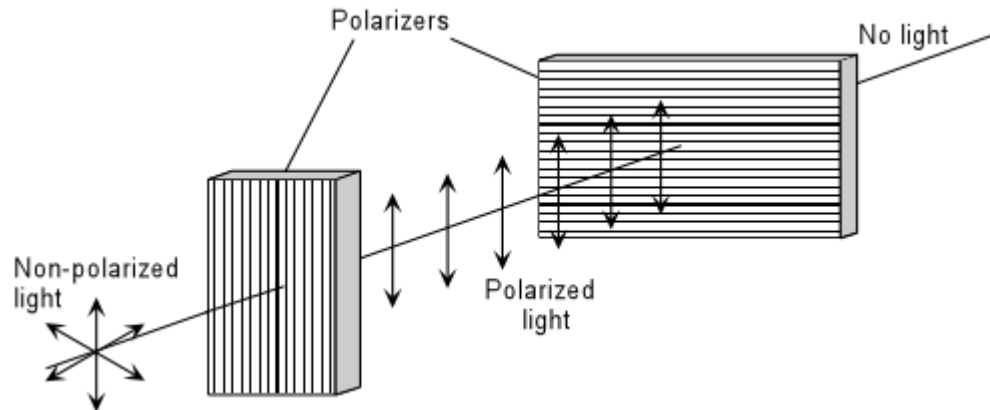
10.5 Polarization of Light

Normal light vibrates equally in all direction perpendicular to its path of propagation. If the light is constrained to vibrate in only on plane, however, we say that it is plane polarized light. The direction that the light vibrates is called the *vibration direction*, which for now will be perpendicular to the direction. There are two common ways that light can become polarized.

The first involves reflection off of a non-metallic surface, such as glass or paint. An unpolarized beam of light, vibrating in all directions perpendicular to its path strikes such a surface and is reflected. The reflected beam will be polarized with vibration directions parallel to the reflecting surface (perpendicular to the page as indicated by the open circles on the ray path). If some of this light also enters the material and is refracted at an angle 90° to the path of the reflected ray, it too will become partially polarized, with vibration directions again perpendicular to the path of the refracted ray, but in the plane perpendicular to the direction of vibration in the reflected ray (the plane of the paper, as shown in the drawing).

Polarization can also be achieved by passing the light through a substance that absorbs light vibrating in all directions except one. Anisotropic crystals have this property in certain directions, called privileged directions, and we will discuss these properties when we discuss uniaxial and biaxial crystals. Crystals were used to produce polarized light in microscopes built before about 1950. The device used to make polarized light in modern microscopes is a Polaroid, a trade name for a plastic film made by the Polaroid Corporation. A Polaroid consists of long-chain organic molecules that are aligned in one direction an placed in a plastic sheet. They are placed close enough to form a closely spaced linear grid, that allows the passage of light vibrating only in the same

direction as the grid. Light vibrating in all other directions is absorbed. Such a device is also called a *polarizer*.



If a beam of non-polarized light encounters a polarizer, only light vibrating parallel to the polarizing direction of the polarizer will be allowed to pass. The light coming out on the other side will then be plane polarized, and will be vibrating parallel to the polarizing direction of the polarizer. If another polarizer with its polarization direction oriented perpendicular to the first polarizer is placed in front of the beam of now polarized light, then no light will penetrate the second polarizer. In this case we say that the light has been extinguished.

Polaroid sunglasses use these same principles. For example, incoming solar radiation is reflected off of the surface of the ocean or the painted hood of your car. Reflected light coming off of either of these surfaces will be polarized such that the vibration directions are parallel to the reflected surface, or approximately horizontal (as in the first method of polarization discussed above). Polaroid sunglasses contain polarizers with the polarization direction oriented vertically. Wearing such glasses will cut out all of the horizontally polarized light reflecting off the water surface or hood of your car.

Chapter Review Questions

1. Define refractive index for a material
2. Define *isotropic* materials
3. Define *anisotropic* materials
4. Define Reflection and Refraction of Light
5. State *Snell's Law*
6. Critical angle for total internal reflection
7. What is Dispersion of Light

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- i. Optics by Eugene Hecht, A. R. Ganesan (Paperback - 01/01/2008)
- ii. Understanding Physics Optics & Modern Physics, 2009 Author: D C Pandey
- iii. Fiber Optics And Optoelectronics Author: R. P. Khare 2004 Publisher: Oxford University Press
- iv. Fiber-Optic Communication Systems, 3Rd Ed Author: Govind P. Agrawal 2007 Publisher: Wiley India Pvt Ltd
- v. Lasers - Theory And Applications , Ghatak A. K. & Thyagarajan K. , 2009, Macmillan India

11.0 THIN LENSES

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Discuss the concept of thin lenses
- ii). Describe Total internal reflection (T.I.R.)
- iii). Describe the working principle of the Optical Fibre
- iv). Explain how an Optical Fiber Transmits Light

Introduction

In this section we will look at two types of thin lenses; the converging lens and the diverging lens. Specifically, we will look at how light rays behave as they move through lenses.

11.1 Convergent Lens

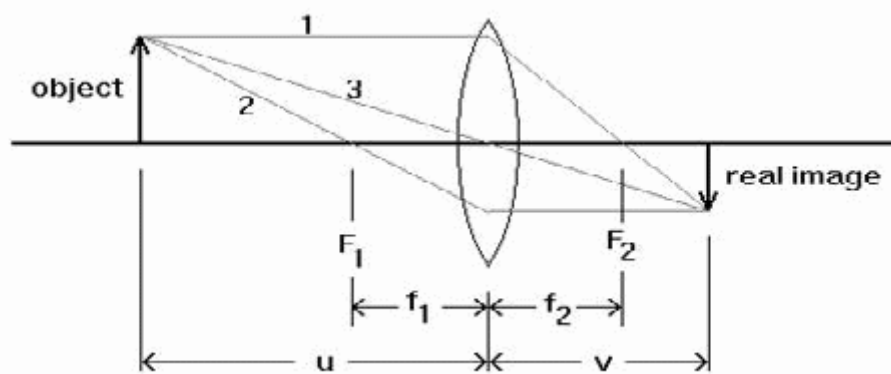


Figure 1 Real Image formation by a Convergent Lens

A convergent lens has two foci, F_1 and F_2 , located on its axis. These will lie on the lens axis at a common distance from the lens. The distance from the focal points to the lens centre is labelled f , and is defined as positive for convergent lenses. There are 3 principal rays that are easy to track in order to figure out the position and size of an object's image (refer to Fig. 2):

1. Parallel Ray: A ray parallel to the axis on the incident side passes through the focus on the other side.
2. Focal Ray: A ray through the focus on the incident side, emerges parallel.
3. Centre Ray: A ray directed towards the centre of the lens on the incident side emerges undeflected.

If the rays originating in an object point actually converge on an image point, so that they could be received on a screen, the image is called real (Fig. 1). If the rays do not actually converge but appear to come from the image point, the image is called virtual (Fig. 2).

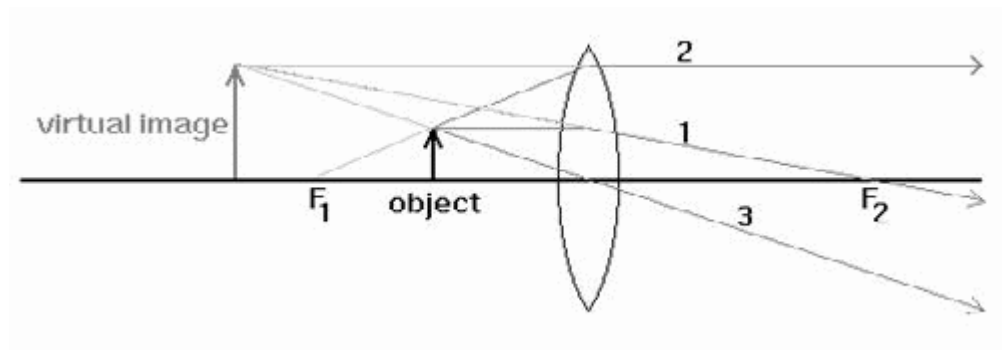


Figure 2 *Virtual Image Formation by Convergent Lens*

11.2 Divergent Lens

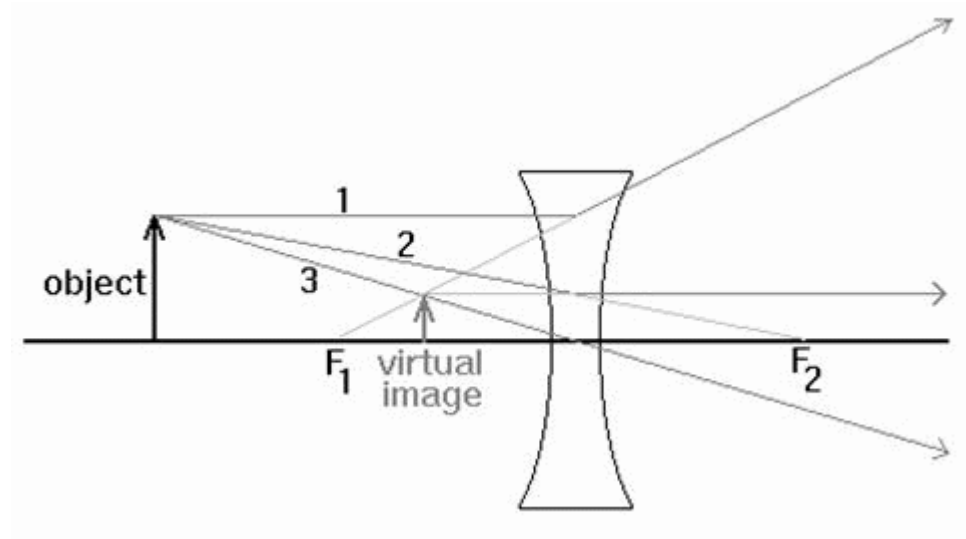


Figure 3 *Virtual Image formation by Divergent Lens*

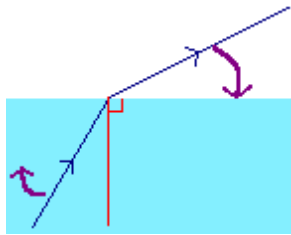
A divergent lens also has two foci, F_1 and F_2 , located on its axis. They have a common distance f from its center, only now f is defined to be negative. The three principal rays are as follows.

1. Parallel Ray: A ray parallel to the axis incident from the left side, emerges as though it was coming from the focus F_1 .
2. Focal Ray: A ray incident from the left heading for focus F_2 emerges parallel.
3. Centre Ray: A ray incident towards the centre emerges undeflected.

11.3 Total Internal Reflection (T.I.R.)

In an earlier section, you were introduced to refraction, the observed effect of light waves changing direction when entering a new medium, due to a change in the speed of the wave. We found that the change in direction of the wave can be quantified using the refractive indices of the two materials.

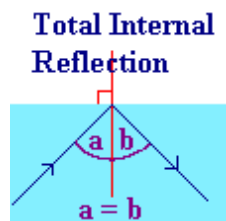
Now, imagine a ray of light entering an optically less dense material, from an optically denser one. What happens? The light ray bends away from the normal. As the following diagram shows, the farther the incident ray is from the normal, the farther the refracted ray will be from it as well.



However, with a small angular change in the angle of incidence comes a bigger change in angle of refraction (due to the refractive indexes of the two materials).

Let's move on to an extreme case of this situation: when the ray exiting the optically denser material is refracted to such an extent that it is bent to 90° from the normal.

The angle of incidence in this special case is called the **critical angle** because beyond this point, there is a difference in the behavior of the light. When the critical angle for the two substances is exceeded, a phenomenon known as **Total Internal Reflection**, or **T.I.R.** occurs. This means that instead of exiting the optically denser material and being refracted, the incident ray is reflected inside the material (i.e. internally).



After this point, normal laws of reflection are followed, by the ray, off of the surface between the two materials.

The critical angle of a boundary can be found quite simply, using **Snell's Law**, which states:

$$\frac{\sin \theta_1}{\sin \theta_2} = \frac{n_2}{n_1}$$

where 1 and 2 correspond to the first and second media entered respectively, and therefore where θ_1 corresponds to the angle of incidence, and θ_2 corresponds to the angle of refraction. In the position of the critical angle, we know that the angle of refraction, θ_2 , is 90° . Therefore, $\sin \theta_2$ is equal to 1. The angle of incidence is of course the critical angle, so we now have:

$$\sin c = \frac{n_2}{n_1}$$

The critical angle, c , can therefore be found simply by knowing the refractive indexes of the two materials. It is also important to note that T.I.R. takes place only at the interface of an optically denser material with one that is optically less dense, and not vice versa.

Total Internal Reflection has many practical uses, one of which is in optical fibers. An optical fiber has two layers: a core made of a material of with a high refractive index, and a second, outer layer with lower refractive index. The light waves transmitted by an optical fiber are reflected off of the boundary between these two substances, as shown in the diagram of a cross-section of a fiber below.



Cross section of an optical fiber.

The smaller the refractive index of the cladding is compared to the refractive index of the core, the smaller the critical angle is, allowing T.I.R. to take place in more conditions (as it can be more often exceeded).

Optical fibers are used in a growing number of fields. In communication they are used for carrying signals precisely, and at the speed of light. This is faster than the speed of energy transmission by electrons, and therefore faster than electric signals. In medicine, optical fibers are used by operating doctors to view previously inaccessible places, such as the inside of a lung. Optical fibers are helpful in that they allow the transmission of

light to or from places not usually possible. Because they are fibers, they can be bent, allowing light to be bent easily and precisely around many corners, without the use of more clumsy devices such as mirrors.

11.4 Optical Fibre



A cable reel trailer with conduit that can carry optical fiber.

An optical fiber consists of a core, cladding, and a buffer (a protective outer coating), in which the cladding guides the light along the core by using the method of total internal reflection. The core and the cladding (which has a lower-refractive-index) are usually made of high-quality silica glass, although they can both be made of plastic as well. Connecting two optical fibers is done by fusion splicing or mechanical splicing and requires special skills and interconnection technology due to the microscopic precision required to align the fiber cores.

Two main types of optical fiber used in optic communications include multi-mode optical fibers and single-mode optical fibers. A multi-mode optical fiber has a larger core (≥ 50 micrometres), allowing less precise, cheaper transmitters and receivers to connect to it as well as cheaper connectors. However, a multi-mode fiber introduces multimode distortion, which often limits the bandwidth and length of the link. Furthermore, because of its higher dopant content, multi-mode fibers are usually expensive and exhibit higher attenuation. The core of a single-mode fiber is smaller (<10 micrometres) and requires more expensive components and interconnection methods, but allows much longer, higher-performance links.

In order to package fiber into a commercially-viable product, it is typically protectively-coated by using ultraviolet (UV), light-cured acrylate polymers, then terminated with optical fiber connectors, and finally assembled into a cable. After that, it can be laid in the ground and then run through the walls of a building and deployed aerially in a

manner similar to copper cables. These fibers require less maintenance than common twisted pair wires, once they are deployed.

Fiber optics is the field of applied science and engineering concerned with the design and application of optical fibers. An **optical fiber** is a thin, flexible, transparent fiber that acts as a waveguide, or "light pipe", to transmit light between the two ends of the fiber. Optical fibers are widely used in fiber-optic communications, which permits transmission over longer distances and at higher bandwidths (data rates) than other forms of communication. Fibers are used instead of metal wires because signals travel along them with less loss and are also immune to electromagnetic interference. Fibers are also used for illumination, and are wrapped in bundles so they can be used to carry images, thus allowing viewing in tight spaces. Specially designed fibers are used for a variety of other applications, including sensors and fiber lasers.

Optical fiber typically consists of a transparent core surrounded by a transparent cladding material with a lower index of refraction. Light is kept in the core by total internal reflection. This causes the fiber to act as a waveguide. Fibers which support many propagation paths or transverse modes are called multi-mode fibers (MMF), while those which can only support a single mode are called single-mode fibers (SMF). Multi-mode fibers generally have a larger core diameter, and are used for short-distance communication links and for applications where high power must be transmitted. Single-mode fibers are used for most communication links longer than 550 meters.

Joining lengths of optical fiber is more complex than joining electrical wire or cable. The ends of the fibers must be carefully cleaved, and then spliced together either mechanically or by fusing them together with an electric arc. Special connectors are used to make removable connections.

11.4.1 How an Optical Fiber Transmits Light

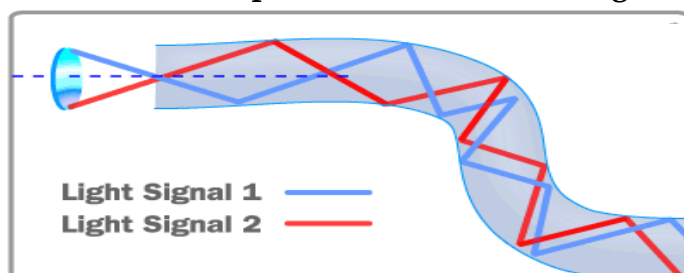


Diagram of total internal reflection in an optical fiber

Suppose you want to shine a flashlight beam down a long, straight hallway. Just point the beam straight down the hallway -- light travels in straight lines, so it is no problem. What if the hallway has a bend in it? You could place a mirror at the bend to reflect the light beam around the corner. What if the hallway is very winding with multiple bends? You might line the walls with mirrors and angle the beam so that it bounces from side-to-side all along the hallway. This is exactly what happens in an optical fiber.

The light in a fiber-optic cable travels through the core (hallway) by constantly bouncing from the cladding (mirror-lined walls), a principle called **total internal reflection**. Because the cladding does not absorb any light from the core, the light wave can travel great distances.

However, some of the light signal **degrades** within the fiber, mostly due to impurities in the glass. The extent that the signal degrades depends on the purity of the glass and the wavelength of the transmitted light (for example, 850 nm = 60 to 75 percent/km; 1,300 nm = 50 to 60 percent/km; 1,550 nm is greater than 50 percent/km). Some premium optical fibers show much less signal degradation -- less than 10 percent/km at 1,550 nm.

Fiber-optic communication is a method of transmitting information from one place to another by sending pulses of light through an optical fiber. The light forms an electromagnetic carrier wave that is modulated to carry information. First developed in the 1970s, fiber-optic communication systems have revolutionized the telecommunications industry and have played a major role in the advent of the Information Age. Because of its advantages over electrical transmission, optical fibers have largely replaced copper wire communications in core networks in the developed world.

The process of communicating using fiber-optics involves the following basic steps: Creating the optical signal involving the use of a transmitter, relaying the signal along the fiber, ensuring that the signal does not become too distorted or weak, receiving the optical signal, and converting it into an electrical signal.

Optical fiber is used by many telecommunications companies to transmit telephone signals, Internet communication, and cable television signals. Due to much lower attenuation and interference, optical fiber has large advantages over existing copper wire in long-distance and high-demand applications. However, infrastructure

development within cities was relatively difficult and time-consuming, and fiber-optic systems were complex and expensive to install and operate. Due to these difficulties, fiber-optic communication systems have primarily been installed in long-distance applications, where they can be used to their full transmission capacity, offsetting the increased cost.

Chapter Review Questions

1. Discuss the concept of thin lenses
2. Describe conditions for Total internal reflection (T.I.R.)
3. Describe the working principle of the Optical Fibre
4. Explain how an Optical Fiber Transmits Light
5. Describe what you understand by an Optical Fibre
6. What is Fiber-optic communication?
7. Give two uses Optical fiber

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12.0 ELECTROMAGNETIC RADIATION

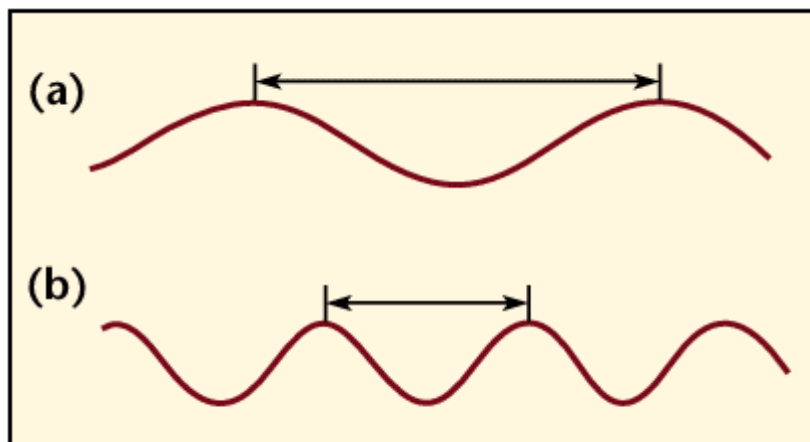
Learning Objectives

By the end of this section, the learner should be able to:-

- i). Describe the Electromagnetic Radiation
- ii). Discuss light as an EM radiation
- iii). Discuss uses of Radio waves
- iv). Discuss the Photoelectric Effect

Introduction

Do you listen to the radio, watch TV, or use a microwave oven? All these devices make use of electromagnetic waves. Radio waves, microwaves, visible light, and x rays are all examples of electromagnetic waves that differ from each other in wavelength.



(a) Longer wavelength; (b) shorter wavelength.

Electromagnetic waves are produced by the motion of electrically charged particles. These waves are also called "electromagnetic radiation" because they radiate from the electrically charged particles. They travel through empty space as well as through air and other substances.

Scientists have observed that electromagnetic radiation has a dual "personality." Besides acting like waves, it acts like a stream of particles (called "photons") that have no mass. The photons with the highest energy correspond to the shortest wavelengths.

Electromagnetic radiation (often abbreviated **E-M radiation** or **EMR**) is a phenomenon that takes the form of self-propagating waves in a vacuum or in matter. It comprises

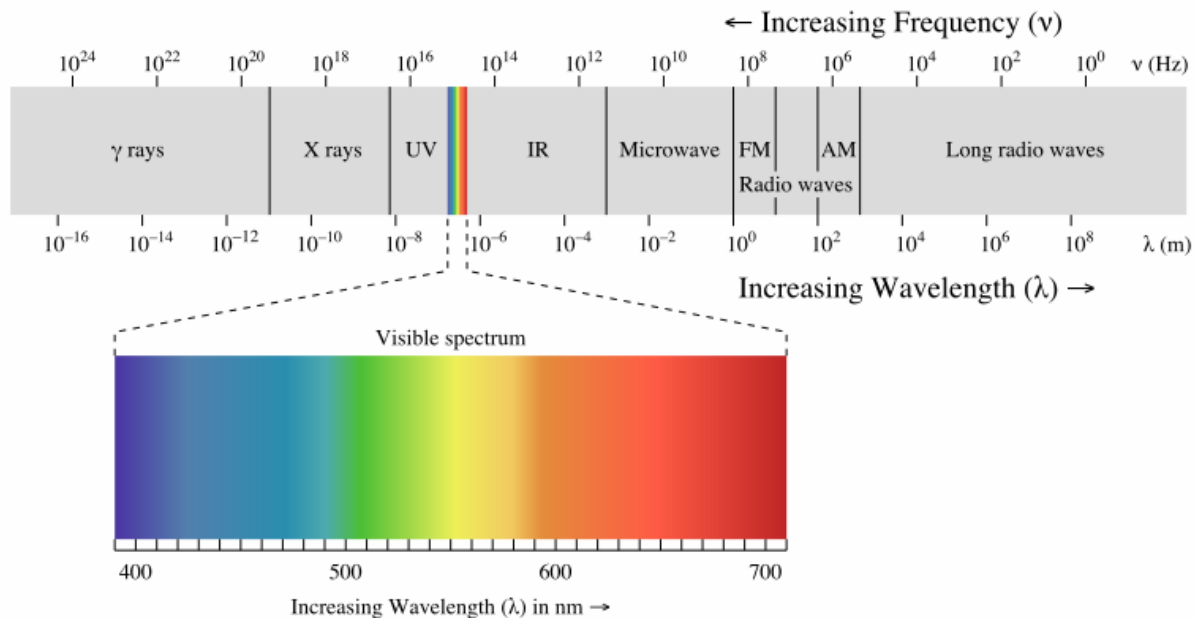
electric and magnetic field components, which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. Electromagnetic radiation is classified into several types according to the frequency of its wave; these types include (in order of increasing frequency and decreasing wavelength): radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays. A small and somewhat variable window of frequencies is sensed by the eyes of various organisms; this is what is called the visible spectrum. The photon is the quantum of the electromagnetic interaction and the basic "unit" of light and all other forms of electromagnetic radiation and is also the force carrier for the electromagnetic force. EM radiation carries energy and momentum that may be imparted to matter with which it interacts.

Generally, EM radiation (the designation 'radiation' excludes static electric and magnetic and near fields) is classified by wavelength into radio, microwave, infrared, the visible region we perceive as light, ultraviolet, X-rays and gamma rays. Arbitrary electromagnetic waves can always be expressed by Fourier analysis in terms of sinusoidal monochromatic waves which can be classified into these regions of the spectrum.

The behavior of EM radiation depends on its wavelength. Higher frequencies have shorter wavelengths, and lower frequencies have longer wavelengths. When EM radiation interacts with single atoms and molecules, its behavior depends on the amount of energy per quantum it carries. Spectroscopy can detect a much wider region of the EM spectrum than the visible range of 400 nm to 700 nm. A common laboratory spectroscope can detect wavelengths from 2 nm to 2500 nm. Detailed information about the physical properties of objects, gases, or even stars can be obtained from this type of device. It is widely used in astrophysics. For example, hydrogen atoms emit radio waves of wavelength 21.12 cm.

Sound waves are not electromagnetic radiation. At the lower end of the electromagnetic spectrum, about 20 Hz to about 20kHz, are frequencies that might be considered in the audio range, however, electromagnetic waves cannot be directly perceived by human ears. Sound waves are the oscillating compression of molecules. To

be heard, electromagnetic radiation must be converted to air pressure waves, or if the ear is submerged, water pressure waves.



12.1 Light as an EM Radiation

EM radiation with a wavelength between approximately 400 nm and 700 nm is directly detected by the human eye and perceived as visible light. Other wavelengths, especially nearby infrared (longer than 700 nm) and ultraviolet (shorter than 400 nm) are also sometimes referred to as light, especially when visibility to humans is not relevant.

If radiation having a frequency in the visible region of the EM spectrum reflects off of an object, say, a bowl of fruit, and then strikes our eyes, this results in our visual perception of the scene. Our brain's visual system processes the multitude of reflected frequencies into different shades and hues, and through this not-entirely-understood psychophysical phenomenon, most people perceive a bowl of fruit.

At most wavelengths, however, the information carried by electromagnetic radiation is not directly detected by human senses. Natural sources produce EM radiation across the spectrum, and our technology can also manipulate a broad range of wavelengths. Optical fiber transmits light which, although not suitable for direct viewing, can carry data that can be translated into sound or an image. The coding used in such data is similar to that used with radio waves.

12.2 Radio Waves

Radio waves can be made to carry information by varying a combination of the amplitude, frequency and phase of the wave within a frequency band. When EM radiation impinges upon a conductor, it couples to the conductor, travels along it, and induces an electric current on the surface of that conductor by exciting the electrons of the conducting material. This effect (the skin effect) is used in antennas. EM radiation may also cause certain molecules to absorb energy and thus to heat up; this is exploited in microwave ovens.

12.3 The Photoelectric Effect

Introduction

In 1913-1914, R.A. Millikan did a series of extremely careful experiments involving the photoelectric effect. He found that all of his results agreed exactly with Einstein's predictions about photons, not with the wave theory. Einstein actually won the Nobel Prize for his work on the photoelectric effect, not for his more famous theory of relativity. Then light *is* made of particles. Some experimental results, like this one, seem to prove beyond all possible doubt that light consists of particles; others insist, just as irrefutably, that it's waves. We can only conclude that light is somehow both a wave and a particle.

It's been determined experimentally that when light shines on a metal surface, the surface emits electrons. For example, you can start a current in a circuit just by shining a light on a metal plate. Why do you think this happens? Light is made up of electromagnetic waves, and the waves carry energy. So if a wave of light hit an electron in one of the atoms in the metal, it might transfer enough energy to knock the electron out of its atom. Historically, light has sometimes been viewed as a *particle* rather than a wave; Newton, for example, thought of light this way. The particle view was pretty much discredited with Young's double slit experiment, which made things look as though light had to be a wave. But in the early 20th century, some physicists Einstein, for one began to examine the particle view of light again. Einstein noted that careful

experiments involving the photoelectric effect could show whether light consists of particles or waves.

It seems that the photoelectric effect would still occur no matter which view is correct. Either way, the light would carry energy, so it would be able to knock electrons around. The details of the photoelectric effect come out differently depending on whether light consists of particles or waves. If it is waves, the energy contained in one of those waves should depend only on its amplitude, that is, on the intensity of the light. Other factors, like the frequency, should make no difference. So, for example, red light and ultraviolet light of the same intensity should knock out the same number of electrons, and the maximum kinetic energy of both sets of electrons should also be the same. Decrease the intensity, and you should get fewer electrons, flying out more slowly; if the light is too faint, you shouldn't get any electrons at all, no matter what frequency you're using.

How would the effect change if we assume that light is made of particles? We should give you some background information on this, first. It all began with some work on radiation by Max Planck... Planck's Constant and the Energy of a Photon. In 1900, Max Planck was working on the problem of how the radiation an object emits is related to its temperature. He came up with a formula that agreed very closely with experimental data, but the formula only made sense if he assumed that the energy of a vibrating molecule was **quantized**--that is, it could only take on certain values. The energy would have to be proportional to the frequency of vibration, and it seemed to come in little "chunks" of the frequency multiplied by a certain constant. This constant came to be known as **Planck's constant**, or h , and it has the value.

$$h = 6.626 \times 10^{-34} \text{ J} \cdot \text{s}$$

That's a pretty small constant, but it was an extremely radical idea to suggest that energy could only come in discrete lumps, even if the lumps were very small. Planck actually didn't realize how revolutionary his work was at the time; he thought he was just fudging the math to come up with the "right answer," and was convinced that someone else would come up with a better explanation for his formula. Based on Planck's work, Einstein proposed that light also delivers its energy in chunks; light

would then consist of little particles, or **quanta**, called **photons**, each with an energy of Planck's constant times its frequency.

In that case, the frequency of the light *would* make a difference in the photoelectric effect.

Higher-frequency photons have more energy, so they should make the electrons come flying out faster; thus, switching to light with the same intensity but a higher frequency should increase the maximum kinetic energy of the emitted electrons. If you leave the frequency the same but crank up the intensity, *more* electrons should come out (because there are more photons to hit them), but they won't come out any *faster*, because each individual photon still has the same energy.

And if the frequency is low enough, then none of the photons will have enough energy to knock an electron out of an atom. So if you use really low-frequency light, you shouldn't get *any* electrons, no matter how high the intensity is. Whereas if you use a high frequency, you should still knock out some electrons even if the intensity is very low.

Chapter Review Questions

1. Describe the Electromagnetic Radiation
2. Discuss light as an EM radiation
3. Discuss uses of Radio waves
4. Discuss the Photoelectric Effect
5. How are Electromagnetic waves produced?
6. Describe Electromagnetic radiation
7. What does photoelectric effect consist of?

Suggested References

- i. A-level Study Guide Computing by P. M. Heathcote, Kevin Bon (Paperback – 1997
- ii. Lasers - Theory And Applications ,Ghatak A. K. & Thyagarajan K.,2009, Macmillan, India
- iii. College physics fifth edition by serway and faughn, 1999, saunders college publishing

13.0 LASER

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Discuss the formation a Laser
- ii). Describe various Uses of Laser
- iii). Explain the Atom-Light Interaction

Introduction

Light Amplification by Stimulated Emission of Radiation (LASER or laser) is a mechanism for emitting electromagnetic radiation, typically light or visible light, via the process of stimulated emission. The emitted **laser light** is (usually) a spatially coherent, narrow low-divergence beam, that can be manipulated with lenses. In laser technology, "coherent light" denotes a light source that produces (emits) light of in-step waves of identical frequency, phase, and polarization. The laser's beam of coherent light differentiates it from light sources that emit *incoherent* light beams, of random phase varying with time and position. Laser light is generally a narrow-wavelength electromagnetic spectrum monochromatic light; yet, there are lasers that emit a broad spectrum of light, or emit different wavelengths of light simultaneously.

13.1 Uses of Laser

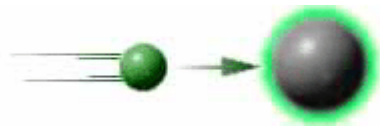
Lasers are used to cut precise patterns in glass and metal, to reshape corneas to correct poor vision, and to provide intense heat in controlled fusion experiments. But we also use lasers as very precise light sources in supermarket checkout lines, CD players, and to transmit most telephone signals.

That is exactly what makes laser light special. It is very organized waves with all the light exactly the same color and going in exactly the same direction. We can also think of light as little particles. With a laser these particles come in a perfectly uniform stream all going in the same direction. Because it is so orderly we can control laser light extremely well, and that is why we can use it to do so many things.

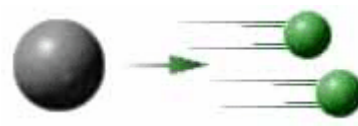
13.2 Atom-Light Interactions

If light of the right color hits an atom, it will bump an electron up to a higher energy level. And later the electron falls back down, giving off light of the same color in some random direction. But Einstein, more than 60 years ago, realized that there was also

something else that could happen. Adjust the "brightness" of the light source, which makes the particles of light called photons, come out faster and see if you notice anything curious happening: Something weird is going on...when a photon hits an atom that is already excited, it looks like the atom lets go of the photon. The photon goes in the same direction as the incoming photon. This is the key thing that Einstein figured out that makes lasers possible. When a photon hits an atom that is already excited, the atom releases a new photon that is **completely identical** to the incoming photon; same color, going in the same direction. We call this process "stimulated emission".



A photon strikes an excited atom...



And the atom emits a new photon *just like* the first one.

When one photon hits an excited atom, then we have two photons travelling together. When one of those finds another excited atom we get three photons, and so on and so on, but they are all exactly the same because they are being cloned by stimulated emission. So the number of photons gets amplified. The word laser is short for "Light Amplification by Stimulated Emission of Radiation". By the way, we're representing the light as little particles in this picture, but you can also think of it as waves. Then the incoming light is a wave, and when it hits the excited atom, the atom releases some energy that just makes the wave get bigger.



An electromagnetic wave strikes an excited atom...



And the wave takes the atom's extra energy to become a *bigger* wave.

13.3 Laptop Screens

A color laptop screen is somewhat like a TV screen, in that each pixel is made up of three "cells," red, green, and blue. Each "cell" is one of those devices we talked about: two polaroid filters with a twisted liquid crystal cell between them, an electric field that can be adjusted, and a red, blue or green filter. If you light up the red and green cells and darken the blue one, you get a yellow pixel, and so forth. But there are only eight possible colors you can get. So when you send light through that second polarizer, you don't want it to be an all-or-nothing proposition; you want to be able to let through any fraction of the light you desire. That means you'd have to change the amount that the liquid crystal twists the light.

Chapter Review Questions

1. Give the full words in the acronym LASER
2. Describe the formation a Laser
3. Describe various Uses of Laser
4. Explain the Atom-Light Interaction

14.0 HOLOGRAPHY AND COLOUR.

Learning Objectives.

By the end of this section, the learner should be able to:-

- i). Define Holography and colour.
- ii). Discuss the Holographic recording process
- iii). Describe the Holographic reconstruction process
- iv). Explain Mass replication in holography
- v). Discuss Holographic data storage

Introduction

14.1 Holography

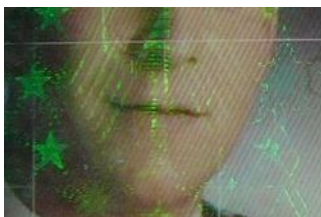


Hologram artwork at the MIT Museum.

Holography is the science of producing **holograms**; it is an advanced form of photography that allows an image to be recorded in three dimensions. The technique of holography can also be used to optically store, retrieve, and process information.

Holography was first discovered by Dennis Gabor while working to improve the resolution of an electron microscope at the British Thomson-Houston Company in Rugby, England. Gabor coined the term "hologram" from the Greek words *holos*, meaning "whole," and *gramma*, meaning "message." Continued development was not possible until the development of the laser in 1960, which was able to supply a monochromatic (single-color) light source from a single point.

Overview



Identigram as a security element in a German identity card (Personalausweis).

The first holograms which recorded 3D objects were made by Emmett Leith and Juris Upatnieks in Michigan, in 1963, and by Yuri Denisyuk in the Soviet Union.

Several types of holograms can be made. The very first holograms were "transmission holograms," which were viewed by shining laser light through them. A later refinement, the "rainbow transmission" hologram, allowed viewing by white light and is commonly seen today on credit cards as a security feature and on product packaging. These versions of the rainbow transmission holograms are formed as surface relief patterns in a plastic film, and they incorporate a reflective aluminum coating which provides the light from "behind" to reconstruct their imagery. Another kind of common hologram (a Denisyuk hologram) is the true "white-light reflection hologram" which is made in such a way that the image is reconstructed naturally using light on the same side of the hologram as the viewer.

One of the most promising recent advances in the short history of holography has been the mass production of low-cost, solid-state lasers—typically used by the millions in DVD recorders and other applications, but sometimes also useful for holography. These cheap, compact, solid-state lasers can compete well with the large, expensive gas lasers previously required to make holograms, and are already helping to make holography much more accessible to low-budget researchers, artists, and dedicated hobbyists.

14.2 Technical Description

The difference between holography and photography is best understood by considering what a black and white photograph actually is: A point-to-point recording of the intensity of light rays that make up an image. Each point on the photograph records just one thing, the intensity (i.e. the square of the amplitude of the electric field) of the light wave that illuminates that particular point. In the case of a color photograph, slightly more information is recorded (in effect the image is recorded three times, viewed through three different color filters), which allows a limited reconstruction of the wavelength of the light, and thus its color.

However, the light which makes up a real scene is not only specified by its amplitude and wavelength, but also by its phase. In a photograph, the phase of the light from the original scene is lost, and with it the three-dimensional effect. In a hologram, information from both the intensity and the phase is recorded. When illuminating the

hologram with the appropriate light, it diffracts part of it into exactly the same wave (up to a constant phase shift invisible to human eyes) which emanated from the original scene, thus retaining the three-dimensional appearance. Although color holograms are possible, in most cases the holograms are recorded monochromatically.

14.3 Holographic Recording Process

To produce a recording of the phase of the light wave at each point in an image, holography uses a "reference beam," which is combined with the light from the scene or object (the "object beam"). Optical interference between the reference beam and the object beam, due to the superposition of the light waves, produces a series of intensity fringes that can be recorded on standard photographic film. These fringes form a type of diffraction grating on the film, which is called the hologram or the interference pattern.

14.4 Holographic Recording

It is also important to note that these recorded fringes do not only directly represent their respective corresponding points in the space of a scene (the way each point on a photograph will only represent a single point in the scene being photographed). Rather, an individual section of even a very small size on a hologram's surface contains enough information to reconstruct the entire original scene (within limits) as viewed through that point's perspective. This is possible because during holographic recording, each point on the hologram's surface is affected by light waves reflected from all points in the scene, rather than from just one point. It can be thought of as if during recording, each point on the hologram's surface were an eye that could record everything it sees in any direction. After the hologram has been recorded, looking at a point in that hologram is like looking "through" one of those eyes.

To demonstrate this concept, one could cut out a small section of a recorded hologram, then view that cut-out section. One could still see most of the entire scene simply by shifting the viewpoint, the same way one would look outside from a small window in a house, for example.

14.5 Holographic Reconstruction Process

Holographic reconstruction.

Once the film is processed, if illuminated once again with the reference beam, diffraction from the fringe pattern on the film reconstructs the original object beam in both intensity and phase (except for rainbow holograms, where the depth information is encoded entirely in the zoneplate angle). Because both the phase and intensity are reproduced, the image appears three-dimensional; the viewer can move his or her viewpoint and see the image rotate exactly as the original object would.

Because of the need for interference between the reference and object beams, holography typically uses a laser in production. The light from the laser is split into two beams, one forming the reference beam, and one illuminating the object to form the object beam. A laser is used because the coherence of the beams allows interference to take place, although early holograms were made before the invention of the laser, and used other (much less convenient) coherent light sources such as mercury-arc lamps.

In simple holograms the coherence length of the beam determines the maximum depth the image can have. A laser will typically have a coherence length of several meters, ample for a deep hologram. Also certain pen laser pointers have been used to make small holograms. The size of these holograms is not restricted by the coherence length of the laser pointers (which can exceed 1 m), but by their low power of below 5 mW.

The diffraction grating reconstructs the point source. The light emerging from the photographic plate is identical to the light emerging when the point source used to be there. If you were standing on the other side of this simple hologram, your eyes would see the curved light rays (these are lines perpendicular to the wavefronts) and follow them perpendicularly back to where they meet, and tell the brain that there is a point there.

This is what human eyes do every day to see images. This is why people can see things that don't correspond directly to reality, like bent spoons in glasses, mirages, and reflections in mirrors, because eyes faithfully follow back the light to where it came from, whether the light actually started there or not: Every time there is a discrepancy between reality and what is seen, it is because light waves have been deviated or bent from their original course.

All objects that humans see, they see as a collection of point sources. Each point on the object radiates out light as a point source and the collection of points eyes see becomes a

whole object. It is the same with holograms: Every single point on the object records its own interference pattern, which gets individually reconstructed, and someone's eyes see all these points reconstructed together to see the whole picture of the hologram all at once.

This explains why one's view of the object in the hologram changes with his position; each time he moves, he is seeing a different ray emitted from each point source (like moving around in front of a window, you see the ray from different sides of objects depending where you're standing). With normal photography, the camera records just one view, so when one moves, he is in effect seeing the same ray again and his view doesn't change. (One is seeing different rays from each droplet of ink, but each droplet of ink is one ray of the picture.) The hologram, in comparison, records every possible view there is to see, all at once.

14.6 Mass Replication

An existing hologram can be replicated, either in an optical way similar to holographic recording, or in the case of surface relief holograms, by embossing. Surface relief holograms are recorded in photoresists or photothermoplastics, and allow cheap mass reproduction. Such embossed holograms are now widely used, for instance as security features on credit cards or quality merchandise. The Royal Canadian Mint even produces holographic gold and silver coinage through a complex stamping process.

The first step in the embossing process is to make a stamper by electrodeposition of nickel on the relief image recorded on the photoresist or photothermoplastic. When the nickel layer is thick enough, it is separated from the master hologram and mounted on a metal backing plate. The material used to make embossed copies consists of a polyester base film, a resin separation layer, and a thermoplastic film constituting the holographic layer.

The embossing process can be carried out with a simple heated press. The bottom layer of the duplicating film (the thermoplastic layer) is heated above its softening point and pressed against the stamper so that it takes up its shape. This shape is retained when the film is cooled and removed from the press. In order to permit the viewing of embossed holograms in reflection, an additional reflecting layer of aluminum is usually added on the hologram recording layer.

14.7 Dynamic Holography

The discussion above describes static holography, in which recording, developing, and reconstructing occur sequentially and a permanent hologram is produced. There exist also holographic materials that don't need the developing process and can record a hologram in a very short time. This allows one to use holography to perform some simple operations in an all-optical way. Examples of applications of such real-time holograms include phase-conjugate mirrors ("time-reversal" of light), optical cache memories, image processing, and optical computing.

The amount of processed information can be very high (in the Terabits range), since the operation is performed in parallel on a whole image. This compliments the fact that the recording time, which is in the order of a microsecond, is still very long compared to the processing time of an electronic computer. The optical processing performed by a dynamic hologram is also much less flexible than electronic processing. On one side, one has to perform the operation always on the whole image, and on the other side, the operation a hologram can perform is basically either a multiplication or a phase conjugation.

The search for novel nonlinear optical materials for dynamic holography is an active area of research. The most common materials are photorefractive crystals, but also in semiconductors or semiconductor heterostructures (such as quantum wells), atomic vapors and gases, plasmas, and even liquids it was possible to generate holograms.

A particularly promising application is optical phase conjugation. It allows one to remove the wavefront distortions a light beam receives when passing through an aberrating medium, by sending it back through the same aberrating medium with a conjugated phase. This is useful, for example, in free-space optical communications, to compensate the atmospheric turbulence.

14.8 Holographic Data Storage

Holography can be applied to a variety of uses other than recording images. Holographic data storage is a technique that can store information at high density inside crystals or photopolymers. As current storage techniques such as Blu-ray reach the denser limit of possible data density (due to the diffraction-limited size of the writing beams), holographic storage has the potential to become the next generation of

popular storage media. The advantage of this type of data storage is that the volume of the recording media is used instead of just the surface.

Currently available Spatial light modulators (SLMs) can produce about 1000 different images a second at 1024×1024 bit resolution. With the right type of media, probably polymers rather than something like lithium niobate (LiNbO_3), this would result in about 1 gigabit per second writing speed. Read speeds can surpass this and experts believe 1 terabit per second readout is possible.

In 2005, companies such as Optware and Maxell have produced a 120 mm disc that uses a holographic layer to store data to a potential 3.9 TB (terabyte), which they plan to market under the name Holographic Versatile Disc. Another company, InPhase Technologies, is developing a competitive format.

14.9 Digital Holography

An alternate method to record holograms is to use a digital device like a CCD (charge-coupled device) camera instead of a conventional photographic film. This approach is often called digital holography. In this case, the reconstruction process can be carried out by digital processing of the recorded hologram by a standard computer. A 3D image of the object can later be visualized on the computer screen or TV set.

14.9 Holography in Art

Salvador Dalí claimed to have been the first to employ holography artistically. He was certainly the first and most notorious surrealist to do so, but the 1972 New York exhibit of Dalí holograms had been preceded by the holographic art exhibition held at the Cranbrook Academy of Art in Michigan, in 1968, and by the one at the Finch College gallery in New York in 1970, which attracted national media attention

The Dalí Holograms were mastered in St. Louis, at the McDonnell Douglas Company, which had just invested in a Ruby Pulse Laser and decided to, aside from meteorological purposes, make industrially oriented projection Holograms for presentations and trade shows. In London, Dalí assembled his models by hanging objects with wires inside of wooden frames. This technique allowed for overlapping and differences in depth.

Since then the quality of the holograms has increased dramatically, mainly due to better holographic emulsions. As of 2005, there are many artists who use holograms in their creations.

Chapter Review Questions

1. Define Holography
2. Discuss the Holographic recording process
3. Describe the Holographic reconstruction process
4. Explain Mass replication in holography
5. Discuss Holographic data storage

Suggested References

- i. Practical Holography Graham Saxb 1994 Publisher: Prentice Hall- Gale
- ii. The Holographic Universe, Michael Talbot, 1996, Harper Collins



University Examination

THIRD TRIMESTER 2008/2009

BACHELOR OF BUSINESS INFORMATION TECHNOLOGY

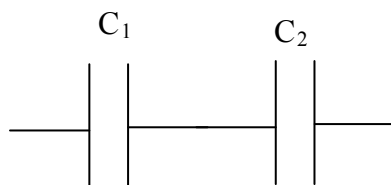
BBIT 1102: Basic Physics for BBIT

2 HOURS

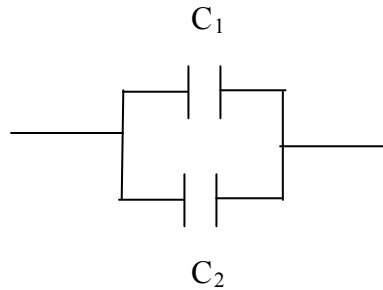
SECTION A: Answer ALL questions from this section [30mks]

Question One

- a. Name the three states of matter (3mks)
- b. Sketch a displacement-distance graph for a transverse wave, showing two complete cycles. Mark on your graph distances to show what is meant by wavelength and amplitude (3mks)
- c. An object is placed 25 cm from a concave mirror of focal length of 20cm the mirror. Find the distance of the image from the mirror. (3mks)
- d. List three factors affecting the resistance of a conductor (3mks)
- e. i. State Ohm's Law (1mk)
- ii. Two resistors of 3Ω and 6Ω are connected in parallel across a p.d. of 6V. Find the total current in the circuit. (3mks)
- f. i. Draw the symbol of a p-n junction diode and indicate the direction of conventional current flow. (2mk)
- ii. What does "biasing" a diode mean? Using well labeled diagrams, differentiate between forward bias and reverse bias. (2mks)
- g. What is a capacitor? (1mk)
- h. Given that C_1 and C_2 are $2\mu\text{F}$ and $3\mu\text{F}$ respectively, calculate the combined capacitance in the arrangement below. (3mks)

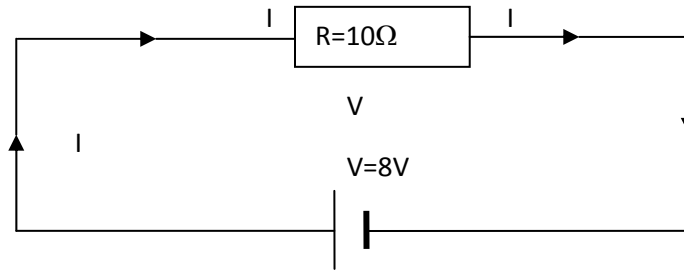


- i. Define a dielectric (1mk)
- j. Given that C_1 and C_2 are $5\mu\text{F}$ and $7\mu\text{F}$ respectively, calculate the combined capacitance in the arrangement below. (2mks)



k. Calculate the current in the following circuit

(3mks)



SECTION B: Answer TWO questions from this section [40mks]

Question 2

- Arrange the following in their order of increasing wavelength; blue light, ultraviolet rays, radio waves, gamma rays, infrared rays. (2mks)
- Define the refractive index of a material (2mks)
 - Define the critical angle for a material (2mks)
- Determine the refractive index of a material if light travels through this material at a speed of $1.5 \times 10^8 \text{ms}^{-1}$ (4mks)
- Name four properties of light (4mks)
 - Find the angle of refraction when
 - a ray of light travels from air to glass at an angle of incidence of 40° (3mks)
 - a ray of light is traveling from glass to air at an angle of 20° (3mks)
 (Take $n_g = 1.5$)

Question 4

- a. Use well labeled diagrams to explain how rays of light behave as they move from one side of lens to the other. (4mks)
- b. State the laws of electromagnetic induction (2mks)
- c. Describe conditions for Total internal reflection (T.I.R.) (2mks)
- d. Explain how an optic fibre works (2mks)
- e.
 - i. Differentiate between a step-up transformer and a step-down transformer (4mk)
 - ii. Name and describe any two sources of power loss in transformers and how they can be minimized (6mks)

Question 5

- a. Name and explain the two ways in which current is induced in a coil (6mks)
- b. Explain what happens when the forward voltage across a p-n junction is gradually increased from zero (2mks)
- c. Describe the mechanisms responsible for junction break down under increasing reverse voltage. (6mks)
- d. Explain why silicon n-p-n transistors are preferred over other types of transistors. (4mks)
- e. Name two applications of transistors (2mks)

Mt Kenya



University

UNIVERSITY EXAMINATION 2009/2010

SCHOOL OF APPLIED AND SOCIAL SCIENCES

DEPARTMENT OF INFORMATION TECHNOLOGY

EXAMINATION FOR BACHELOR OF BUSINESS INFORMATION TECHNOLOGY

BBIT 1102: BASIC ELECTRICITY & OPTICS

Time: 2Hours

Instructions

Answer question ONE and any other TWO questions

Question One

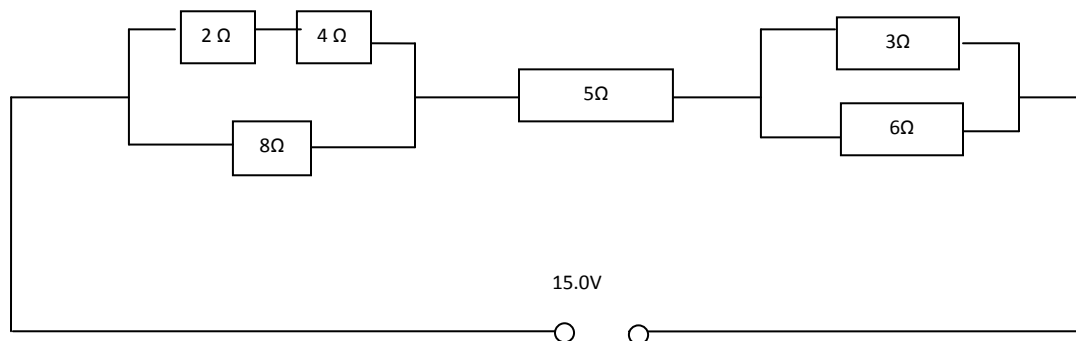
- (a) (i) State Ohm's law (2mks)
 - (ii) Define Capacitance (2mks)
- (b) (i) Differentiate between Hard and Soft X-rays (3mks)
 - (ii) State the conditions necessary for total internal reflection. (2mks)
- (c) (i) Differentiate between the following
 - I. Conductors
 - II. Semi-conductors
 - III. Insulators (3mks)
 - (ii) Differentiate between thin and thick lenses (2mks)
- (d) State the factors on which resistance of a conductor depends. (4mks)
- (e) (i) State the factors which affect capacitance of a capacitor. (3mks)
 - (ii) State FOUR properties of electromagnetic waves (4mks)
- (f) The frequency of an X-ray radiation used in killing deep cancer growth is 10^{12} Hz. Calculate the wavelength of this radiation. (3mks)

Question Two

- a) i) Define laser (2mks)
ii) Outline four (4) types of lasers (4mks)
iii) Outline four application areas of lasers (4mks)
- b) i) Differentiate between intrinsic and extrinsic semiconductor (2mks)
ii) With the aid of a diagram explain the working principles of a transistor (4mks)
iii) With the aid of a diagram explain how diodes are used to as a rectifier of a.c current and smoothing out the output (4mks)

Question Three

- (a) Define the term resistance as used in electricity. (2mks)
- (b) Calculate the current flowing through a circuit supplied by a 12v battery and connected to a $4\ \Omega$ resistor. (4mks)
- (c) Show from first principles that the combined resistance R_T for two resistors R_1 and R_2 combined in parallel is given as $R_T = \frac{R_1 R_2}{R_1 + R_2}$ (4mks)
- (d) Resistors are connected in a circuit diagram as shown in Fig 1 below.



Calculate

- (i) Total resistance in the circuit
- (ii) Total current in the circuit
- (iii) Current in the 3Ω resistor
- (iv) Current through 8Ω resistor (10mks)

Question Four

- a) i) With the aid of a diagram outline the working principle of fibre optics (4mks)
- ii) With the aid of a diagram show that the lens equation is given by

$$\frac{1}{Z} = \frac{1}{V} + \frac{1}{u}$$

where Z is the focal length, V the image distance and u the object distance. (8mks)

- b) The figure 2 below shows a combination of capacitors. If $C_1 = C_2 = C_3 = C_4 = C_5 = 30\mu\text{f}$.

Find

- i. Equivalent capacitance
- ii. Voltage drop across C_5
- iii. Energy possessed by C_3
- iv. Charge on C_2

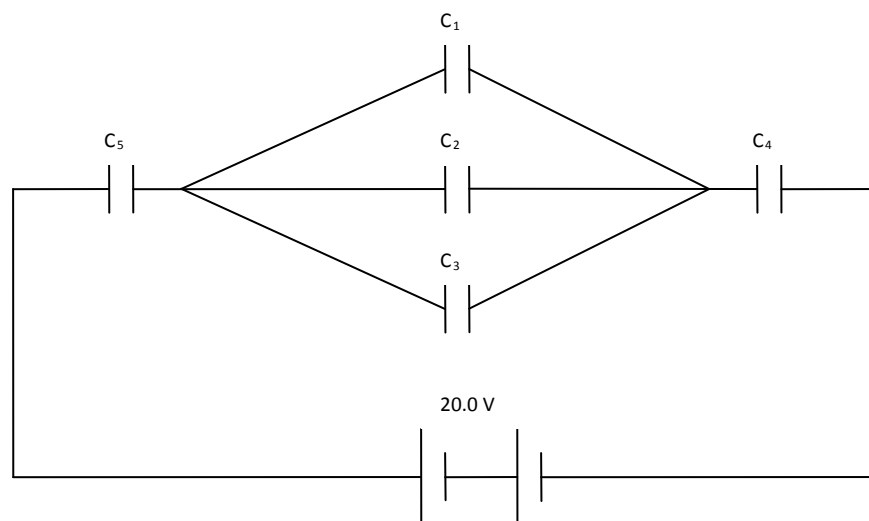


Figure 2

(8mks)

Question Five

- a) i) State Faraday's law
ii) State Lenz's law
iii) Outline mutual inductance (4mks)
- b) Outline three (3) ways in which energy is lost in transformers (6mks)
- c) A transformer is to be used to provide power to a 12V lamp from an a.c mains supply of 315V. Current through the lamp is 5A and efficiency of the transformer is 80%. Find
- Find the number of turns of the secondary coil in the primary coil has 1000 turns.
 - Power supplied to the transformer
 - Current in the primary coil
- (10mks)