Physics

XII

Resource material of Ziauddin University Examination board

BENCHMARKS

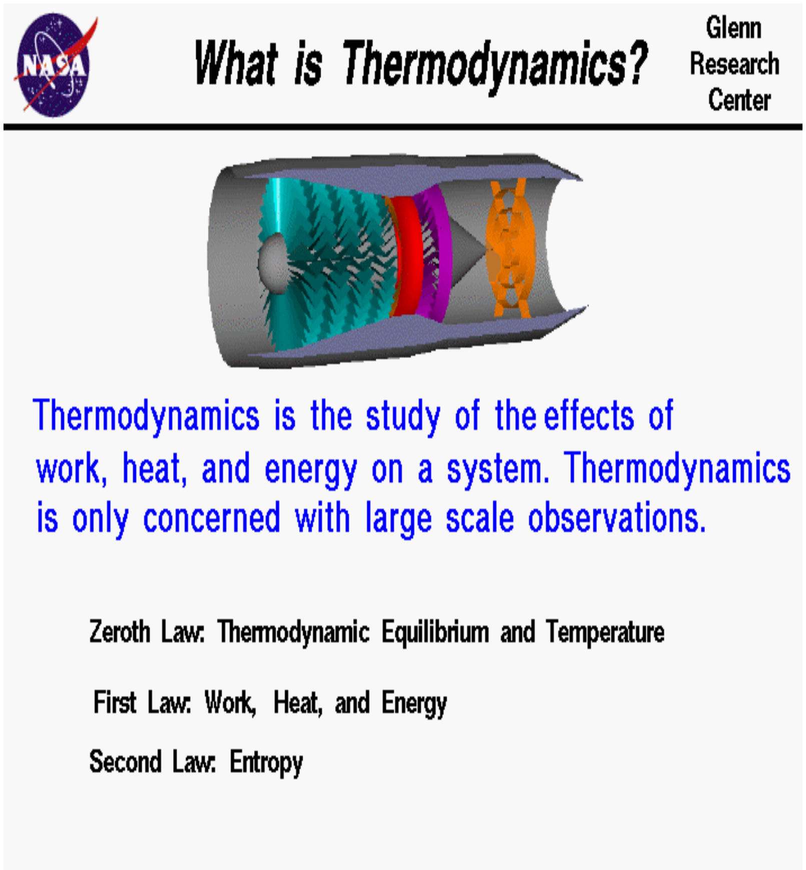
- Ask questions that can be investigated empirically.
- Develop solutions to problems through reasoning, observation, and investigations.
- Design and conduct scientific investigations.
- Recognize and explain the limitations of measuring devices.
- Gather and synthesize information from books and other sources of information.
- Discuss topics in groups by making clear presentations, restating or summarizing what others have said, asking for clarification or elaboration, taking alternative perspectives, and defending a position.
- Justify plans or explanations on a theoretical or empirical basis.
- Describe some general limitations of scientific knowledge.
- Show how common themes of science, mathematics, and technology apply in real world contexts.
- Discuss the historical development of the key scientific concepts and principles.
- Explain the social and economical advantages and risks of new technology.
- Develop an awareness and sensitivity to the natural world.
- Describe the historical, political and social factors affecting developments in science.
- Appreciate the ways in which models, theories and laws in physics have been tested and validated
- Assess the impacts of applications of physics on society and the environment.
- Justify the appropriateness of a particular investigation plan.
- Identify ways in which accuracy and reliability could be improved in investigations.
- Use terminology and report styles appropriately and successfully to communicate information.
- Assess the validity of conclusions from gathered data and information.
- Explain events in terms of Newton’s laws and law of conservation of momentum
- Explain the effects of energy transfers and energy transformations.
- Explain mechanical, electrical and magnetic properties of solids and their significance.
- Demonstrate an understanding of the principles related to fluid dynamics and their applications.
- Explain that heat flow and work are two forms of energy transfers between systems and their significance.
- Understand wave properties, analyze wave interactions and explain the effects of those interactions.
- Demonstrate an understanding of wave model of light as e.m waves and describe how it explains diffraction patterns, interference and polarization.

CHAPTER CONTENT

	Name of chapter
Unit # 10	Thermodynamic
Unit # 11	Electrostatics
Unit # 12	Current Electricity
Unit # 13	Electromagnetism
Unit # 14	Electromagnetism Induction
Unit # 15	Alternating current
Unit # 16	Physics of solid
Unit # 17	Electronics
Unit # 18	Dawn of Modern Physics
Unit # 19	Atomic Spectra
Unit # 20	Nuclear Physics

Unit#10

Thermodynamics

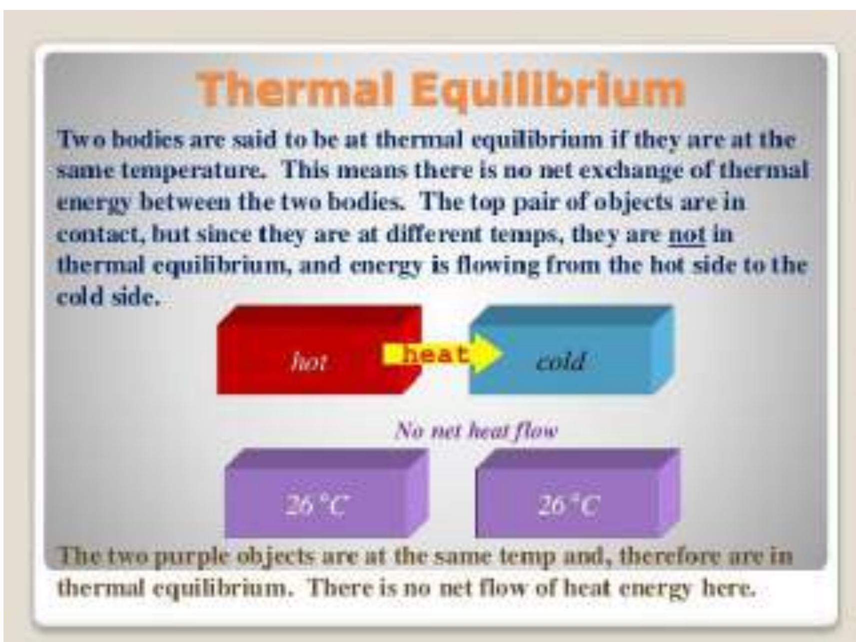


Topics	Understandings	Skills
• Thermal equilibrium • Heat and work • Internal energy • First law of thermodynamics • Molar specific heats of a gas • Heat engine • Second law of thermodynamics • Carnot's cycle • Refrigerator • Entropy	The students will: • Describe that thermal energy is transferred from a region of higher temperature to a region of lower temperature. • Describe that regions of equal temperatures are in thermal equilibrium . • Describe that heat flow and work are two forms of energy transfer between systems and calculate heat being transferred. • Define thermodynamics and various terms associated with it. • Relate a rise in temperature of a body to an increase in its internal energy. • Describe the mechanical equivalent of heat concept, as it was historically developed, and solve problems involving work being done and temperature change. • Explain that internal energy is determined by the state of the system and that it can be expressed as the sum of the random distribution of kinetic and potential energies associated with the molecules of the system. • Calculate work done by a thermodynamic system during a volume change. • Describe the first law of thermodynamics expressed in terms of the change in internal energy, the heating of the system and work done on the system. • Explain that first law of thermodynamics expresses the conservation of energy. • Define the terms, specific heat and molar specific heats of a gas. • Apply first law of thermodynamics to derive $C_p - C_v = R$. • State the working principle of heat engine. • Describe the concept of reversible and irreversible processes. • State and explain second law of thermodynamics. • Explain the working principle of Carnot's engine • Explain that the efficiency of a	The students will: • determine the mechanical equivalent of heat by electric method. • determine the specific heat of solid by electrical method.

	Carnot engine is independent of the nature of the working substance and depends on the temperatures of hot and cold reservoirs. • Describe that refrigerator is a heat engine operating in reverse as that of an ideal heat engine. • Derive an expression for the coefficient of performance of a refrigerator. • Describe that change in entropy is positive when heat is added and negative when heat is removed from the system. • Explain that increase in temperature increases the disorder of the system. • Explain that increase in entropy means degradation of energy. • Explain that energy is degraded during all natural processes. • Identify that system tend to become less orderly over time.	

Unit overview

Thermal Equilibrium



Two physical systems are in thermal equilibrium if there is no net flow of thermal energy between them when they are connected by a path permeable to heat. Thermal equilibrium obeys the zeroth law of thermodynamics. A system is said to be in thermal equilibrium with itself if the temperature within the system is spatially uniform and temporally constant.

Systems in thermodynamic equilibrium are always in thermal equilibrium, but the converse is not always true. If the connection between the systems allows transfer of energy as heat but does not allow transfer of matter or transfer of energy as work, the two systems may reach thermal equilibrium without reaching thermodynamic equilibrium.

Videos

Reference pages

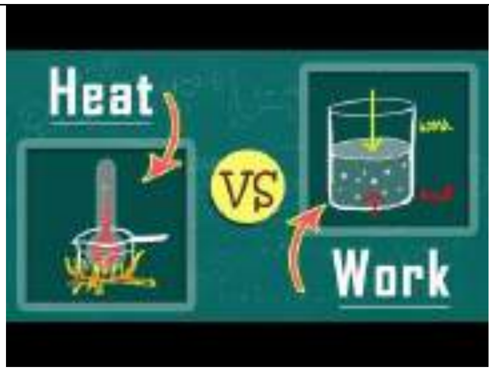
https://images.search.yahoo.com/yhs/search?p=Thermal+equilibrium+byjus&fr=yhs-ima-002&hspart=ima&hsimp=yhs-002&imgurl=http%3A%2F%2Fwww.justscience.in%2Fwp-content%2Fuploads%2F2017%2F05%2FWHAT-ARE-THE-PRINCIPLES-BEHIND-THERMAL-EQUILIBRIUM.jpg#id=5&iurl=https%3A%2F%2Fimage.slidesharecdn.com%2Fcapter10-140508160606-phpapp01%2F95%2Fcapter-10-for-9th-grade-physics-28-638.jpg%3Fcb%3D1399565284&action=click

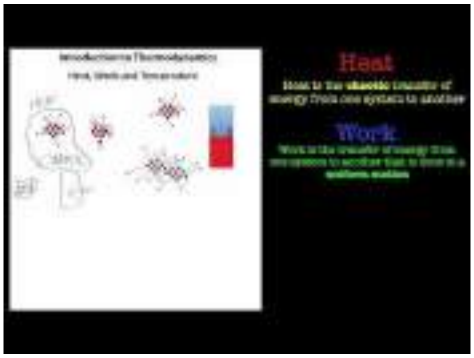
https://en.wikipedia.org/wiki/Thermal_equilibrium

Heat and work

Heat and work are two different ways of transferring energy from one system to another. The the distinction between Heat and Work is important in the field of thermodynamics. Heat is the transfer of thermal energy between systems, while work is the transfer of mechanical energy between two systems. This distinction between the microscopic motion (heat) and macroscopic motion (work) is crucial to how thermodynamic processes work. Heat can be transformed into work and vice verse (see mechanical equivalent of heat), but they aren't the same thing. The first law of thermodynamics states that heat and work both contribute to the total internal energy of a system, but the second law of thermodynamics limits the amount of heat that can be turned into work

Videos





Reference pages

https://energyeducation.ca/encyclopedia/Heat_vs_work

Internal Energy

An energy form inherent in every system is the internal energy, which arises from the molecular state of motion of matter. The symbol U is used for the internal energy and the unit of measurement is the joules (J).

Internal energy increases with rising temperature and with changes of state or phase from solid to liquid and liquid to gas. Planetary bodies can be thought of as combinations of heat reservoirs and heat engines. The heat reservoirs store internal energy E, and the heat engines convert some of this thermal energy into various types of mechanical, electrical and chemical energies.

Internal Energy Explanation

Internal energy U of a system or a body with well defined boundaries is the total of the kinetic energy due to the motion of molecules and the potential energy associated with the vibrational motion and electric energy of atoms within molecules. Internal energy also includes the energy in all the chemical bonds. From a microscopic point of view, the internal energy may be found in many different forms. For any material or repulsion between the individual molecules.

Internal energy is a state function of a system and is an extensive quantity. One can have a corresponding intensive thermodynamic property called specific internal energy, commonly symbolized by the lowercase letter u, which is internal energy per mass of the substance in question. As such the SI unit of specific internal energy would be the J/g. If the internal energy is expressed on an amount of substance basis then it could be referred to as molar internal energy and the unit would be the J/mol.

Internal Energy of a Closed System

For a closed system the internal energy is essentially defined by

$\Delta U = q + W$

Where

- U is the change in internal energy of a system during a process
- q is the heat
- W is the mechanical work.

If an energy exchange occurs because of temperature difference between a system and its surroundings, this energy appears as heat otherwise it appears as work. When a force acts on a system through a distance the energy is transferred as work. The above equation shows that energy is conserved.

Internal Energy Change

Every substance possesses a fixed quantity of energy which depends upon its chemical nature and its state of existence. This is known as intrinsic energy. Every substance has a definite value of internal energy and is equal to the energies possessed by all its constituents namely atoms, ions or molecules.

The change in internal energy which occurs during chemical reactions. The change in internal energy of a reaction may be considered as the difference between the internal energies of the two states.

Let E_A and E_b are the initial energies in states A and B respectively. Then the difference between the initial energies in the two states will be

$\Delta U = E_B – E_A$

The difference in internal energies has a fixed value and will be independent of the path taken between two states A and B. For the chemical reaction, the change in internal energy may be considered as the difference between the internal energies of the products and that of the reactants.

$$\Delta U = E_{products} – E_{reactants}$$

Thus, the internal energy, ΔU is a state function. This means that ΔU depends only on the initial and final states and is independent of the path. In other words, ΔU will be the same even if the change is brought about differently.

What is the significance of internal energy?

Internal energy is important for understanding phase changes, chemical reactions, nuclear reactions, and many other microscopic phenomena, as the possible energies between molecules and atoms are important. Both objects exhibit macroscopic and microscopic energy in vacuum.

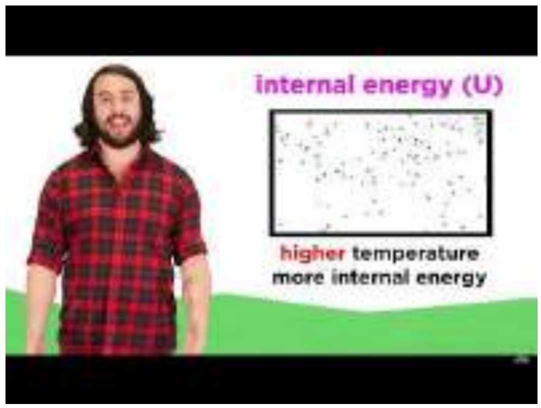
What factors affect internal energy?

The internal energy can be altered by modifying the object's temperature or volume without altering the amount of particles inside the body. Temperature: As a system's temperature increases, the molecules will move faster, thus have more kinetic energy and thus the internal energy will increase.

Is internal energy a state function?

A state function defines a system's equilibrium state, and thus defines the system itself as well. For example, internal energy, enthalpy, and entropy are state quantities since they quantitatively describe a thermodynamic system's equilibrium state, regardless of how the system has arrived in that state.

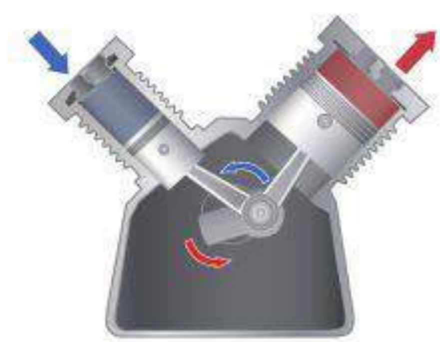
Videos



Reference pages

https://byjus.com/chemistry/internal-energy/

First law of thermodynamics



A hot gas, when confined in a chamber, exerts pressure on a piston, causing it to move downward. The movement can be harnessed to do work equal to the total force applied to the top of the piston times the distance that the piston moves. (Image: © GoodIll | Shutterstock)

The First Law of Thermodynamics states that heat is a form of energy, and thermodynamic processes are therefore subject to the principle of conservation of energy. This means that heat energy cannot be created or destroyed. It can, however, be transferred from one location to another and converted to and from other forms of energy.

Thermodynamics is the branch of physics that deals with the relationships between heat and other forms of energy. In particular, it describes how thermal energy is converted to and from other forms of energy and how it affects matter. The fundamental principles of thermodynamics are expressed in four laws.

“The First Law says that the internal energy of a system has to be equal to the work that is being done on the system, plus or minus the heat that flows in or out of the system and any other work that is done on the system," said Saibal Mitra, a professor of physics at Missouri State University. "So, it’s a restatement of conservation of energy."

Mitra continued, "The change in internal energy of a system is the sum of all the energy inputs and outputs to and from the system similarly to how all the deposits and withdrawals you make determine the changes in your bank balance.” This is expressed mathematically as: $\Delta U = Q - W$, where ΔU is the change in the internal energy, Q is the heat added to the system, and W is the work done by the system.

Videos

Reference pages

https://www.livescience.com/50881-first-law-thermodynamics.html

Molar Specific Heats of Gases

The molar specific heats of ideal monoatomic gases are:

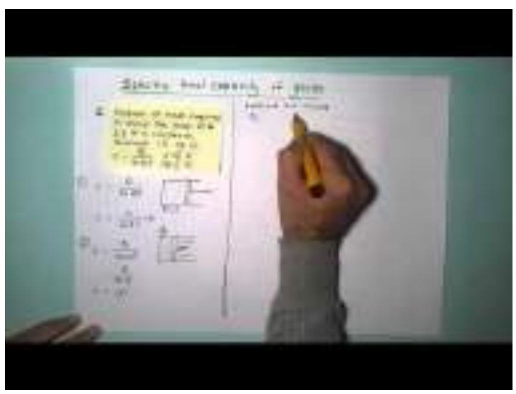
Rationale:

Constant volume: $C_V = \frac{3}{2}R = 12.5\frac{J}{mol \cdot K}$ $\frac{R}{2}$ for each of the three translational degrees of freedom.

Constant pressure: $C_P = \frac{5}{2}R = 20.8\frac{J}{mol \cdot K}$ $C_P = C_V + R$

For diatomic molecules, two rotational degrees of freedom are added, corresponding to the rotation about two perpendicular axes through the center of the molecule. This would be expected to give $C_V = 5/2\ R$, which is borne out in examples like nitrogen and oxygen. A general polyatomic molecule will be able to rotate about three perpendicular axes, which would be expected to give $C_V = 3R$. The departure from this value which is observed indicates that vibrational degrees of freedom must also be included for a complete description of specific heats of gases

Videos

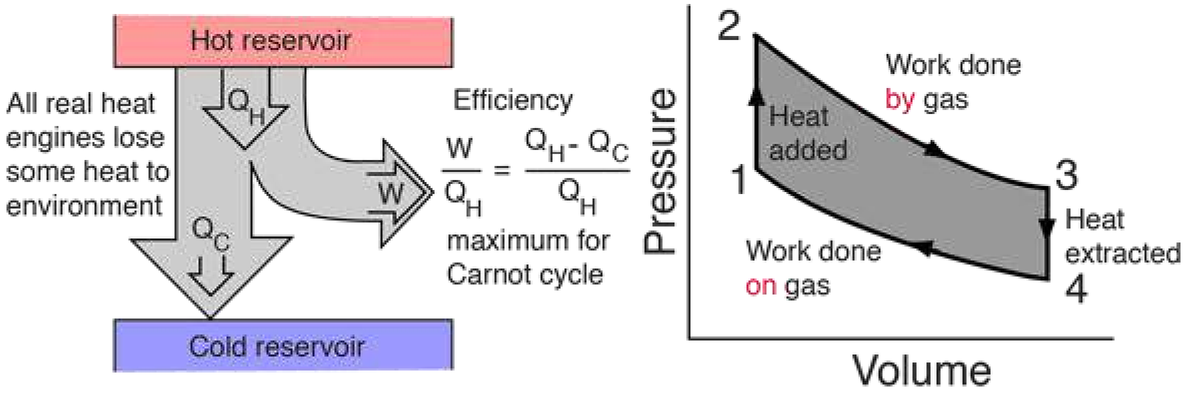


Reference pages

http://hyperphysics.phy-astr.gsu.edu/hbase/Kinetic/shegas.html

Heat Engine

A heat engine typically uses energy provided in the form of heat to do work and then exhausts the heat which cannot be used to do work. Thermodynamics is the study of the relationships between heat and work. The first law and second law of thermodynamics constrain the operation of a heat engine. The first law is the application of conservation of energy to the system, and the second sets limits on the possible efficiency of the machine and determines the direction of energy flow.



General heat engines can be described by the reservoir model (left) or by a PV diagram (right)

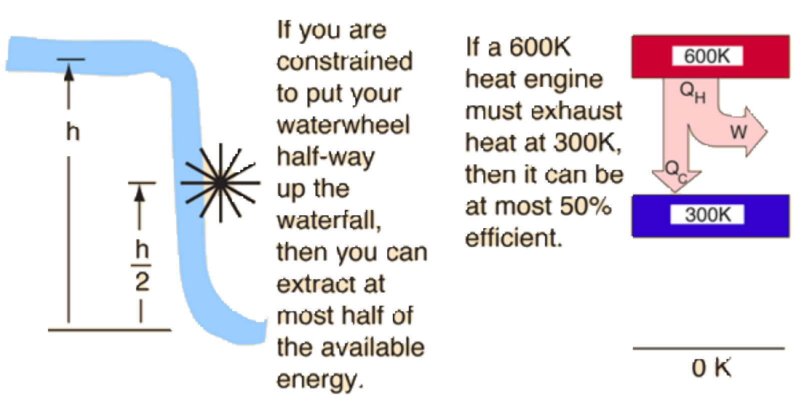
Videos

Reference pages

http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/heaeng.html

Second Law of Thermodynamics

The second law of thermodynamics is a general principle which places constraints upon the direction of heat transfer and the attainable efficiencies of heat engines. In so doing, it goes beyond the limitations imposed by the first law of thermodynamics. Its implications may be visualized in terms of the waterfall analogy.

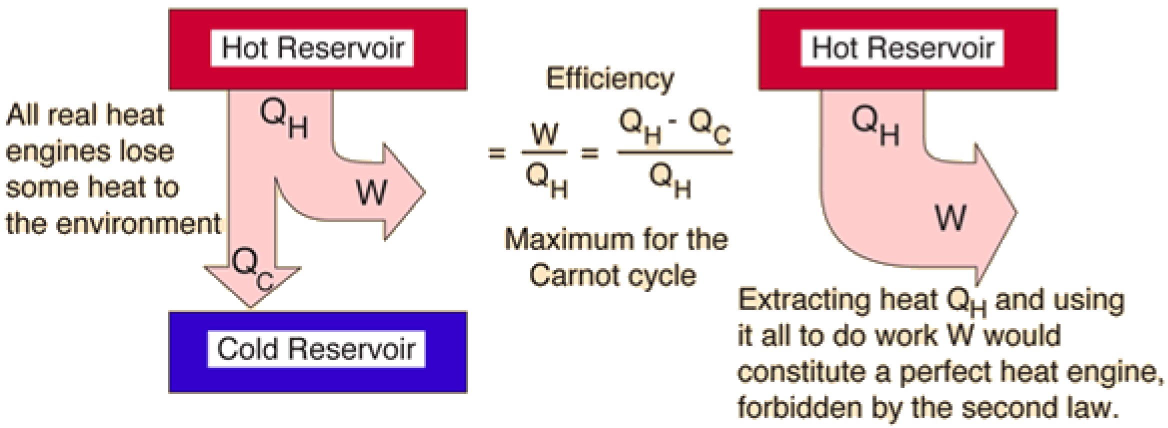


The maximum efficiency which can be achieved is the Carnot efficiency.

Second Law: Heat Engines

Second Law of Thermodynamics: It is impossible to extract an amount of heat Q_H from a hot reservoir and use it all to do work W. Some amount of heat Q_C must be exhausted to a cold reservoir. This precludes a perfect heat engine.

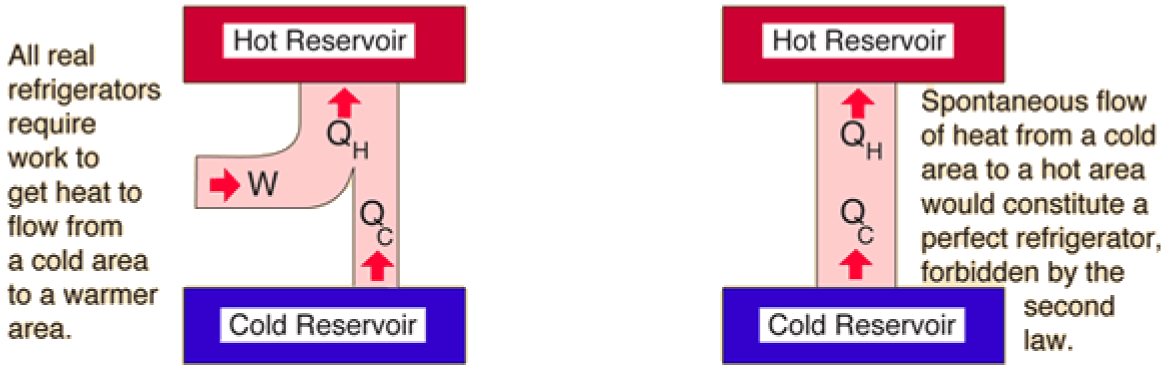
This is sometimes called the "first form" of the second law, and is referred to as the Kelvin-Planck statement of the second law.



Second Law: Refrigerator

Second Law of Thermodynamics: It is not possible for heat to flow from a colder body to a warmer body without any work having been done to accomplish this flow. Energy will not flow spontaneously from a low temperature object to a higher temperature object. This precludes a perfect refrigerator. The statements about refrigerators apply to air conditioners and heat pumps, which embody the same principles.

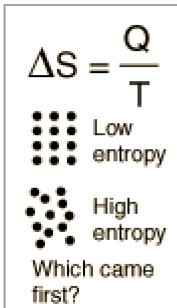
This is the "second form" or Clausius statement of the second law.



It is important to note that when it is stated that energy will not spontaneously flow from a cold object to a hot object, that statement is referring to net transfer of energy. Energy can transfer from the cold object to the hot object either by transfer of energetic particles or electromagnetic radiation, but the net transfer will be from the hot object to the cold object in any spontaneous process. Work is required to transfer net energy to the hot object.

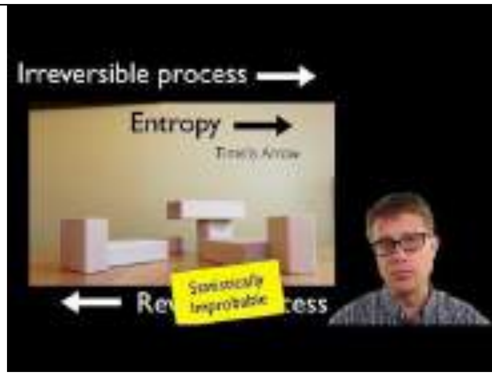
Second Law: Entropy

Second Law of Thermodynamics: In any cyclic process the entropy will either increase or remain the same.

Entropy:	a state variable whose change is defined for a reversible process at T where Q is the heat absorbed.	
Entropy:	a measure of the amount of energy which is unavailable to do work.	
Entropy:	a measure of the disorder of a system.	
Entropy:	a measure of the multiplicity of a system.	

Since entropy gives information about the evolution of an isolated system with time, it is said to give us the direction of "time's arrow". If snapshots of a system at two different times shows one state which is more disordered, then it could be implied that this state came later in time. For an isolated system, the natural course of events takes the system to a more disordered (higher entropy) state.

Videos



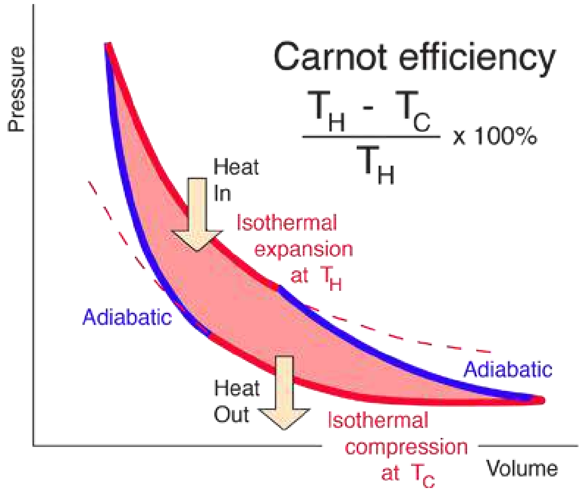
Reference pages

http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/seclaw.html#c1

Carnot Cycle

The most efficient heat engine cycle is the Carnot cycle, consisting of two isothermal processes and two adiabatic processes. The Carnot cycle can be thought of as the most efficient heat engine cycle allowed by physical laws. When the second law of thermodynamics states that not all the supplied heat in a heat engine can be used to do work, the Carnot efficiency sets the limiting value on the fraction of the heat which can be so used.

In order to approach the Carnot efficiency, the processes involved in the heat engine cycle must be reversible and involve no change in entropy. This means that the Carnot cycle is an idealization, since no real engine processes are reversible and all real physical processes involve some increase in entropy.



For

T_H = [ ] K

T_C = [ ] K

the Carnot efficiency is

[ ] %

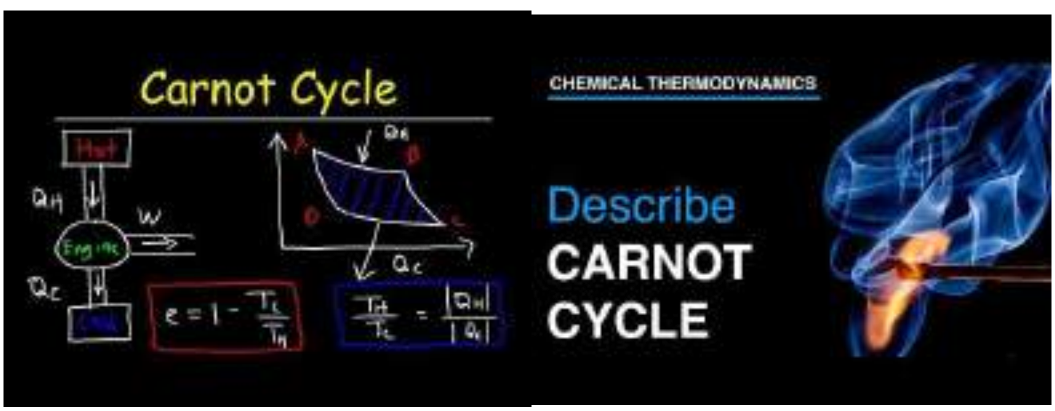
The temperatures in the Carnot efficiency expression must be expressed in Kelvins. For the other temperature scales, the following conversions apply:

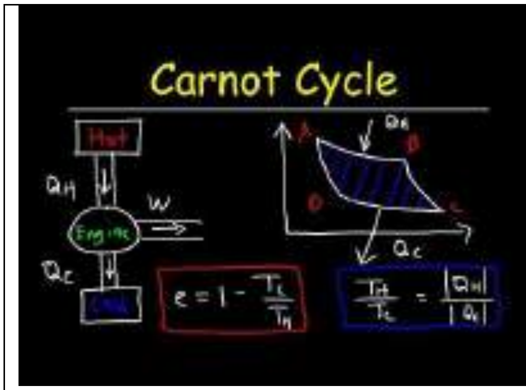
T_H = [ ] K = [ ] °C = [ ] °F

T_C = [ ] K = [ ] °C = [ ] °F

The conceptual value of the Carnot cycle is that it establishes the maximum possible efficiency for an engine cycle operating between T_H and T_C. It is not a practical engine cycle because the heat transfer into the engine in the isothermal process is too slow to be of practical value. As Schroeder puts it, "So don't bother installing a Carnot engine in your car; while it would increase your gas mileage, you would be passed on the highway by pedestrians."

Video





Reference

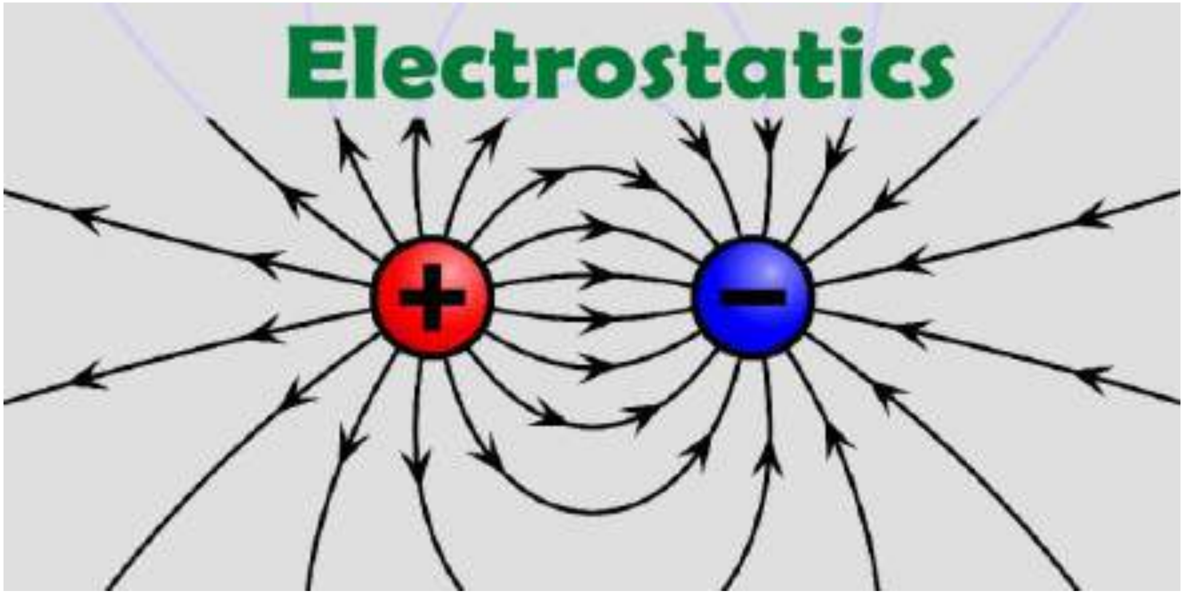
http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/carnot.html

Learning Outcomes

The students will:

- Describe that thermal energy is transferred from a region of higher temperature to a region of lower temperature.
- Describe that regions of equal temperatures are in thermal equilibrium .
- Describe that heat flow and work are two forms of energy transfer between systems and calculate heat being transferred.
- Define thermodynamics and various terms associated with it.
- Relate a rise in temperature of a body to an increase in its internal energy.
- Describe the mechanical equivalent of heat concept, as it was historically developed, and solve problems involving work being done and temperature change.
- Explain that internal energy is determined by the state of the system and that it can be expressed as the sum of the random distribution of kinetic and potential energies associated with the molecules of the system.
- Calculate work done by a thermodynamic system during a volume change.
- Describe the first law of thermodynamics expressed in terms of the change in internal energy, the heating of the system and work done on the system.
- Explain that first law of thermodynamics expresses the conservation of energy.
- Define the terms, specific heat and molar specific heats of a gas.
- Apply first law of thermodynamics to derive $C_p - C_v = R$.
- State the working principle of heat engine.
- Describe the concept of reversible and irreversible processes.
- State and explain second law of thermodynamics.
- Explain the working principle of Carnot's engine
- Explain that the efficiency of a Carnot engine is independent of the nature of the working substance and depends on the temperatures of hot and cold reservoirs.
- Describe that refrigerator is a heat engine operating in reverse as that of an ideal heat engine.
- Derive an expression for the coefficient of performance of a refrigerator.
- Describe that change in entropy is positive when heat is added and negative when heat is removed from the system.
- Explain that increase in temperature increases the disorder of the system.
- Explain that increase in entropy means degradation of energy.
- Explain that energy is degraded during all natural processes.
- Identify that system tend to become less orderly over time.

Unit # 11



Topics	Understandings	Skills
•Force between charges in different media • Electric field • Electric field of various charge configurations • Electric field due to a dipole • Electric flux • Gauss's law and its applications • Electric potential • Capacitors	• state Coulomb's law and explain that force between two point charges is reduced in a medium other than free space using Coulomb's law. • derive the expression E = l/4πεo q/r2 for the magnitude of the electric field at a distance 'r' from a point charge 'q'. • describe the concept of an electric field as an example of a field of force.	• draw graphs of charging and discharging of a capacitor through a resistor. **Science, Technology and Society** Connections The students will: • describe the principle of inkjet printers and Photostat copier as an application of electrostatic phenomenon.

• Energy stored in a capacitor	• define electric field strength as force per unit positive charge . • solve problems and analyze information using E = F/q. • solve problems involving the use of the expression . • E = l/4πεo q/r2 Conceptual linkage: ²This chapter is built on Electrostatics Physics X 35 • calculate the magnitude and direction of the electric field at a point due to two charges with the same or opposite signs. • sketch the electric field lines for two point charges of equal magnitude with same or opposite signs. • describe the concept of electric dipole. • define and explain electric flux. • describe electric flux through a surface enclosing a charge. • state and explain Gauss's law. • describe and draw the electric field due to an infinite size conducting plate of positive or negative charge. • sketch the electric field produced by a hollow spherical charged conductor. • sketch the electric field between and near the edges of two infinite size oppositely charged parallel plates. • define electric potential at a point in terms of the work done in bringing unit positive charge from infinity to that point. • define the unit of potential. • solve problems by using the expression V =W/q. • describe that the electric field at a point is given by the negative of potential gradient at that point. • solve problems by using the expression E = V/d. • derive an expression for electric potential at a point due to a point charge. • calculate the potential in the field of a point charge using the equation V = l/4πεo q/r. • define and become familiar with the use of electron volt. • define capacitance and the farad and solve problems by using C=Q/V. • describe the functions of capacitors in simple circuits. • solve problems using formula for capacitors in series and in parallel. • explain polarization of dielectric of a capacitor.	• describe the applications of Gauss's law to find the electric force due to various charge configurations • list the use of capacitors in various household appliances such as in flash gun of camera, refrigerator, electric fan, rectification circuit etc.

	• demonstrate charging and discharging of a capacitor through a resistance. • prove that energy stored in a capacitor is W=1/2QV and hence W=1/2CV2.	

Topics overview

1.Force between charges in different media

According to Coulomb's law: The electrostatic force of attraction or repulsion between two point charges is directly proportional to the product of charges. The electrostatic force of attraction or repulsion between two point charges is inversely proportional to the square of distance between them.

$$F_m = \frac{1}{4\pi\varepsilon}\frac{q_1q_2}{r^2} \qquad \ldots(2)$$

Dividing equation (1) by (2)

$$\frac{F}{F_m} = \frac{\varepsilon}{\varepsilon_o} = \varepsilon_r$$

The ratio $\frac{\varepsilon}{\varepsilon_o} = \varepsilon_r$, is called the relative permittivity or dielectric constant of the medium. The value of ε_r for air or vacuum is 1.

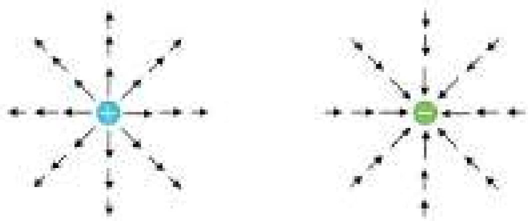
$$\therefore \quad \varepsilon = \varepsilon_o\varepsilon_r$$

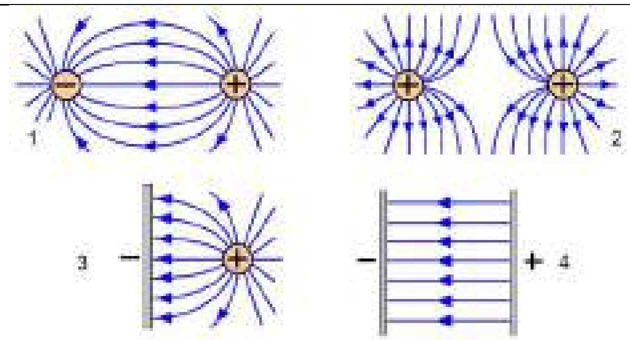
Since $F_m = \frac{F}{\varepsilon_r}$, the force between two point charges depends on the nature of the medium in which the two charges are situated.

Video Link:

2.Electric field:

A region around a charged particle or object within which a force would be exerted on other charged particles or objects.

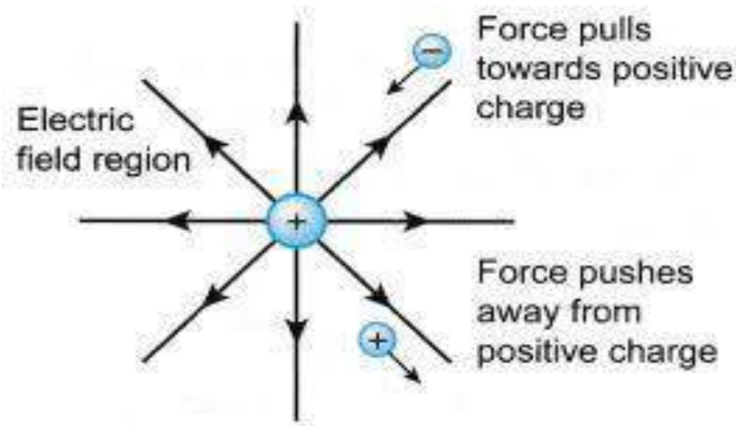


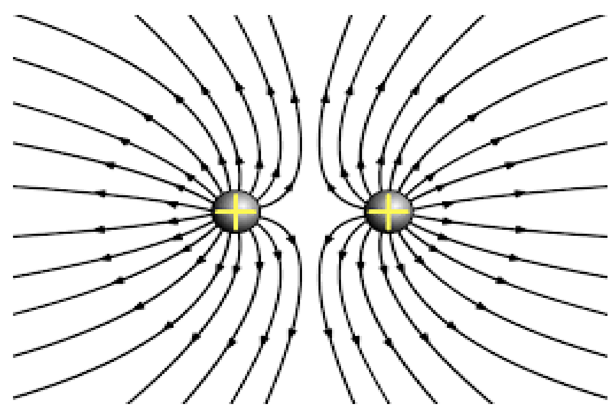


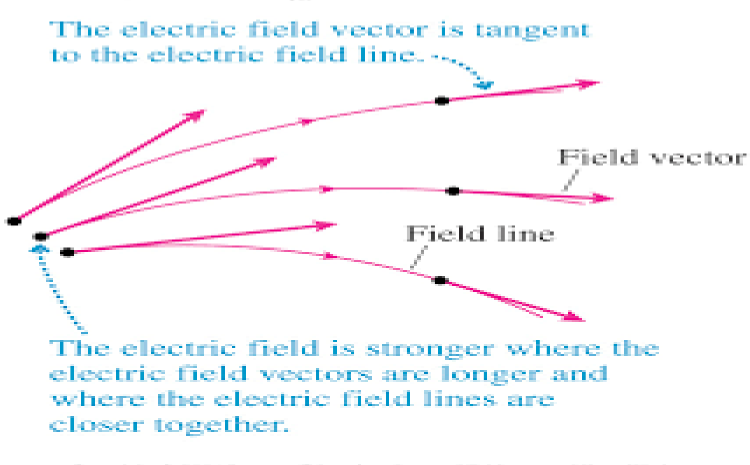
An electric field (sometimes abbreviated as E-field) surrounds an electric charge, and exerts force on other charges in the field, attracting or repelling them. Electric fields are created by electric charges, or by time-varying magnetic fields. Electric fields and magnetic fields are both manifestations of the electromagnetic force, one of the four fundamental forces (or interactions) of nature.

Electric fields are important in many areas of physics, and are exploited practically in electrical technology. On an atomic scale, the electric field is responsible for the attractive force between the atomic nucleus and electrons that holds atoms together, and the forces between atoms that cause chemical bonding.

The electric field is defined mathematically as a vector field that associates to each point in space the (electrostatic or Coulomb) force per unit of charge exerted on an infinitesimal positive test charge at rest at that point. The SI unit for electric field is volt per meter (V/m), exactly equivalent to newton per coulomb (N/C) in the SI system.







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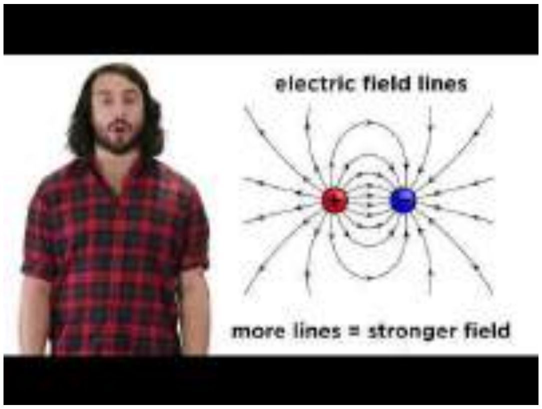


3.Electric field of various charge configurations

Conductors with static charges :

An electrical conductor is an object through which electrons or ions can move about relatively freely. Metals make good conductors. If a net charge is placed on a conductor and it is then left alone, the charge very quickly settles down to an equilibrium distribution. There are several interesting things to note about that situation. (See figure 1.3.)

• The net charge is spread out over the surface of the conductor, but not uniformly.
• There is an electric field in the space around the conductor but not inside it.
• At points just outside the surface of the conductor, the electric field and the electric field lines are perpendicular to the surface.

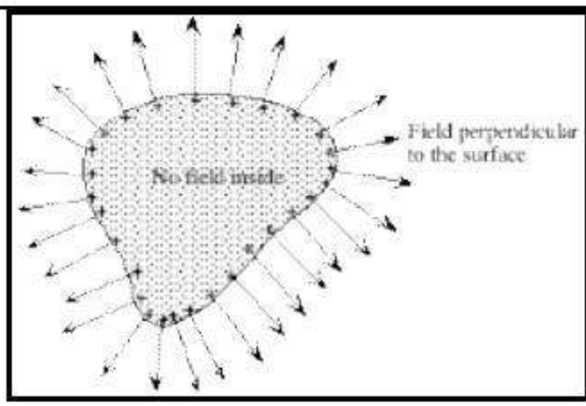


Figure 1.3 Electrostatic field near the surface of a conductor
The charge density varies over the surface. The field near the surface is strongest where the charge density is highest.

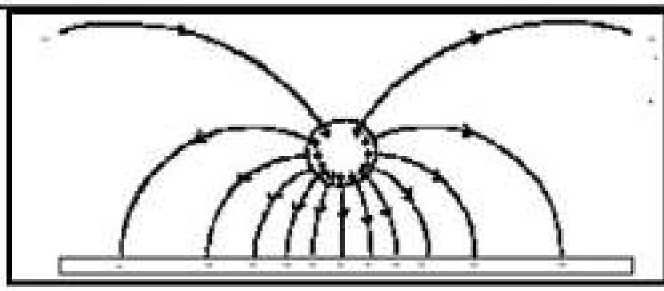


Figure 1.4 Electric field between a positively charged cylinder and a nearby plane surface.

We can describe the way that charge spreads out on the surface by specifying the concentration of charge or **surface charge density** - the charge per surface area. The magnitude (E) of the electric field at the surface of a conductor is proportional to the surface charge density (σ). This relation is usually written as

$$E = \frac{\sigma}{\varepsilon} \quad \text{... (1.2)}$$

The constant ε is a property of the medium that surrounds the conductor, and is called the permittivity of the medium. If the surrounding space is empty (a vacuum) we indicate that by putting $\varepsilon = \varepsilon_0$, and we call the constant ε_0 (pronounced 'epsilon nought') the **permittivity of free space**. Although a vacuum is a pretty rare thing, the permittivity of air is very nearly equal to ε_0, so in electrostatics we usually regard air as being equivalent to empty space.

The SI unit of surface charge density is the coulomb per square metre ($C.m^{-2}$). The SI unit of permittivity is called the farad per metre, $F.m^{-1}$ which, in terms of units that you know already, is equivalent to $C^2.N^{-1}.m^{-2}$. The permittivity of free space is one of the fundamental constants of nature; its value is

$$\varepsilon_0 = 8.85 \times 10^{-12}\,F.m^{-1}.$$

Equation 1.2 (with $\varepsilon = \varepsilon_0$) is *always* true for conductors in a vacuum. It is a consequence of **Gauss's law**, which is one of the four basic laws of electricity.

Field lines and electric field strength

Field line diagrams represent the strength of the field at each point provided that they are correctly drawn. In a correctly drawn field-line diagram each line must begin (and end) on equal amounts of charge. The field lines are also drawn so that the field strength is proportional to the concentration of the lines (figure 1.5).

Think of a small imaginary surface, area A, drawn perpendicular to the field at some place in space. Count the number, n, of field lines that go through the surface. Then the magnitude of the electric field averaged across the area A is represented by the number of field lines per area.

$$\bar{E} \propto \frac{n}{A} \quad \text{... (1.3)}$$

Thus, as the field lines spread out from a charged body the electric field strength falls off correspondingly.

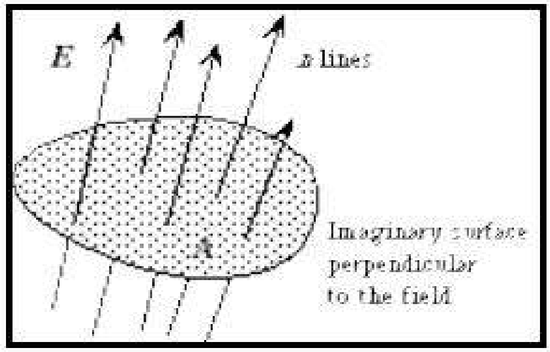


Figure 1.5 Field strength and concentration of field lines

The product of the component of the average field perpendicular to the surface and the surface area is called the **flux** of the field through the surface. So the number of field lines through a surface represents the flux of the electric field through that surface.

In principle once a charge distribution is known the electric field can be deduced and vice versa. In practice such calculations can usually be done only numerically (by computer) except for simple geometries. Calculations of the relationship between electric field and charge distribution are vital in many branches of science and technology. Examples range from the study of ion diffusion in living cells, through the design of electrical equipment, to the investigation of thunderstorms.

For highly symmetrical conductors accurate field-line diagrams are fairly easy to draw. Some examples are given in figures 1.6, 1.7 and 1.8.

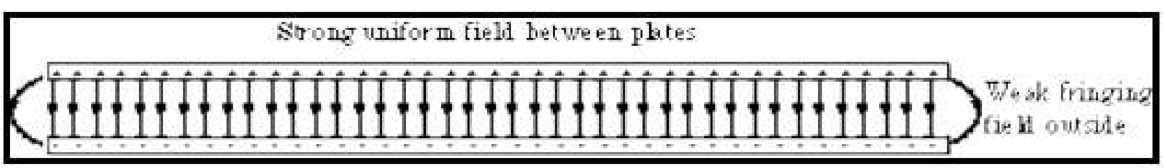


Figure 1.6 Field lines for parallel plates

The fringing field at the ends of the plates can be ignored if the plate area is large, or if the plates are close together.

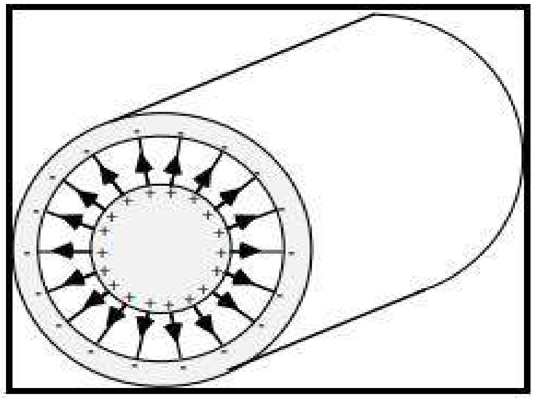


Figure 1.7 Coaxial cylinders
The field lines are radial.

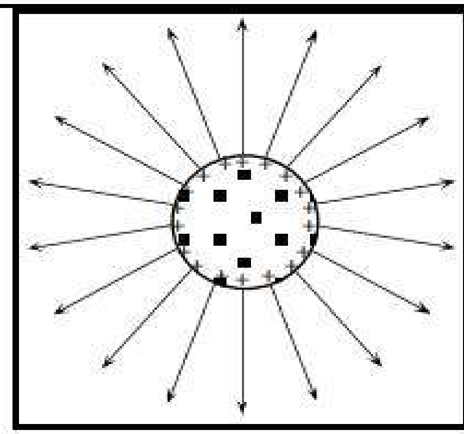
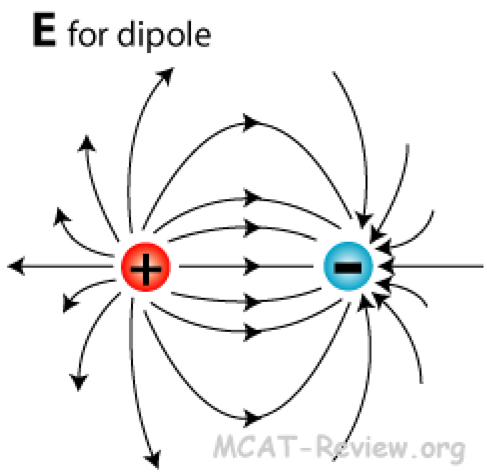


Figure 1.8 Charged metal sphere
The field lines are radial in three dimensions. This diagram shows a two-dimensional slice through the centre of the sphere.

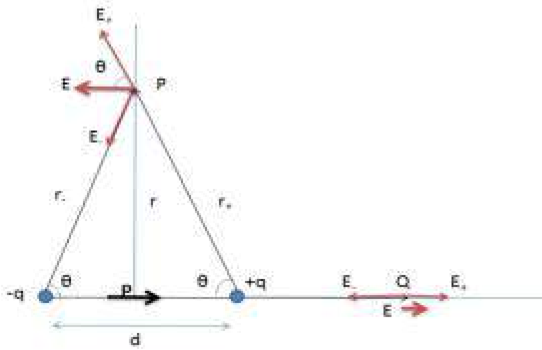
4.Electric field due to a dipole



A dipole is a separation of opposite electrical charges and it is quantified by an electric dipole moment. The electric dipole moment associated with two equal charges of opposite polarity separated by a distance '*d*' is defined as the vector quantity having a magnitude equal to the product of the charge and the distance between the charges and having a direction from the negative to the positive charge along the line between the charges.

It is a useful concept in dielectrics and other applications in solid and liquid materials. These applications involve the energy of a dipole and the electric field of a dipole.

Consider an electric dipole with charges +q and –q separated by a distance of d. We shall designate components due to +q and –q using subscripts + and – respectively.



We shall for the sake of simplicity only calculate the fields along symmetry axes, i.e. a point **P** along the perpendicular bisector of the dipole and a point **Q** along the axis of the dipole.

Along perpendicular bisector (Point **P**)

The electric fields due to the positive and negative charges (Coulomb's law):

$$E_+ = \frac{1}{(4\pi\varepsilon_0}\frac{q}{r_+^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(\sqrt{r^2+(\frac{d}{2})^2})^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+(\frac{d}{2})^2}$$

Similarly,

$$E_- = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_-^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+(\frac{d}{2})^2}$$

The vertical components of electric field cancel out as P is equidistant from both charges.

$$\Rightarrow E = E_+ \; cos\,\theta \; + \; E_- \; cos\,\theta$$

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+(\frac{d}{2})^2}\; cos\,\theta \; + \; \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2+(\frac{d}{2})^2}\; cos\,\theta$$

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{2q}{r^2+(\frac{d}{2})^2}\; cos\,\theta$$

Now,

$$\Rightarrow cos\,\theta = \frac{\frac{d}{2}}{r_+} = \frac{\frac{d}{2}}{r_-} = \frac{\frac{d}{2}}{\sqrt{r^2+(\frac{d}{2})^2}}$$

Substituting this value we get,

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{2q}{r^2+(\frac{d}{2})^2}\frac{\frac{d}{2}}{\sqrt{r^2+(\frac{d}{2})^2}} = \frac{1}{4\pi\varepsilon_0}\frac{qd}{(r^2+(\frac{d}{2})^2)^{\frac{3}{2}}}$$

Dipole moment $p = q \times d$

When $r >> d$, we can neglect the $\frac{d}{2}$ term. Thus we have,

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^2}^{\frac{3}{2}}$$

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{p}{r^3}$$

The dipole moment direction is defined as pointing towards the positive charge. Thus, the direction of electric field is opposite to the dipole moment:

$$\overrightarrow{E} = -\frac{1}{4\pi\varepsilon_0}\frac{\overrightarrow{p}}{r^3}$$

Along axis of dipole (Point **Q**)

The electric fields due to the positive and negative charges are:

$$E_+ = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_+^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-\frac{d}{2})^2}$$

$$E_- = \frac{1}{4\pi\varepsilon_0}\frac{q}{r_-^2} = \frac{1}{4\pi\varepsilon_0}\frac{q}{r+\frac{d}{2})^2}$$

Since the electric fields are along the same line but opposing directions,

$E = E_+ - E_-$

$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{q}{(r-\frac{d}{2})^2} - \frac{1}{4\pi\varepsilon_0}\frac{q}{(r+\frac{d}{2})^2}$

$\Rightarrow E = \frac{q}{4\pi\varepsilon_0}\left[\frac{1}{(r-\frac{d}{2})^2} - \frac{1}{(r+\frac{d}{2})^2}\right]$

$\Rightarrow E = \frac{q}{4\pi\varepsilon_0}\left[\frac{(r+\frac{d}{2})^2-(r-\frac{d}{2})^2}{(r^2-(\frac{d}{2})^2)^2}\right]$

$\Rightarrow E = \frac{q}{4\pi\varepsilon_0}\left[\frac{4r\frac{d}{2}}{(r^2-(\frac{d}{2})^2)^2}\right]$

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\left[\frac{2rqd}{(r^2 - (\frac{d}{2})^2)^2}\right]$$

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\left[\frac{2rp}{(r^2 - (\frac{d}{2})^2)^2}\right]$$

Factoring r^4 from denominator and numerator:

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{1}{r^4}\left[\frac{2pr}{(1 - (\frac{d}{2r})^2)^2}\right]$$

Now if $r >> d$, we can neglect the $(\frac{d}{2r})^2$ term becomes very much smaller than 1. Thus, we can neglect this term. The equation becomes:

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{1}{r^4}\left[\frac{2pr}{1^2}\right]$$

$$\Rightarrow E = \frac{1}{4\pi\varepsilon_0}\frac{2p}{r^3}$$

Since in this case the electric field is along the dipole moment, $(E_+ > E_-)$

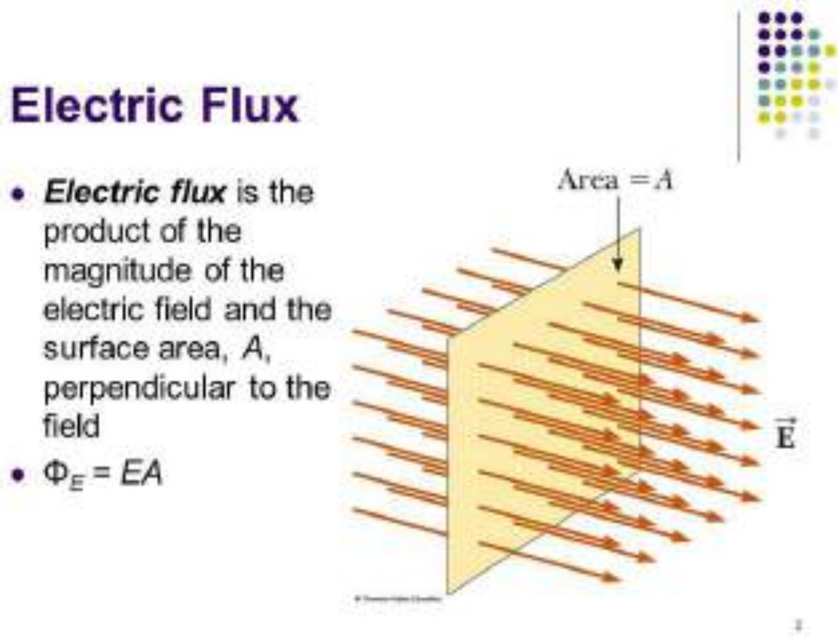
$$\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{p}}{r^3}$$

Notice :

That in both cases the electric field tapers quickly as the inverse of the cube of the distance. Compared to a point charge which only decreases as the inverse of the square of the distance, the dipoles field decreases much faster because it contains both a positive and negative charge. If they were brought to the same point their electric fields would cancel out completely but since they have a small distance separating them, they have a feeble electric field.

Video Link:

5.Electric Flux:

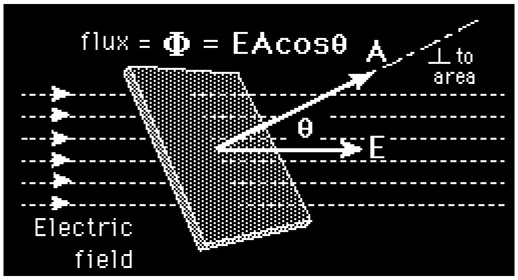


In electromagnetism, electric flux is the measure of the electric field through a given surface, although an electric field in itself cannot flow. It is a way of describing the electric field strength at any distance from the charge causing the field.

The electric field E can exert a force on an electric charge at any point in space. The electric field is proportional to the gradient of the voltage.

In this section, we will discuss the concept of electric flux, its calculation and the analogy between the flux of an electric field and that of water. Let us imagine the flow of water with a velocity v in a pipe in a fixed direction, say to the right. If we take the cross-sectional plane of the pipe and consider a small unit area given by ds from that plane, the volumetric flow of the liquid crossing that plane normal to the flow can be given as vds. When the plane is not normal to the flow of the fluid but is inclined at an angle Θ, the total volume of liquid crossing the plane per unit time is given as $vds.\cos\Theta$. Here, $ds\cos\Theta$ is the projected area in the plane perpendicular to the flow of the liquid.

The electric field is analogous to the flow of liquid in the case shown above. The quantity we are going to deal with here is not an observable quantity as the liquid we considered above. Let us understand this with the help of the figure below.



Electric Flux Formula

The total number of electric field lines passing a given area in a unit time is defined as the electric flux. Similar to the example above, if the plane is normal to the flow of the electric field, the total flux is given as:

$$\phi_p = EA$$

When the same plane is tilted at an angle Θ, the projected area is given as $Acos\Theta$ and the total flux through this surface is given as:

$$\phi = EAcos\Theta$$

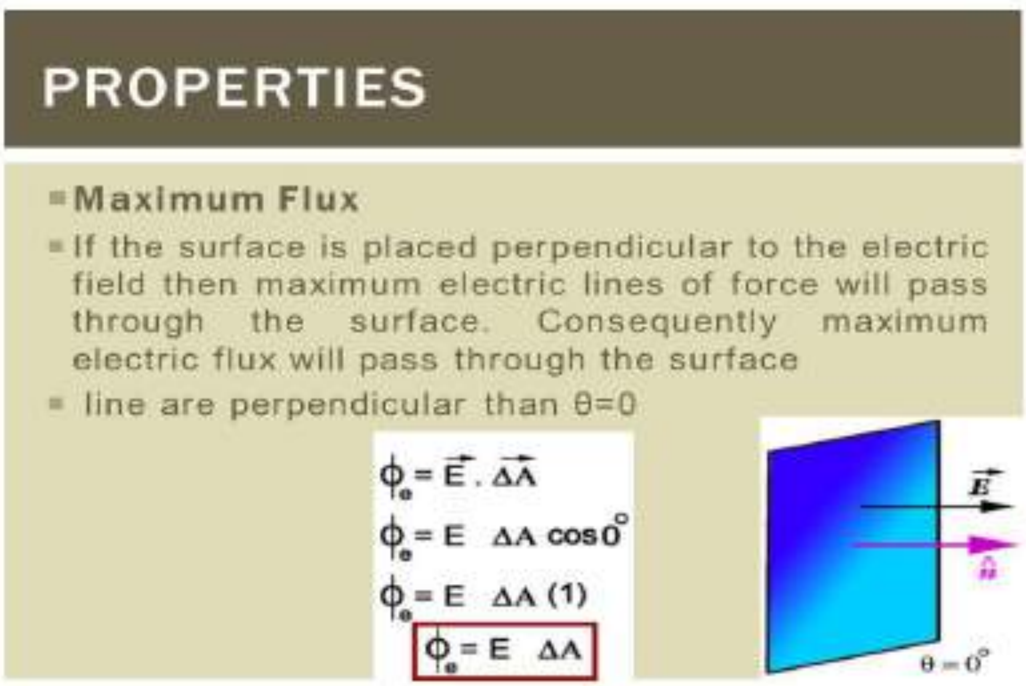
Where,

- E is the magnitude of the electric field
- A is the area of the surface through which the electric flux is to be calculated
- Θ is the angle made by the plane and the axis parallel to the direction of flow of the electric field

To learn more about electric flux, the electric current in conductors and other related topics, download BYJU'S The Learning App.

Types and properties

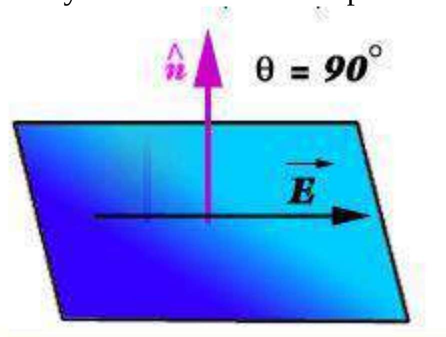
1.Maximum Electric Flux



Video Link:

2.Minimum Electric Flux

If the surface is placed parallel to the electric field then no electric lines of force will pass through the surface. Consequently no electric flux will pass through the surface.



$$\phi_e = \vec{E} \cdot \Delta\vec{A}$$

$$\phi_e = E \; \Delta A \cos 90^{\circ}$$

$$\phi_e = E \; \Delta A \, (0)$$

$$\boxed{\phi_e = 0}$$

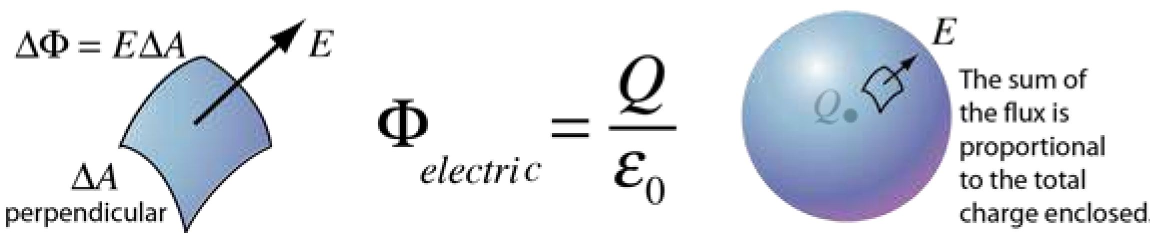
Unit of Electric Flux

$$\boxed{\frac{\text{Newton . meter}^2}{\text{Coulomb}}} \quad \text{OR} \quad \boxed{\text{Volt . meter}}$$

6.Gauss's law and its applications

Gauss’s law:

The total of the electric flux out of a closed surface is equal to the charge enclosed divided by the permittivity.



The electric flux through an area is defined as the electric field multiplied by the area of the surface projected in a plane perpendicular to the field. Gauss's Law is a general law applying to any closed surface. It is an important tool since it permits the assessment of the amount of enclosed charge by mapping the field on a surface outside the charge distribution. For geometries of sufficient symmetry, it simplifies the calculation of the electric field.

Another way of visualizing this is to consider a probe of area A which can measure the electric field perpendicular to that area. If it picks any closed surface and steps over that surface, measuring the perpendicular field times its area, it will obtain a measure of the net electric charge within the surface, no matter how that internal charge is configured.

Applications of Gauss’s Law

Gauss’s Law can be used to solve complex electrostatic problems involving unique symmetries like cylindrical, spherical or planar symmetry. Also, there are some cases in which calculation of electric field is quite complex and involves tough integration. Gauss’s Law can be used to simplify evaluation of electric field in a simple way.

We apply Gauss’s Law in following way:

- Choose a Gaussian surface, such that evaluation of electric field becomes easy
- Make use of symmetry to make problems easier

- Remember, it is not necessary that Gaussian surface to coincide with real surface that is, it can be inside or outside the Gaussian surface

Electric Field due to Infinite Wire

Consider an infinitely long wire with linear charge density λ and length L. To calculate electric field, we assume a cylindrical Gaussian surface due to the symmetry of wire. As the electric field E is radial in direction; flux through the end of the cylindrical surface will be zero, as electric field and area vector are perpendicular to each other. The only flowing electric flux will be through the curved Gaussian surface. As the electric field is perpendicular to every point of the curved surface, its magnitude will be constant.

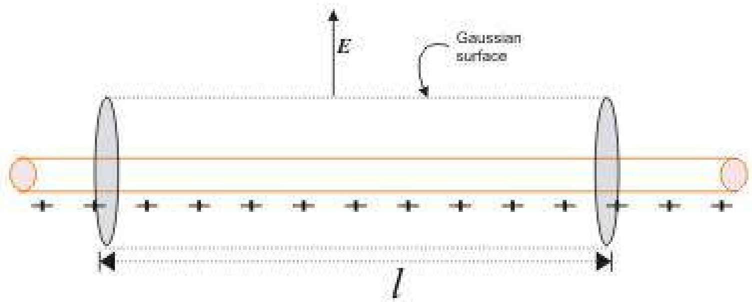


Image 1: We consider a cylindrical Gaussian surface of radius r and length l

The surface area of the curved cylindrical surface will be 2πrl. The electric flux through the curve will be

$$E \times 2\pi rl$$

and

According to Gauss's Law

$$\Phi = \frac{q}{\varepsilon_0}$$

$$E \times 2\pi rl = \frac{\lambda l}{\varepsilon_0}$$

$$E = \frac{\lambda}{2\pi\varepsilon_0 r}$$

, the above relation is

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{n}$$

where $\hat{n}$ is radial unit vector pointing the direction of electric field $\vec{E}$.

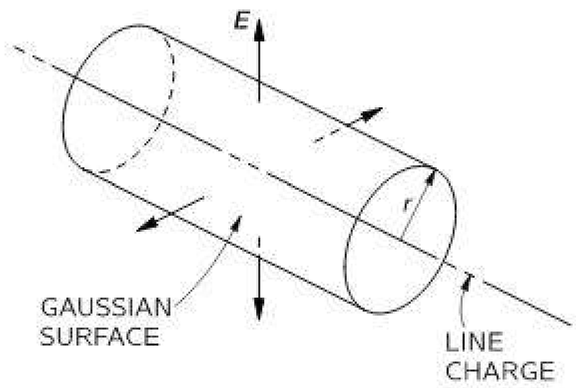


Image 2: Direction of Electric field is radially outward in case of positive linear charge density

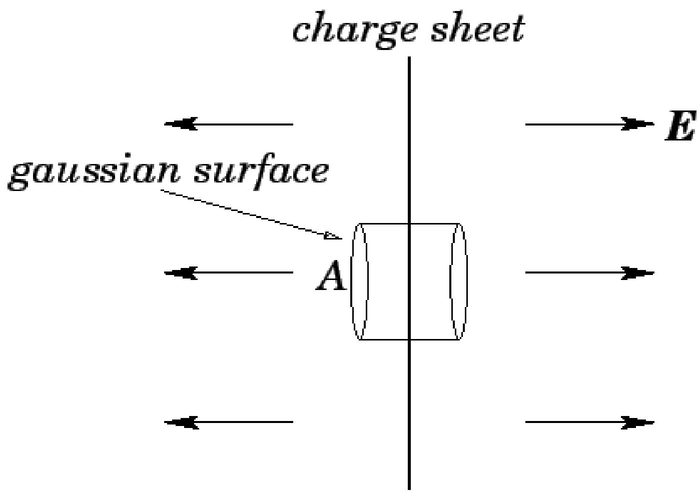
Note 1: Direction of the electric field will be radially outward if linear charge density is positive and it will be radially inward if linear charge density is negative.

Note 2: We considered only the enclosed charge inside the Gaussian surface

Note 3: The assumption that the wire is infinitely long is important because, without this assumption, the electric field will not be perpendicular to the curved cylindrical Gaussian surface and will at some angle with the surface.

Electric Field due to Infinite Plate Sheet

Imagine an infinite plane sheet, with surface charge density **σ** and cross-sectional area A. The position of the infinite plane sheet is given in the figure below:



The direction of the electric field due to infinite charge sheet will be perpendicular to the plane of the sheet. Let's consider cylindrical Gaussian surface, whose axis is normal to the plane of the sheet. The electric field $\vec{E}$ can be evaluated from Gauss's Law as

According to Gauss's Law:

$$\Phi = \frac{q}{\varepsilon_0}$$

From continuous charge distribution charge q will be σ A. Talking about net electric flux, we will consider electric flux only from the two ends of the assumed Gaussian surface. This is because the curved surface area and an electric field are normal to each other, thereby producing zero electric flux. So the net electric flux will be

$$\Phi = EA - (-EA)$$

$$\Phi = 2EA$$

Then we can write

$$2EA = \frac{\sigma A}{\varepsilon_0}$$

The term A cancel out which means electric field due to infinite plane sheet is independent of cross section area A and equals to

$$E = \frac{\sigma}{2\varepsilon_0}$$

In vector form, the above equation can be written as

$$\vec{E} = \frac{\lambda}{2\pi\varepsilon_0 r}\hat{n}$$

where $\hat{n}$ is a unit vector depicting direction of electric field perpendicular and away from the infinite sheet.

Note 1: The direction of electric field is away from the infinite sheet if the surface charge density is positive and towards the infinite sheet if the surface charge density is negative.
Note 2: Electric field due to the infinite sheet is independent of its position.

Electric Field due thin Spherical Shell

Consider a thin spherical shell of surface charge density σ and radius "R". By observation, it's obvious that shell has spherical symmetry. The electric field due to the spherical shell can be evaluated in two different positions:

- Electric Field Outside the Spherical Shell
- Electric Field Inside the Spherical Shell

Electric Field Outside the Spherical Shell

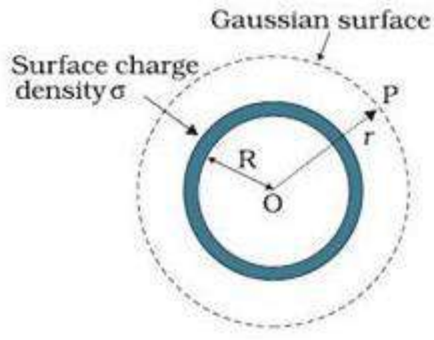


Image 4: Diagram of spherical shell with point P outside

To find electric field outside the spherical shell, we take a point P outside the shell at a distance r from the center of the spherical shell. By symmetry, we take Gaussian spherical surface with radius r and center O. The Gaussian surface will pass through P, and experience a constant electric field $\vec{E}$ all around as all points is equally distanced "r'' from the center of the sphere. Then,

According to Gauss's Law

$$\Phi = \frac{q}{\varepsilon_0}$$

The enclosed charge inside the Gaussian surface q will be σ × 4 πR^2. The total electric flux through the Gaussian surface will be

$$\Phi = E \times 4\,\pi r^2$$

Then by Gauss's Law, we can write

$$E \times 4\,\pi r^2 = \sigma \times \frac{4\pi R^3}{\varepsilon_0}$$

$$E = \frac{\sigma\, R^2}{\varepsilon_0\;\, r^2}$$

Putting the value of surface charge density σ as q/4 πR^2, we can rewrite the electric field as

$$E = \frac{kq}{r^2}$$

In vector form, electric field is

$$\vec{E} = \frac{kq}{r^2}\,\hat{r}$$

where $\hat{r}$ is radius vector, depicting the direction of electric field.

Note: If the surface charge density σ is negative, the direction of the electric field will be radially inward.

Electric Field Inside the Spherical Shell

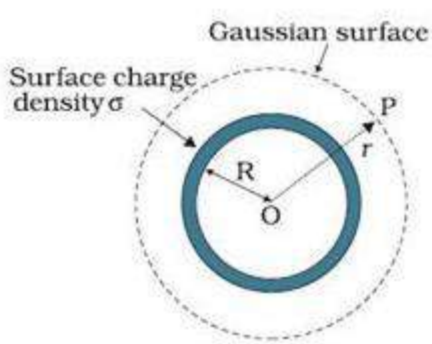


Image 5: Diagram of Spherical shell with point P inside

To evaluate electric field inside the spherical shell, let's take a point P inside the spherical shell. By symmetry, we again take a spherical Gaussian surface passing through P, centered at O and with radius r. Now according to Gauss's Law

$$\Phi = \frac{q}{\varepsilon_0}$$

The net electric flux will be $E \times 4 \pi r^2$. But the enclosed charge q will be zero, as we know that surface charge density is dispersed outside the surface, therefore there is no charge inside the spherical shell. Then by Gauss's Law

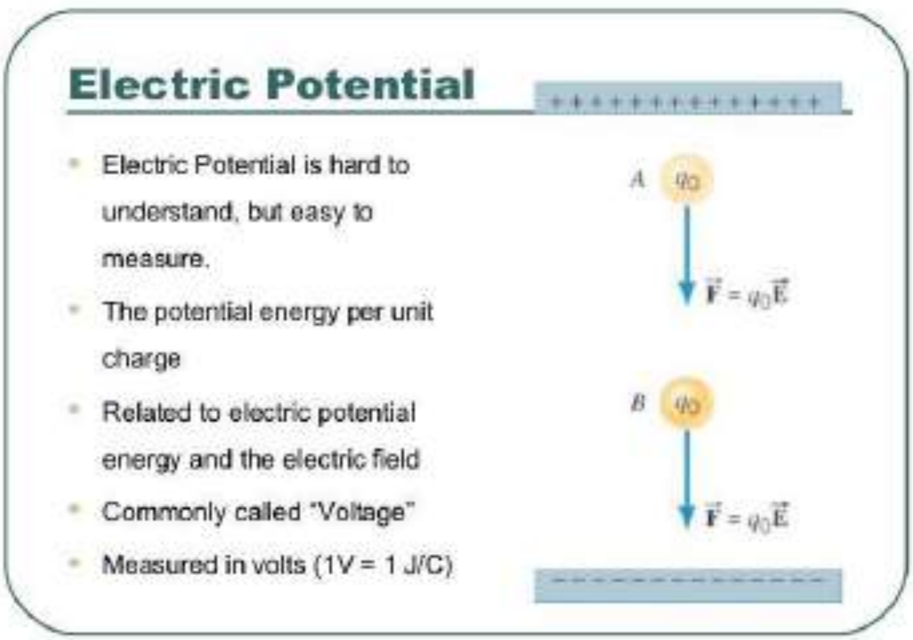
$$E \times 4\pi r^2 = 0$$

$$E = 0$$

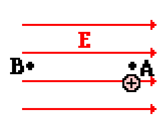
Note: There is no electric field inside spherical shell because of absence of enclosed charge

7.Electric potential

An electric potential is the amount of work needed to move a unit of charge from a reference point to a specific point inside the field without producing an acceleration. Typically, the reference point is the Earth or a point at infinity, although any point can be used.

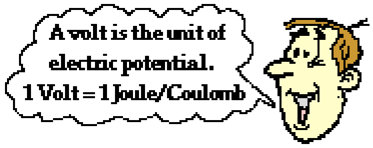


The concept of electric potential was introduced. Electric potential is a location-dependent quantity that expresses the amount of potential energy per unit of charge at a specified location. When a Coulomb of charge (or any given amount of charge) possesses a relatively large quantity of potential energy at a given location, then that location is said to be a location of high electric potential. And similarly, if a Coulomb of charge (or any given amount of charge) possesses a relatively small quantity of potential energy at a given location, then that location is said to be a location of low electric potential. As we begin to apply our concepts of potential energy and electric potential to circuits, we will begin to refer to the difference in electric potential between two points. This part of Lesson 1 will be devoted to an understanding of electric potential difference and its application to the movement of charge in electric circuits.



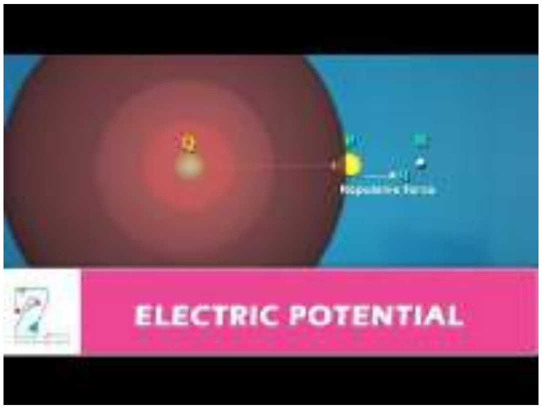
Consider the task of moving a positive test charge within a uniform electric field from location A to location B as shown in the diagram at the right. In moving the charge against the electric field from location A to location B, work will have to be done on the charge by an external force. The work done on the charge changes its potential energy to a higher value; and the amount of work that is done is equal to the change in the potential energy. As a result of this change in potential energy, there is also a difference in electric potential between locations A and B. This difference in electric potential is represented by the symbol **ΔV** and is formally referred to as the **electric potential difference**. By definition, the electric potential difference is the difference in electric potential (V) between the final and the initial location when work is done upon a charge to change its potential energy. In equation form, the electric potential difference is

$$\Delta V = V_B - V_A = \frac{\text{Work}}{\text{Charge}} = \frac{\Delta PE}{\text{Charge}}$$



The standard metric unit on electric potential difference is the volt, abbreviated **V** and named in honor of Alessandro Volta. One Volt is equivalent to one Joule per Coulomb. If the electric potential difference between two locations is 1 volt, then one Coulomb of charge will gain 1 joule of potential energy when moved between those two locations. If the electric potential difference between two locations is 3 volts, then one coulomb of charge will gain 3 joules of potential energy when moved between those two locations. And finally, if the electric potential difference between two locations is 12 volts, then one coulomb of charge will gain 12 joules of potential energy when moved between those two locations. Because electric potential difference is expressed in units of volts, it is sometimes referred to as the **voltage**.

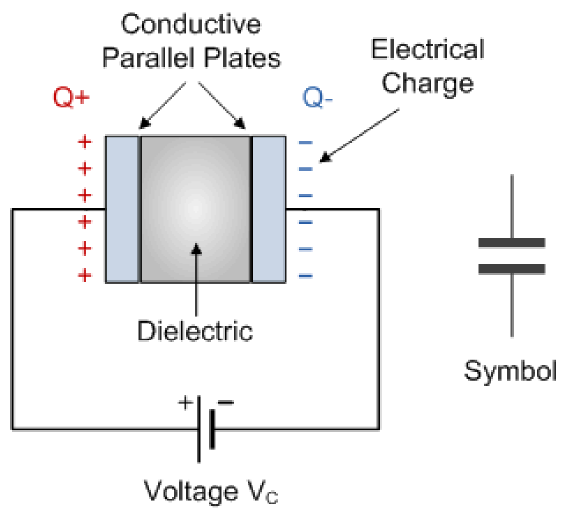
Video Link:



7.Capacitor

A **capacitor** is a device that stores electrical energy in an electric field. It is a passive electronic component with two terminals.

The effect of a capacitor is known as capacitance. While some capacitance exists between any two electrical conductors in proximity in a circuit, a capacitor is a component designed to add capacitance to a circuit. The capacitor was originally known as a **condenser** or **condensator**.[1] This name and its cognates are still widely used in many languages, but rarely in English, one notable exception being condenser microphones, also called capacitor microphones.



Capacitance

The capacitance (C) of the capacitor is equal to the electric charge (Q) divided by the voltage (V):

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

C is the capacitance in farad (F)
Q is the electric charge in coulombs (C), that is stored on the capacitor
V is the voltage between the capacitor's plates in volts (V)

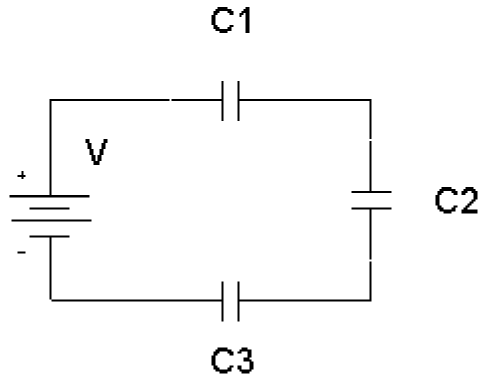
Capacitance of plates capacitor

The capacitance (C) of the plates capacitor is equal to the permittivity (ε) times the plate area (A) divided by the gap or distance between the plates (d):

$$C = \varepsilon \times \frac{A}{d}$$

C is the capacitance of the capacitor, in farad (F).
ε is the permittivity of the capacitor's dialectic material, in farad per meter (F/m).
A is the area of the capacitor's plate in square meters (m^2].
d is the distance between the capacitor's plates, in meters (m).

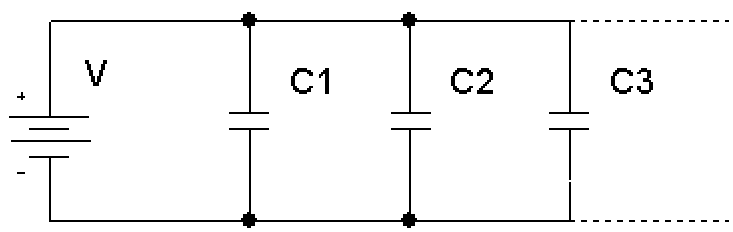
Capacitors in series



The total capacitance of capacitors in series, C1,C2,C3,.. :

$$\frac{1}{C_{Total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$$

Capacitors in parallel



The total capacitance of capacitors in parallel, C1,C2,C3,.. :

$$C_{Total} = C_1 + C_2 + C_3 + ...$$

Compound Capacitor

CAPACITANCE IN THE PRESENCE OF DIELECTRIC

1-**When dielectric is completely filled between the plates**

Let the space between the plates of capacitor is filled with a dielectric of relative permittivity **εr.**

The presence of dielectric reduces the electric intensity by **εr** times and thus the capacitance increases by **εr** times.

$$C' = C \times \varepsilon r$$

1-**When dielectric is partially filled between the plates**

Electric field without dielectric:

$$E_1 = \frac{\sigma}{\varepsilon_0}$$

Electric field with dielectric:

$$E_2 = \frac{\sigma}{\varepsilon_0 \varepsilon_r}$$

Since potential difference between the paltes is:

$$V = V_1 + V_2$$

But $V = E\,d$

Therefore,

$$V = E_1 d_1 + E_2 d_2$$

As

$d_1 = (d-t)$

$d_2 = t$

$$V = \frac{\sigma}{\varepsilon_0}(d-t) + \frac{\sigma}{\varepsilon_0 \varepsilon_r} t$$

$$V = \frac{\sigma}{\varepsilon_0}\left(d - t + \frac{t}{\varepsilon_r}\right)$$

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$$V = \frac{\sigma}{\varepsilon_0}\left\{d + t\left(\frac{1}{\varepsilon_r} - 1\right)\right\}$$

But $\sigma = q/A$

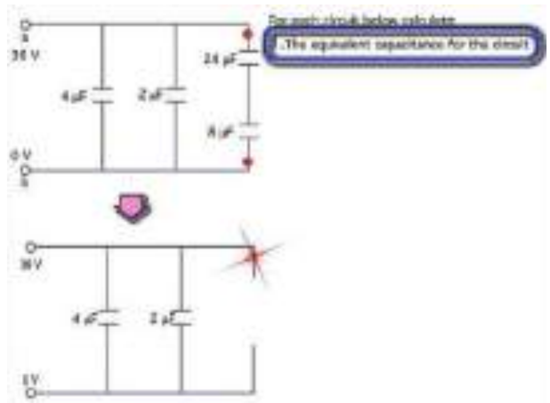
$$V = \frac{q}{A\varepsilon_0}\left\{d + t\left(\frac{1}{\varepsilon_r} - 1\right)\right\}$$

Also $q = CV$

$$V = \frac{CV}{A\varepsilon_0}\left\{d + t\left(\frac{1}{\varepsilon_r} - 1\right)\right\}$$

$$C = \frac{A\varepsilon_0}{\left\{d + t\left(\frac{1}{\varepsilon_r} - 1\right)\right\}}$$

Video Link:



8.Energy stored in a capacitor

The capacitor's stored energy E_C in joules (J) is equal to the capacitance C in farad (F) times the square capacitor's voltage V_C in volts (V) divided by 2:

$$E_C = C \times V_C^{\,2} / 2$$

AC circuits

Angular frequency

$$\omega = 2\pi f$$

ω - angular velocity measured in radians per second (rad/s)
f - frequency measured in hertz (Hz).

Assessment:

01.An oil drop having a mass of 0.002kg and charge equal to 6 electron's charge is suspended stationary in a uniform electric field. Find the intensity of electric field.
(Charge of electron = 1.6×10^{-19}C)

02. Calculate the potential difference between two plates when they are separated by a distance of a 0.005m and are able to hold an electron motionless between them.
(Mass of electron = 9.1×10^{-31} Kg)

03.Two horizontal parallel metallic plates, separated by a distance of 0.5cm are connected with a battery of 10 volts.
Find:

1. The electric field intensity between the plates.
2. The force on a proton placed between the plates.

04.A thin sheet of positive charge attracts a light charged sphere having a charge -5×10^{-6} C with a force 1.69N. Calculate the surface charge density of the sheet.
($\epsilon_o = 8.85\times 10^{-12}\ C^2/Nm^2$)

05.A capacitor of 200 pF is charged to a P.D. of 100 volts. Its plates are then connected in parallel to another capacitor and are found that the P.D. between the plates falls to 60 volts. What is the capacitance of the second capacitor?

06.A charged particle of –17.7 μC is close to a positively charged thin sheet having surface charge density 2×10^{-8} Coul/m^2. Find the magnitude and direction of force acting on the charged particle.

07.A proton of mass 1.67×10^{-27} kg and a charge of 1.6×10^{-19}C is to be held motionless between two horizontal parallel plates 10cm apart: find the voltage required to be applied between the plates.

08.How many electrons should be removed from each of the two similar spheres, each of 10 gm, so that electrostatic repulsion is balanced by the gravitational force?

09.A capacitor of 12 μF is charged to a potential difference 100V. Its plates are hen disconnected from the source and are connected parallel to another capacitor. The potential difference in this combination comes down to 60V. What is the capacitance of the second capacitance?

10.Two point charges of $+2 \times 10^{-4}$ C and -2×10^{-4} C are placed at a distance of 40 cm from each other. A charge of $+5 \times 10^{-5}$ C is placed midway between them. What is the magnitude and direction of force on it?

Reference pages

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https://www.google.com/search?q=Electric+field&source=lmns&bih=657&biw=1366&hl=en&ved=2ahUKEwjon7_H6PvpAhUW_BoKHYviCRwQ_AUoAHoECAEQAA

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https://www.physicsclassroom.com/class/circuits/Lesson-1/Electric-Potential-Difference
https://www.rapidtables.com/electric/capacitor.html
https://www.citycollegiate.com/capacitorXIIc.htm

Learning Objectives

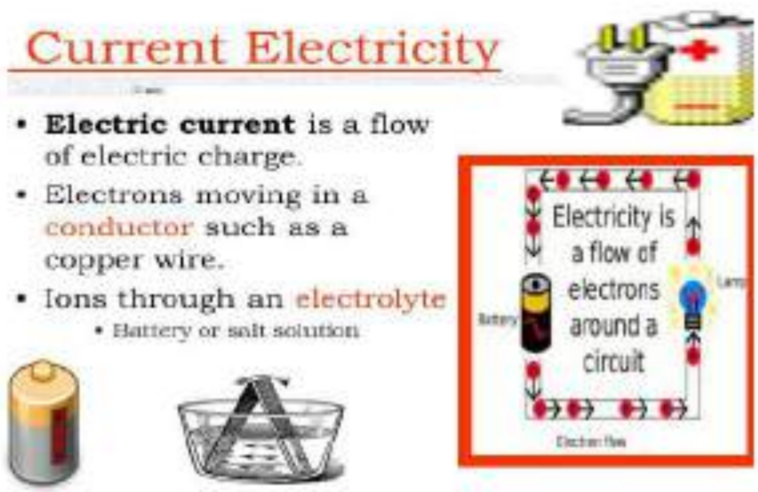
- state Coulomb's law and explain that force between two point charges is reduced in a medium other than free space using Coulomb's law.
- derive the expression E = l/4πεo q/r2 for the magnitude of the electric field at a distance 'r' from a point charge 'q'.
- describe the concept of an electric field as an example of a field of force.
- define electric field strength as force per unit positive charge .
- solve problems and analyze information using E = F/q.
- solve problems involving the use of the expression .
- E = l/4πεo q/r2 Conceptual linkage: [2]This chapter is built on Electrostatics Physics X 35
- calculate the magnitude and direction of the electric field at a point due to two charges with the same or opposite signs.
- sketch the electric field lines for two point charges of equal magnitude with same or opposite signs.
- describe the concept of electric dipole.
- define and explain electric flux.
- describe electric flux through a surface enclosing a charge.
- state and explain Gauss's law.
- describe and draw the electric field due to an infinite size conducting plate of positive or negative charge.
- sketch the electric field produced by a hollow spherical charged conductor.
- sketch the electric field between and near the edges of two infinite size oppositely charged parallel plates.
- define electric potential at a point in terms of the work done in bringing unit positive charge from infinity to that point.
- define the unit of potential.
- solve problems by using the expression V =W/q.
- describe that the electric field at a point is given by the negative of potential gradient at that point.
- solve problems by using the expression E = V/d.
- derive an expression for electric potential at a point due to a point charge.
- calculate the potential in the field of a point charge using the equation V = l/4πεo q/r.
- define and become familiar with the use of electron volt.
- define capacitance and the farad and solve problems by using C=Q/V.
- describe the functions of capacitors in simple circuits.
- solve problems using formula for capacitors in series and in parallel.
- explain polarization of dielectric of a capacitor.
- demonstrate charging and discharging of a capacitor through a resistance.
- prove that energy stored in a capacitor is W=1/2QV and hence W=1/2CV2.

Length

120-150 minutes depending on age group/prior knowledge

Unit-12

Current Electricity



Topics	Understandings	Skills
Steady current • Electric potential difference • Resistivity and its dependence upon temperature • Internal resistance • power dissipation in resistance • Thermoelectricity • Kirchhoff's Laws • The potential divider • Balanced potentials (Wheatstone bridge and potentiometer	• describe the concept of steady current. • state Ohm's law. • define resistivity and explain its dependence upon temperature. • define conductance and conductivity of conductor. • state the characteristics of a thermistor and its use to measure low temperatures. • distinguish between e.m.f and p.d. using the energy considerations. • explain the internal resistance of sources and its consequences for external circuits. • describe some sources of e.m.f. • describe the conditions for maximum power transfer. • describe thermocouple and its function. • explain variation of thermoelectric e.m.f. with temperature. Conceptual linkage: 2This chapter is built on Current Electricity Physics X 37 • apply Kirchhoff's first law as conservation of charge to solve problem. • apply Kirchhoff's second law as conservation of energy to solve problem. • describe the working of rheostat in the potential divider circuit. • describe what is a Wheatstone bridge and how it is used to find unknown resistance.	• indicate the value of resistance by reading colour code on it. • determine resistance of wire by slide wire bridge. • determine resistance of voltmeter by drawing graph between R and I/V. • determine resistance of voltmeter by discharging a capacitor through it. • analyze the variation of resistance of thermistor with temperature. • determine internal resistance of a cell using potentiometer. • determine e.m.f of a cell using potentiometer. • determine the e.m.f. and internal resistance of a cell by plotting V against I graph. • investigate the relationship between current passing through a tungsten filament lamp and the potential applied across it.

	• describe the function of potentiometer to measure and compare potentials without drawing any current from the circuit.	

Let us start with the very first theory of current Electricity

1.Steady current

A constant current (steady current, time-independent current, stationary current) is a type of Direct Current (DC) that does not change its intensity with time.

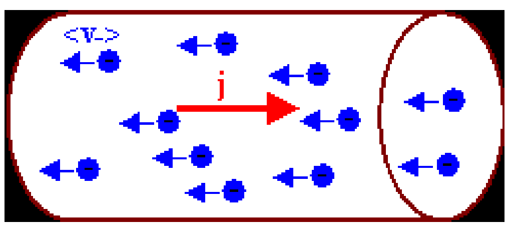
Why does a steady current only produce a magnetic field, not an electric field? An electric field causes the steady current. For an electric current to flow through a conductor, there must be an electric field (ie, voltage) causing that current across the conductor.

Most electrical devices are not electrostatic devices. Most electrical devices require the flow of a current. A current requires moving charges.

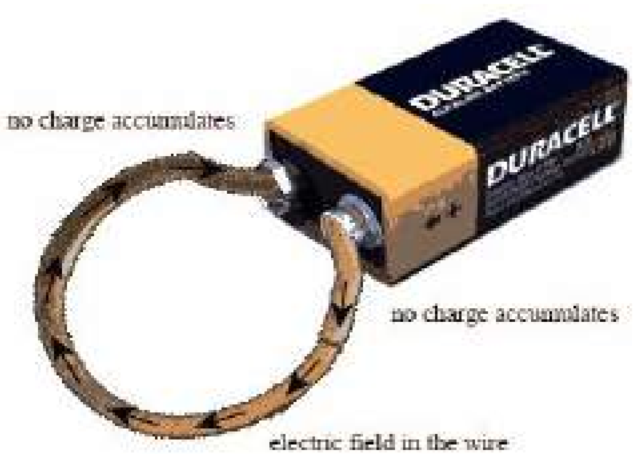
Let

$\rho_+ = n_+q_+$ be the density of the positive charges in some region, i.e. the amount of positive charge per unit volume, and let $\rho_- = n_-q_-$ be the density of the negative charges. Here n_+ and n_- are the number of positively and negatively charged particles per unit volume and q_+ and q_- are the charge of each positively and negatively charged particle, respectively.

(n_+ and n_- are positive numbers q_+ is a positive number with units and q_- is a negative number with units. Therefore ρ_+ is a positive number with units and ρ_- is a negative number with units.)



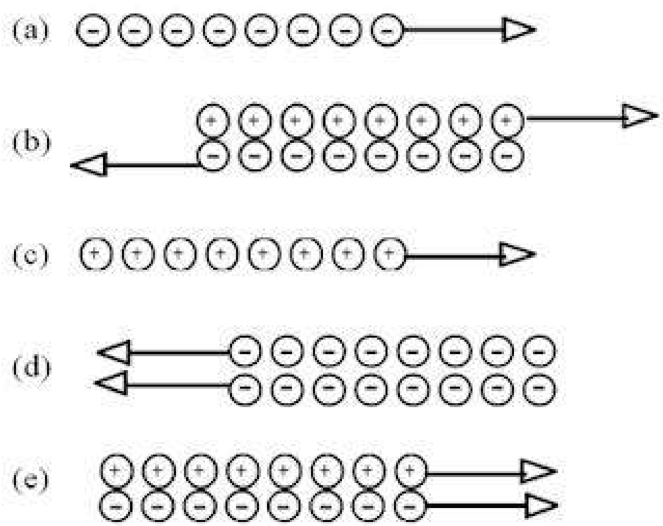
In neutral ordinary matter $\rho_+ + \rho_- = 0$, i.e. the net charge per unit volume is zero.



Steady currents can only flow in continuous loops. At any point, just as much charge has to flow out of a small volume surrounding the point as flows into the volume. If this were not so, charge would accumulate at the point, setting up its own electric field. This field would exert an additional force on the moving charges, disrupting the steady current. The electric field in a homogeneous wire with constant cross-sectional area carrying a steady current is the same everywhere. If it were not, electrons would move with different velocities in different sections, and charges would accumulate in certain regions. The field produced by these charges would disrupt the steady current. The diagram on the right shows the field in a wire carrying a steady current.

Module 1: Question 1

Which diagram below does not represent an electrical current?



*Discuss this with your fellow students on Piazza!
*Discuss different ways one can produce a steady current.

Problem:

A annealed copper wire has a length of 160 m and a diameter of 1.00 mm. If the wire is connected to a 1.5 V battery, how much current flows through the wire?

Solution:

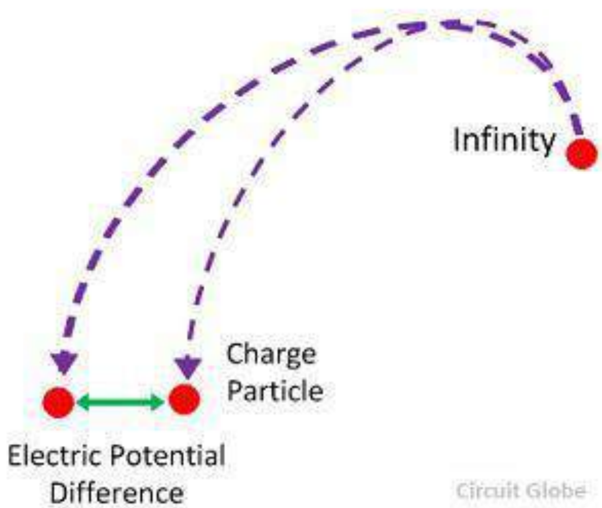
Reasoning:

The current can be found from Ohm's Law, $V = IR$. V is the battery voltage, so if R can be determined, the current can be calculated.
The resistance of the wire is $R = \rho l/A$.
For copper $\rho = 1.72*10-8\ \Omega m$.
Details of the calculation:
The cross-sectional area of the wire is $A = \pi r2 = \pi(0.0005)2 = 7.85*0-7$ m2.
The resistance of the wire then is $((1.72*10-8)*160/(7.85*10-7))\Omega = 3.5\ \Omega$.
The current is $I = V/R = (1.5/3.5)A = 0.428$ A.

Video Link:

2.Electric potential difference

The electrical potential difference is defined as the amount of work done to carrying a unit charge from one point to another in an electric field. In other words, the potential difference is defined as the difference in the electric potential of the two charged bodies.

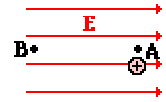


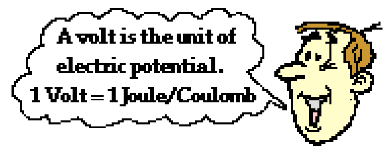
When a body is charged to a different electric potential as compared to the other charged body, the two bodies are said to a potential difference. Both the bodies are under stress and strain and try to attain minimum potential

Unit: The unit of potential difference is volt.

Consider the task of moving a positive test charge within a uniform electric field from location A to location B as shown in the diagram at the right. In moving the charge against the electric field from location A to location B, work will have to be done on the charge by an external force. The work done on the charge changes its potential energy to a higher value; and the amount of work that is done is equal to the change in the potential energy. As a result of this change in potential energy, there is also a difference in electric potential between locations A and B. This difference in electric potential is represented by the symbol ΔV and is formally referred to as the electric potential difference. By definition, the electric potential difference is the difference in electric potential (V) between the final and the initial location when work is done upon a charge to change its potential energy. In equation form, the electric potential difference is

$$\Delta V = V_B - V_A = \frac{\text{Work}}{\text{Charge}} = \frac{\Delta PE}{\text{Charge}}$$

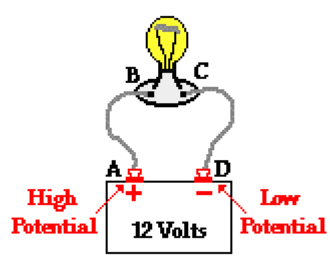




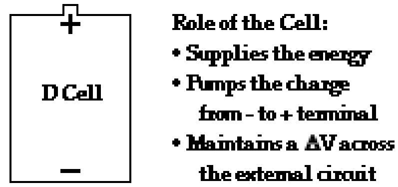
The standard metric unit on electric potential difference is the volt, abbreviated V and named in honor of Alessandro Volta. One Volt is equivalent to one Joule per Coulomb. If the electric potential difference between two locations is 1 volt, then one Coulomb of charge will gain 1 joule of potential energy when moved between those two locations. If the electric potential difference between two locations is 3 volts, then one coulomb of charge will gain 3 joules of potential energy when moved between those two locations. And finally, if the electric potential difference between two locations is 12 volts, then one coulomb of charge will gain 12 joules of potential energy when moved between those two locations. Because electric potential difference is expressed in units of volts, it is sometimes referred to as the voltage.

Electric Potential Difference and Simple Circuits

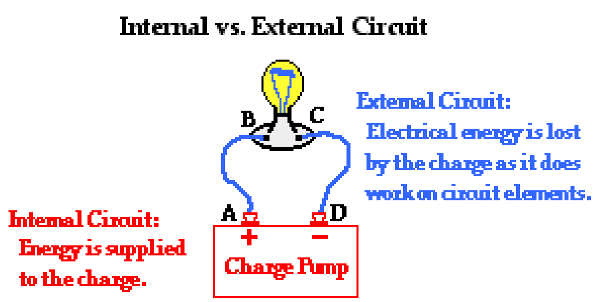
Electric circuits, as we shall see, are all about the movement of charge between varying locations and the corresponding loss and gain of energy that accompanies this movement. In the previous part of Lesson 1, the concept of electric potential was applied to a simple battery-powered electric circuit. In that discussion, it was explained that work must be done on a positive test charge to move it through the cells from the negative terminal to the positive terminal. This work would increase the potential energy of the charge and thus increase its electric potential. As the positive test charge moves through the external circuit from the positive terminal to the negative terminal, it decreases its electric potential energy and thus is at low potential by the time it returns to the negative terminal. If a 12 volt battery is used in the circuit, then every coulomb of charge is gaining 12 joules of potential energy as it moves through the battery. And similarly, every coulomb of charge loses 12 joules of electric potential energy as it passes through the external circuit. The loss of this electric potential energy in the external circuit results in a gain in light energy, thermal energy and other forms of non-electrical energy.



With a clear understanding of electric potential difference, the role of an electrochemical cell or collection of cells (i.e., a battery) in a simple circuit can be correctly understood. The cells simply supply the energy to do work upon the charge to move it from the negative terminal to the positive terminal. By providing energy to the charge, the cell is capable of maintaining an electric potential difference across the two ends of the external circuit. Once the charge has reached the high potential terminal, it will naturally flow through the wires to the low potential terminal. The movement of charge through an electric circuit is analogous to the movement of water at a water park or the movement of roller coaster cars at an amusement park. In each analogy, work must be done on the water or the roller coaster cars to move it from a location of low gravitational potential to a location of high gravitational potential. Once the water or the roller coaster cars reach high gravitational potential, they naturally move downward back to the low potential location. For a water ride or a roller coaster ride, the task of lifting the water or coaster cars to high potential requires energy. The energy is supplied by a motor-driven water pump or a motor-driven chain. In a battery-powered electric circuit, the cells serve the role of the charge pump to supply energy to the charge to lift it from the low potential position through the cell to the high potential position.



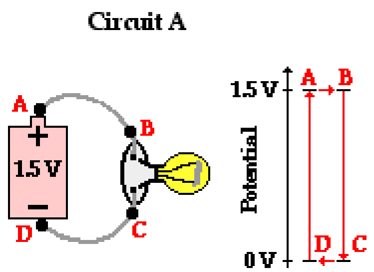
It is often convenient to speak of an electric circuit such as the simple circuit discussed here as having two parts - an internal circuit and an external circuit. The internal circuit is the part of the circuit where energy is being supplied to the charge. For the simple battery-powered circuit that we have been referring to, the portion of the circuit containing the electrochemical cells is the internal circuit. The external circuit is the part of the circuit where charge is moving outside the cells through the wires on its path from the high potential terminal to the low potential terminal. The movement of charge through the internal circuit requires energy since it is an uphill movement in a direction that is against the electric field. The movement of charge through the external circuit is natural since it is a movement in the direction of the electric field. When at the positive terminal of an electrochemical cell, a positive test charge is at a high electric pressure in the same manner that water at a water park is at a high water pressure after being pumped to the top of a water slide. Being under high electric pressure, a positive test charge spontaneously and naturally moves through the external circuit to the low pressure, low potential location.

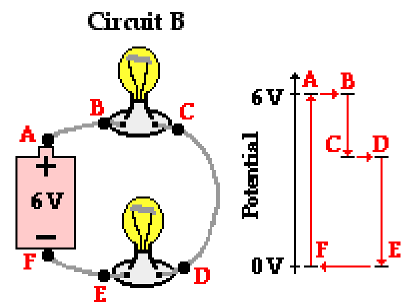


As a positive test charge moves through the external circuit, it encounters a variety of types of circuit elements. Each circuit element serves as an energy-transforming device. Light bulbs, motors, and heating elements (such as in toasters and hair dryers) are examples of energy-transforming devices. In each of these devices, the electrical potential energy of the charge is transformed into other useful (and non-useful) forms. For instance, in a light bulb, the electric potential energy of the charge is transformed into light energy (a useful form) and thermal energy (a non-useful form). The moving charge is doing work upon the light bulb to produce two different forms of energy. By doing so, the moving charge is losing its electric potential energy. Upon leaving the circuit element, the charge is less energized. The location just prior to entering the light bulb (or any circuit element) is a high electric potential location; and the location just after leaving the light bulb (or any circuit element) is a low electric potential location. Referring to the diagram above, locations A and B are high potential locations and locations C and D are low potential locations. The loss in electric potential while passing through a circuit element is often referred to as a voltage drop. By the time that the positive test charge has returned to the negative terminal, it is at 0 volts and is ready to be re-energized and pumped back up to the high voltage, positive terminal.

Electric Potential Diagrams

An electric potential diagram is a convenient tool for representing the electric potential differences between various locations in an electric circuit. Two simple circuits and their corresponding electric potential diagrams are shown below.





In Circuit A, there is a 1.5-volt D-cell and a single light bulb. In Circuit B, there is a 6-volt battery (four 1.5-volt D-cells) and two light bulbs. In each case, the negative terminal of the battery is the 0 volt location. The positive terminal of the battery has an electric potential that is equal to the voltage rating of the battery. The battery energizes the charge to pump it from the low voltage terminal to the high voltage terminal. By so doing the battery establishes an electric potential difference across the two ends of the external circuit. Being under electric pressure, the charge will now move through the external circuit. As its electric potential energy is transformed into light energy and heat energy at the light bulb locations, the charge decreases its electric potential. The total voltage drop across the external circuit equals the battery voltage as the charge moves from the positive terminal back to 0 volts at the negative terminal. In the case of Circuit B, there are two voltage drops in the external circuit, one for each light bulb. While the amount of voltage drop in an individual bulb depends upon various factors (to be discussed later), the cumulative amount of drop must equal the 6 volts gained when moving through the battery.

Investigate!

1. Moving an electron within an electric field would change the ____ the electron.

a. mass of
b. amount of charge on
c. potential energy of

2. If an electrical circuit were analogous to a water circuit at a water park, then the battery voltage would be comparable to

a. the rate at which water flows through the circuit
b. the speed at which water flows through the circuit
c. the distance that water flows through the circuit
d. the water pressure between the top and bottom of the circuit
e. the hindrance caused by obstacles in the path of the moving water

3. If the electrical circuit in your Walkman were analogous to a water circuit at a water park, then the battery would be comparable to _____.

a. the people that slide from the elevated positions to the ground
b. the obstacles that stand in the path of the moving water
c. the pump that moves water from the ground to the elevated positions
d. the pipes through which water flows

e. the distance that water flows through the circuit

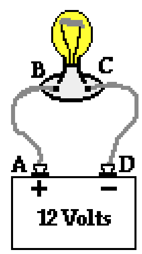
4. Which of the following is true about the electrical circuit in your flashlight?

a. Charge moves around the circuit very fast - nearly as fast as the speed of light.
b. The battery supplies the charge (electrons) that moves through the wires.
c. The battery supplies the charge (protons) that moves through the wires.
d. The charge becomes used up as it passes through the light bulb.
e. The battery supplies energy that raises charge from low to high voltage.
f. ... nonsense! None of these are true.

5. If a battery provides a high voltage, it can ____.

a. do a lot of work over the course of its lifetime
b. do a lot of work on each charge it encounters
c. push a lot of charge through a circuit
d. last a long time

The diagram below at the right shows a light bulb connected by wires to the + and - terminals of a car battery. Use the diagram in answering the next four questions.



6. Compared to point D, point A is _____ electric potential.

a. 12 V higher in
b. 12 V lower in
c. exactly the same
d. ... impossible to tell

7. The electric potential energy of a charge is zero at point _____.

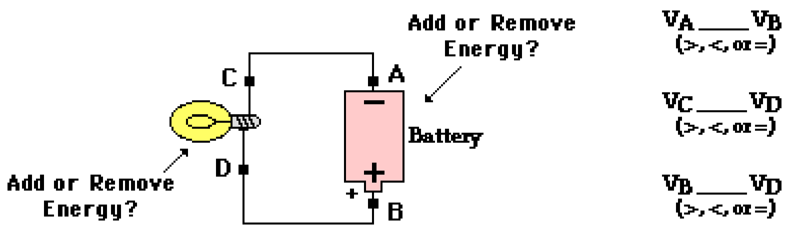
8. Energy is required to force a positive test charge to move ___.

a. through the wire from point A to point B
b. through the light bulb from point B to point C
c. through the wire from point C to point D
d. through the battery from point D to point A

9. The energy required to move +2 C of charge between points D and A is ____ J.

a. 0.167 b. 2.0 c. 6.0 d. 12 e. 24

10. The following circuit consists of a D-cell and a light bulb. Use >, <, and = symbols to compare the electric potential at A to B and at C to D. Indicate whether the devices add energy to or remove energy from the charge.



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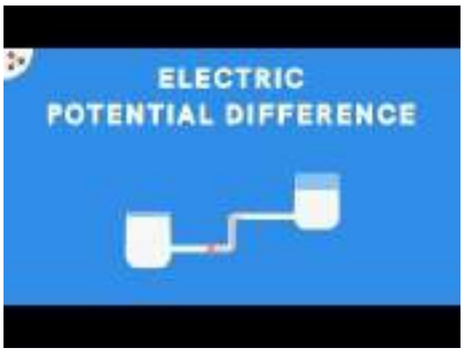
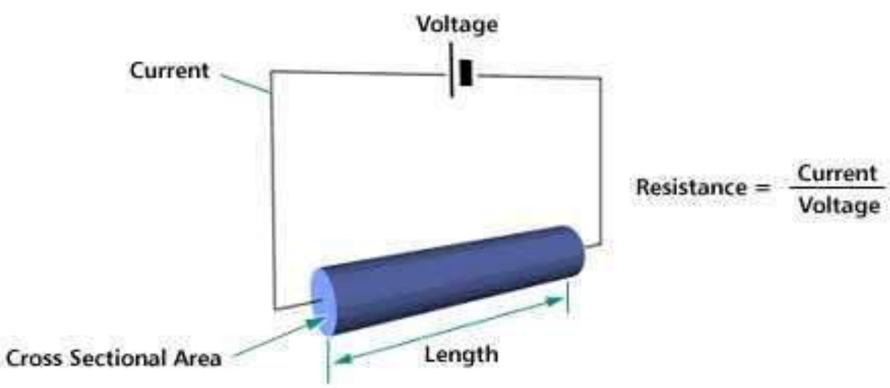
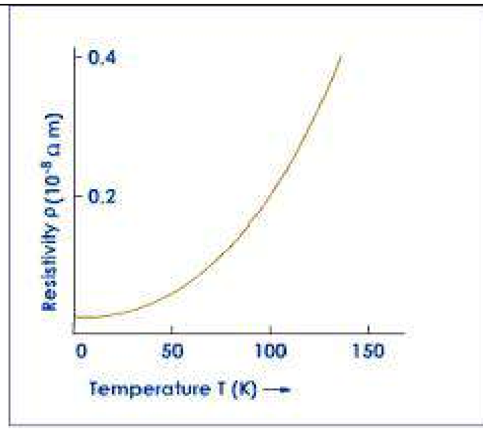


3.Resistivity and its dependence upon temperature

Restivity is affected by temperature - for most materials the resistivity increases with temperature. An exception is semiconductors (e.g. silicon) in which the resistivity decreases with temperature. The ease with which a material conducts heat is measured by thermal conductivity.





Resitivity is a measure of the resistance to electrical conduction for a given size of material. Its opposite is electrial conductivity (=1/resistivity).

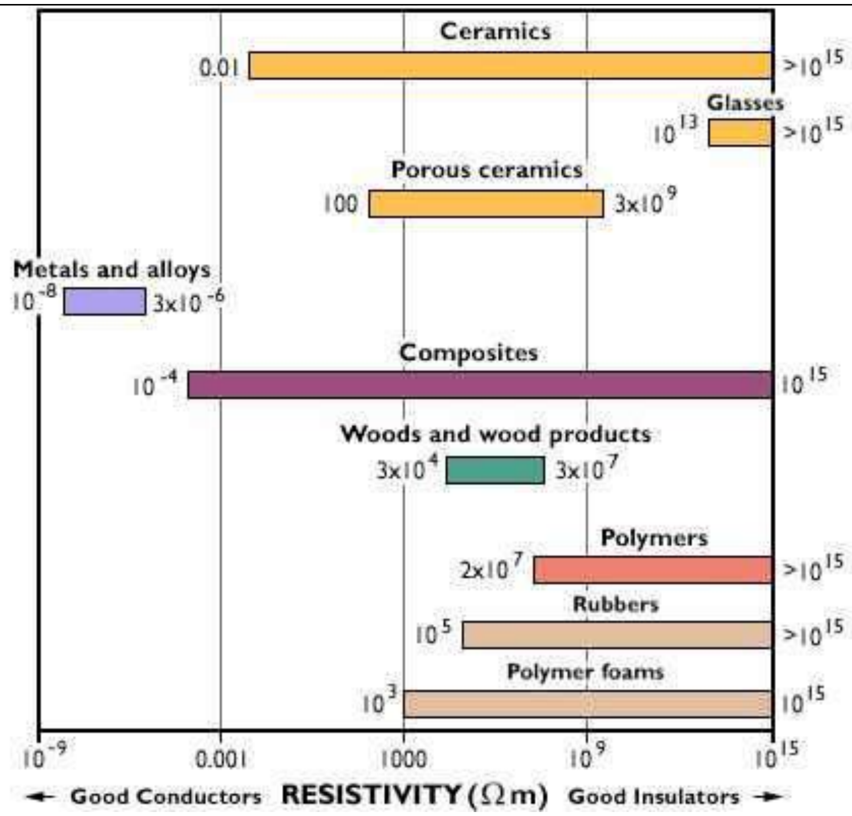
Metals are good electrical conductors (high conductivity and low resistivity), while non-metals are mostly poor conductors (low conductivity and high resistivity).

The more familiar term electrical resistance measures how difficult it is for a piece of material to conduct electricity - this depends on the size of the piece: the resistance is higher for a longer or narrower section of material.

To remove the effect of size from resistance, resistivity is used - this is a material property which does not depend on size.

Restivity is affected by temperature - for most materials the resistivity increases with temperature. An exception is semiconductors (e.g. silicon) in which the resistivity decreases with temperature.

The ease with which a material conducts heat is measured by thermal conductivity. As a first estimate, good electrical conductors are also good thermal conductors.



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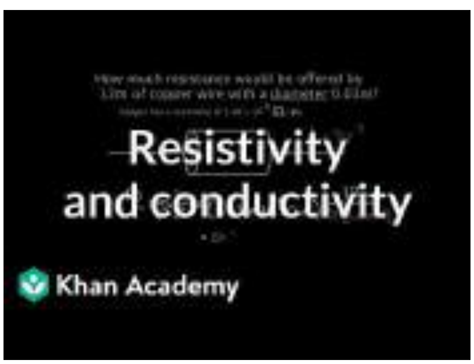
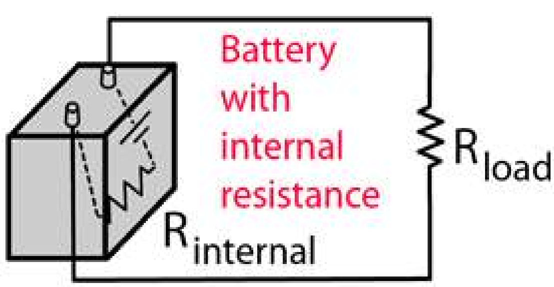


4.Internal resistance



Internal resistance refers to the opposition to the flow of current offered by the cells and batteries themselves resulting in the generation of heat. Internal resistance is measured in Ohms. The relationship between internal resistance (r) and emf (e) of cell s given by.

$$e = I\,(r + R)$$

Where, e = EMF i.e. electromotive force (Volts), I = current (A), R = Load resistance, and r is the internal resistance of cell measured in ohms.

On rearranging the above equation we get;

$$e = IR + Ir \quad \text{or,} \quad e = V + Ir$$

In the above equation, V is the potential difference (terminal) across the cell when the current (I) is flowing through the circuit.

Note: The emf (e) of a cell is always greater than the potential difference (terminal) across the cell

Example: 1 The potential difference across the cell when no current flows through the circuit is 3 V. When the current I = 0.37 Ampere is flowing, the terminal potential difference falls to 2.8 Volts. Determine the internal resistance (r) of the cell?

Solution:

$$e = V + Ir$$

Or, $$e - V = Ir$$

Or, $$(e - V)/I = r$$

Therefore,

$$r = (3.0 - 2.8)/0.37 = 0.54 \text{ Ohm.}$$

Due to the Internal Resistance of the cell, the electrons moving through the cell turns some of the electrical energy to heat energy. Therefore, the potential difference available to the rest of the circuit is:

V = E (EMF of cell) – I r (the p.d. across the internal resistor)

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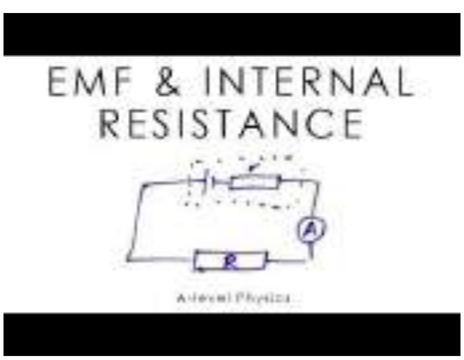


5.power dissipation in resistance

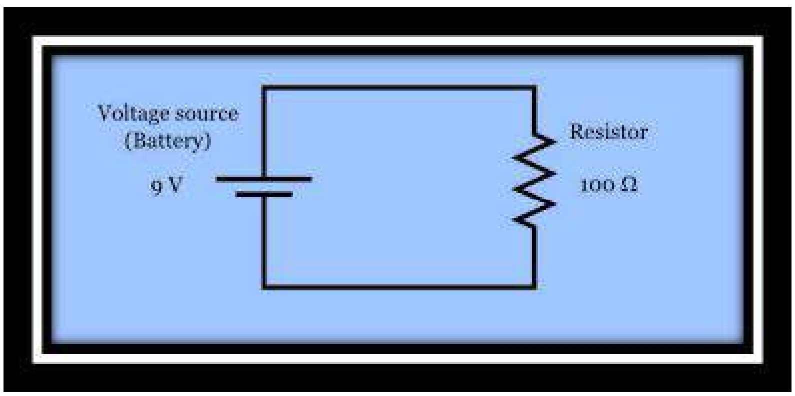
The definition of power dissipation is the process by which an electronic or electrical device produces heat (energy loss or waste) as an undesirable derivative of its primary action. Such as the case with central processing units, power dissipation is a principal concern in computer architecture.

Furthermore, power dissipation in resistors is considered a naturally occurring phenomenon. The fact remains that all resistors that are part of a circuit and has a voltage drop across it will dissipate electrical power. Moreover, this electrical power converts into heat energy, and therefore all resistors have a (power) rating. Also, a resistor's power rating is a classification that parameterizes the maximum power that it can dissipate before it reaches critical failure.

As you may know, the unit Watt (W) is how we express power, and the formula for power is P (power) = I (current) x E (voltage). In regards to the laws of physics, if there is an increase in voltage (E), then the current (I) will also increase, and the power dissipation of a resistor, will, in turn, increase as well. However, if you increase the value of the resistor, current will decrease, and the resistor's power dissipation will decrease as well. This correlation follows Ohm's law, which states the formula for current as I (current) = V (voltage) ÷ R (resistance).

Calculating the Power Dissipated by a Resistor

In the field of electronics, power dissipation is also a measurement parameter that quantifies the releasing of heat within a circuit due to inefficiencies. In other words, power dissipation is a measure of how much power (P = I x E) in a circuit is converted into heat. As I mentioned earlier, each resistor has a power rating, and in terms of design, this allows designers to assess whether or not a particular resistor will meet their design needs within a circuit. So, now, let's take a closer look at how to calculate this critical design parameter.



Firstly, according to Ohm's law,

V (voltage) = I (current) × R (resistance)

I (current) = V (voltage) ÷ R (resistance)

P (power) = I (current) × V (voltage)

Therefore, to calculate the power dissipated by the resistor, the formulas are as follows:

P (power dissipated) = I2 (current) × R (resistance)

or

P (power dissipated) = V2 (voltage) ÷ R (resistance)

So, using the above circuit diagram as our reference, we can apply these formulas to determine the power dissipated by the resistor.

Voltage = 9V

Resistance = 100Ω

I (current) = 9V ÷ 100Ω or I (current) = 90 mA

P (power) = 90 mA × 9V or P (power) = .81 W or 810 mW

P (power dissipated) = V2 (voltage) ÷ R (resistance)

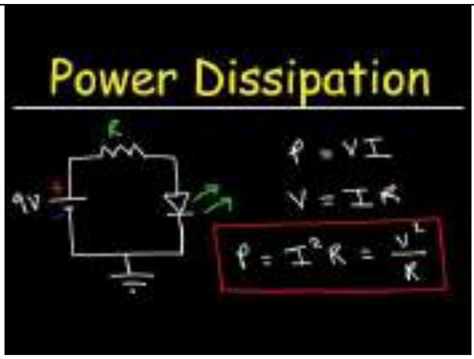
or

P (power dissipated) = 92 ÷ 100

or

P (power dissipated) = 81 ÷ 100 or P (power dissipated) = 810 mW

Video Link:



6.Thermoelectricity

Thermoelectricity, also called Peltier-Seebeck effect, direct conversion of heat into electricity or electricity into heat through two related mechanisms, the Seebeck effect and the Peltier effect.

Thermoelectricity is a two-way process. It can refer either to the way a temperature difference between one side of a material and the other can produce electricity, or to the reverse: the way applying an electric current through a material can create a temperature difference between its two sides, which can be used to heat or cool things without combustion or moving parts.

The first part of the thermoelectric effect, the conversion of heat to electricity, was discovered in 1821 by the Estonian physicist Thomas Seebeck and was explored in more detail by French physicist Jean Peltier, and it is sometimes referred to as the Peltier-Seebeck effect.

The reverse phenomenon, where heating or cooling can be produced by running an electric current through a material, was discovered in 1851 by William Thomson, also known as Lord Kelvin (for whom the absolute Kelvin temperature scale is named), and is called the Thomson effect. The effect is caused by charge carriers within the material (either electrons, or places where an electron is missing, known as “holes”) diffusing from the hotter side to the cooler side, similarly to the way gas expands when it is heated. The thermoelectric property of a material is measured in volts per Kelvin.

The fundamental problem in creating efficient thermoelectric materials is that they need to be good at conducting electricity, but not at conducting thermal energy. That way, one side can get hot while the other gets cold, instead of the material quickly equalizing the temperature. But in most materials, electrical and thermal conductivity go hand in hand. New nano-engineered materials provide a way around that, making it possible to fine-tune the thermal and electrical properties of the material. Some MIT groups, including ones led by professors Gang Chen and Michael Strano, have been developing such materials.

Such systems are produced for the heating and cooling of a variety of things, such as car seats, food and beverage carriers, and computer chips. Also under development by researchers including MIT's Anantha Chandrakasan are systems that use the Peltier-Seebeck effect to harvest waste heat, for everything from electronic devices to cars and powerplants, in order to produce usable electricity and thus improve overall efficiency.

7.Kirchhoff's Laws

We saw in the Resistors tutorial that a single equivalent resistance, (R_T) can be found when two or more resistors are connected together in either series, parallel or combinations of both, and that these circuits obey Ohm's Law.

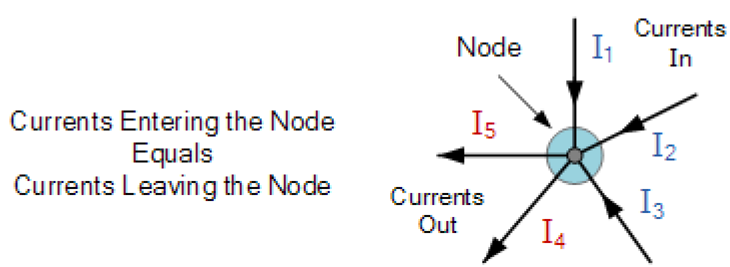
However, sometimes in complex circuits such as bridge or T networks, we can not simply use Ohm's Law alone to find the voltages or currents circulating within the circuit. For these types of calculations we need certain rules which allow us to obtain the circuit equations and for this we can use **Kirchhoffs Circuit Law**.

In 1845, a German physicist, Gustav Kirchhoff developed a pair or set of rules or laws which deal with the conservation of current and energy within electrical circuits. These two rules are commonly known as: *Kirchhoffs Circuit Laws* with one of Kirchhoffs laws dealing with the current flowing around a closed circuit, Kirchhoffs Current Law, (KCL) while the other law deals with the voltage sources present in a closed circuit, Kirchhoffs Voltage Law, (KVL).

Kirchhoffs First Law – The Current Law, (KCL)

Kirchhoffs Current Law or KCL, states that the "*total current or charge entering a junction or node is exactly equal to the charge leaving the node as it has no other place to go except to leave, as no charge is lost within the node*". In other words the algebraic sum of ALL the currents entering and leaving a node must be equal to zero, $I_{(exiting)} + I_{(entering)} = 0$. This idea by Kirchhoff is commonly known as the **Conservation of Charge**.

Kirchhoff's Current Law



$$I_1 + I_2 + I_3 + (-I_4 + -I_5) = 0$$

Here, the three currents entering the node, I_1, I_2, I_3 are all positive in value and the two currents leaving the node, I_4 and I_5 are negative in value. Then this means we can also rewrite the equation as;

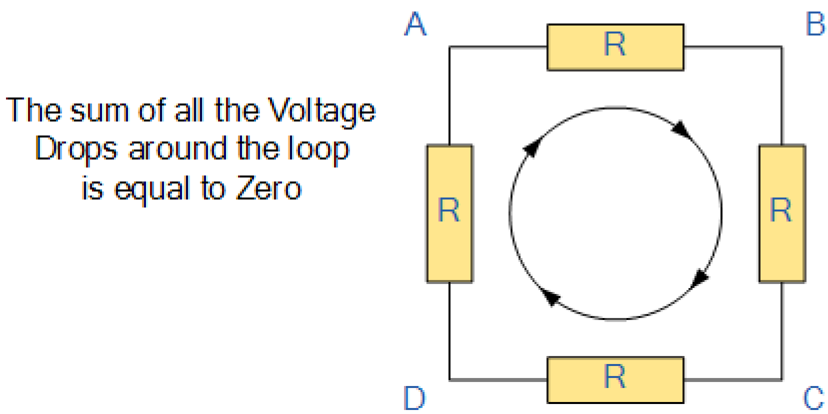
$$I_1 + I_2 + I_3 - I_4 - I_5 = 0$$

The term **Node** in an electrical circuit generally refers to a connection or junction of two or more current carrying paths or elements such as cables and components. Also for current to flow either in or out of a node a closed circuit path must exist. We can use Kirchhoff's current law when analysing parallel circuits.

Kirchhoffs Second Law – The Voltage Law, (KVL)

Kirchhoffs Voltage Law or KVL, states that "*in any closed loop network, the total voltage around the loop is equal to the sum of all the voltage drops within the same loop*" which is also equal to zero. In other words the algebraic sum of all voltages within the loop must be equal to zero. This idea by Kirchhoff is known as the **Conservation of Energy**.

Kirchhoff's Voltage Law



$$V_{AB} + V_{BC} + V_{CD} + V_{DA} = 0$$

Starting at any point in the loop continue in the **same direction** noting the direction of all the voltage drops, either positive or negative, and returning back to the same starting point. It is important to maintain the same direction either clockwise or anti-clockwise or the final voltage sum will not be equal to zero. We can use Kirchhoff's voltage law when analysing series circuits.

When analysing either DC circuits or AC circuits using **Kirchhoffs Circuit Laws** a number of definitions and terminologies are used to describe the parts of the circuit being analysed such as: node, paths, branches, loops and meshes. These terms are used frequently in circuit analysis so it is important to understand them.

Common DC Circuit Theory Terms:

- Circuit – a circuit is a closed loop conducting path in which an electrical current flows.
- Path – a single line of connecting elements or sources.
- Node – a node is a junction, connection or terminal within a circuit were two or more circuit elements are connected or joined together giving a connection point between two or more branches. A node is indicated by a dot.
- Branch – a branch is a single or group of components such as resistors or a source which are connected between two nodes.
- Loop – a loop is a simple closed path in a circuit in which no circuit element or node is encountered more than once.

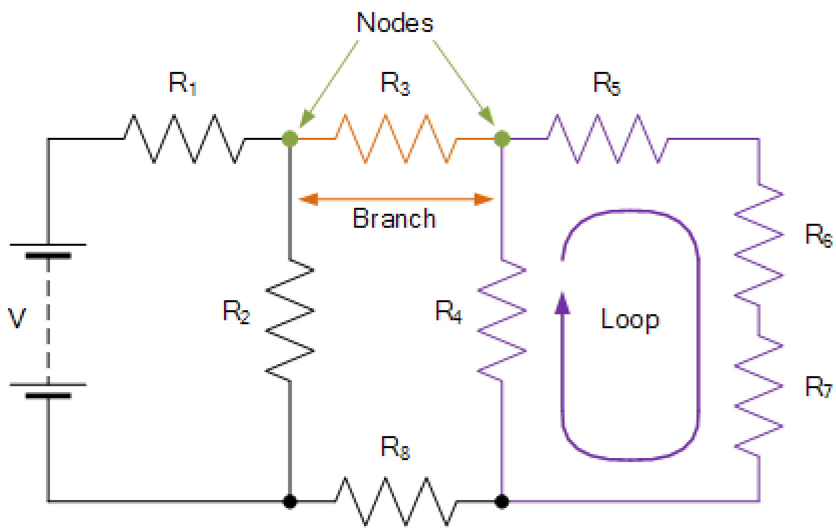
- Mesh – a mesh is a single closed loop series path that does not contain any other paths. There are no loops inside a mesh.

Note that:

Components are said to be connected together in Series if the same current value flows through all the components.

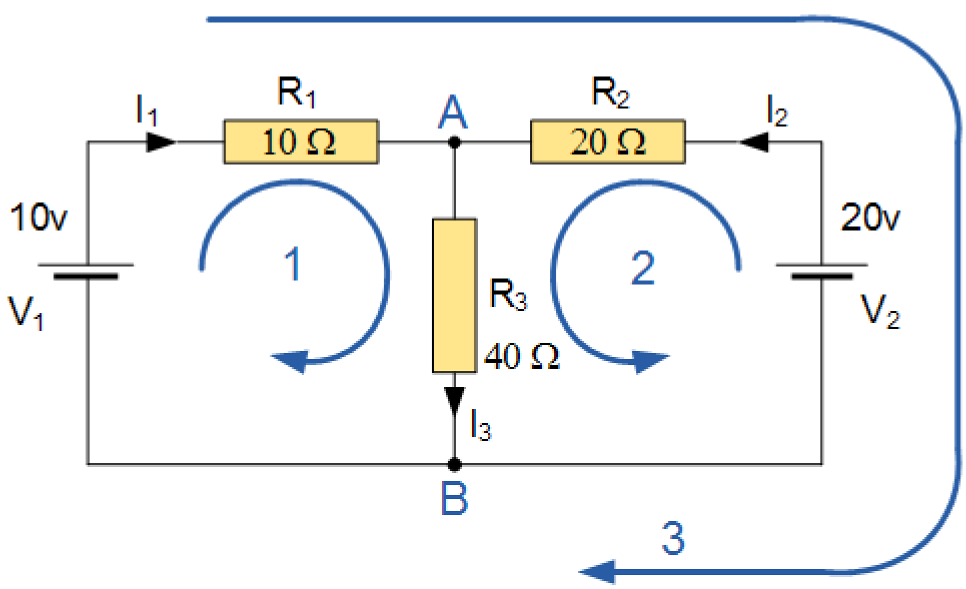
Components are said to be connected together in Parallel if they have the same voltage applied across them.

A Typical DC Circuit



Kirchhoffs Circuit Law Example No1

Find the current flowing in the 40Ω Resistor, R_3



The circuit has 3 branches, 2 nodes (A and B) and 2 independent loops.

Using **Kirchhoffs Current Law**, **KCL** the equations are given as:

At node A : $I_1 + I_2 = I_3$

At node B : $I_3 = I_1 + I_2$

Using **Kirchhoffs Voltage Law**, **KVL** the equations are given as:

Loop 1 is given as : $10 = R_1 I_1 + R_3 I_3 = 10I_1 + 40I_3$

Loop 2 is given as : $20 = R_2 I_2 + R_3 I_3 = 20I_2 + 40I_3$

Loop 3 is given as : $10 – 20 = 10I_1 – 20I_2$

As I_3 is the sum of $I_1 + I_2$ we can rewrite the equations as;

Eq. No 1 : $10 = 10I_1 + 40(I_1 + I_2) = 50I_1 + 40I_2$

Eq. No 2 : $20 = 20I_2 + 40(I_1 + I_2) = 40I_1 + 60I_2$

We now have two "**Simultaneous Equations**" that can be reduced to give us the values of I_1 and I_2

Substitution of I_1 in terms of I_2 gives us the value of I_1 as -0.143 Amps

Substitution of I_2 in terms of I_1 gives us the value of I_2 as +0.429 Amps

As : $I_3 = I_1 + I_2$

The current flowing in resistor R_3 is given as : $-0.143 + 0.429 = 0.286$ Amps

and the voltage across the resistor R_3 is given as : $0.286 \times 40 = 11.44$ volts

The negative sign for I_1 means that the direction of current flow initially chosen was wrong, but never the less still valid. In fact, the 20v battery is charging the 10v battery.

Application of Kirchhoffs Circuit Laws

These two laws enable the Currents and Voltages in a circuit to be found, ie, the circuit is said to be "Analysed", and the basic procedure for using **Kirchhoff's Circuit Laws** is as follows:

- **1.** Assume all voltages and resistances are given. (If not label them V1, V2,… R1, R2, etc.)
- **2.** Assigns a current to each branch or mesh (clockwise or anticlockwise)
- **3.** Label each branch with a branch current. (I1, I2, I3 etc.)
- **4.** Find Kirchhoff's first law equations for each node.
- **5.** Find Kirchhoff's second law equations for each of the independent loops of the circuit.
- **6.** Use Linear simultaneous equations as required to find the unknown currents.

As well as using **Kirchhoffs Circuit Law** to calculate the various voltages and currents circulating around a linear circuit, we can also use loop analysis to calculate the currents in each independent loop which helps to reduce the amount of mathematics required by using just Kirchhoff's laws. In the next tutorial about DC circuits, we will look at Mesh Current Analysis to do just that.

8.The potential divider

A potential divider is a simple circuit that uses resisters(or thermistors / LDR's) to supply a variable potential difference.

They can be used as audio volume controls, to control the temperature in a freezer or monitor changes in light in a room.

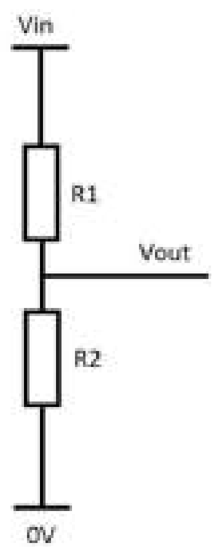
Two resistors divide up the potential difference supplied to them from a cell. The proportion of the available p.d. that the two resistors get depends on there resistance values.

- V_{in} = p.d. supplied by the cell
- V_{out} = p.d. across the resistor of interest
- R_1 = resistance of resistor of interest R_1
- R_2= resistance of resistor R_2

$$V_{out} = \frac{V_{in}R_1}{R_1 + R_2}$$

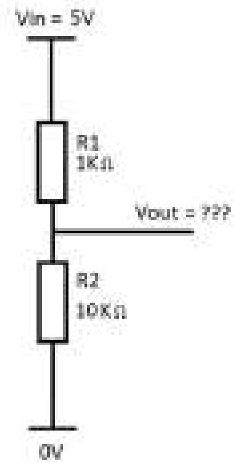
How does it work?

A potential divider is a simple circuit which takes advantage of the way voltages drop across resistors in series. It is a very useful and common circuit and is widely used in our range of electronic kits. The idea is that by using two resistors in series it is possible to divide a voltage and create a different voltage between them. In the example below two identical resistors are in series with a power supply. The total voltage across the circuit is 'Vin' however this total voltage is split between our two resistors meaning 'Vout' is at a different voltage. The amount by which the voltage drops over across each resistor depends on the relative values of each resistor and the total resistance.



Example:

This is a worked example of using the formula above to calculate the missing Vout value for a circuit. Look at the circuit below and take note of the values that are known. Vin is 5V, R1 is 1KΩ and R2 is 10KΩ



Next, substitute the known values into the formula:

$$Vout = \frac{Vin \times R2}{R1 + R2}$$

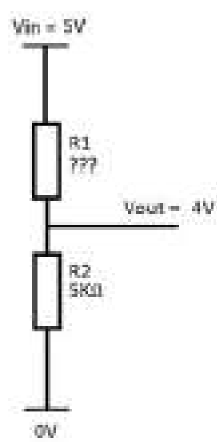
$$Vout = \frac{5V \times 10K\Omega}{1K\Omega + 10K\Omega}$$

$$Vout = 4.55V$$

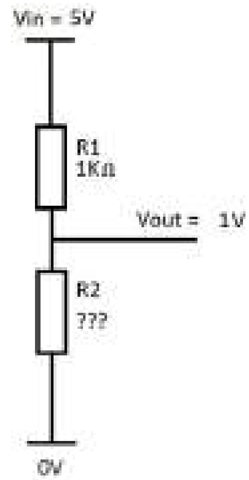
Assessment :

Example Questions:

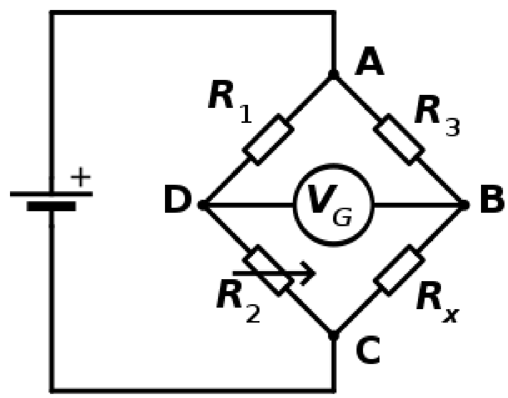
Now try finding the missing values in these three examples. **Question 1:**



Question 2:



9.Balanced potentials (Wheatstone bridge and potentiometer



A **Wheatstone bridge** is an electrical circuit used to measure an unknown electrical resistance by balancing two legs of a bridge circuit, one leg of which includes the unknown component. The primary benefit of the circuit is its ability to provide extremely accurate measurements (in contrast with something like a simple voltage divider). Its operation is similar to the original potentiometer.

The Wheatstone bridge was invented by Samuel Hunter Christie (sometimes spelled "Christy") in 1833 and improved and popularized by Sir Charles Wheatstone in 1843. One of the Wheatstone bridge's initial uses was for soils analysis and comparison.

Working of Galvanometer

The bridge is in balance condition when no current flows through the coil or the potential difference across the galvanometer is zero. This condition occurs when the potential difference across the a to b and a to d are equal, and the potential differences across the b to c and c to d remain same.

The current enters into the galvanometer divides into I_1 and I_2, and their magnitude remains same. The following condition exists when the current through the galvanometer is zero.

$$I_1 P = I_2 R \ldots \ldots \ldots equ(1)$$

The bridge in a balanced condition is expressed as

$$I_1 = I_3 = \frac{E}{P+Q}$$

$$I_2 = I_4 = \frac{E}{R+S}$$

Where E – emf of the battery.

By substituting the value of I_1 and 1_2 in equation (1) we get.

$$\frac{PE}{P+Q} = \frac{RE}{R+S}$$

$$\frac{P}{P+Q} = \frac{R}{R+S}$$

$$P(R+S) = R(P+Q)$$

$$PR + PS = RP + RQ$$

$$PS = RQ \ldots\ldots\ldots equ(2)$$

$$R = \frac{P}{Q} \times S \ldots\ldots\ldots equ(3)$$

The equation (2) shows the balance condition of the Wheatstone bridge.

The value of unknown resistance is determined by the help of the equation (3). The R is the unknown resistance, and the S is the standard arm of the bridge and the P and Q are the ratio arm of the bridge.

Errors in Wheatstone Bridge

The following are the errors in the Wheatstone bridge.

. The difference between the true and the mark value of the three resistances can cause the error in measurement.
. The galvanometer is less sensitive. Thus, inaccuracy occurs in the balance point.
. The resistance of the bridge changes because of the self-heating which generates an error.
. The thermal emf cause serious trouble in the measurement of low-value resistance.

. The personal error occurs in the galvanometer by taking the reading or by finding the null point.

The above mention error can be reduced by using the best qualities resistor and galvanometer. The error because of self-heating of resistance can minimise by measuring the resistance within the short time. The thermal effect can also be reduced by connecting the reversing switch between the battery and the bridge.

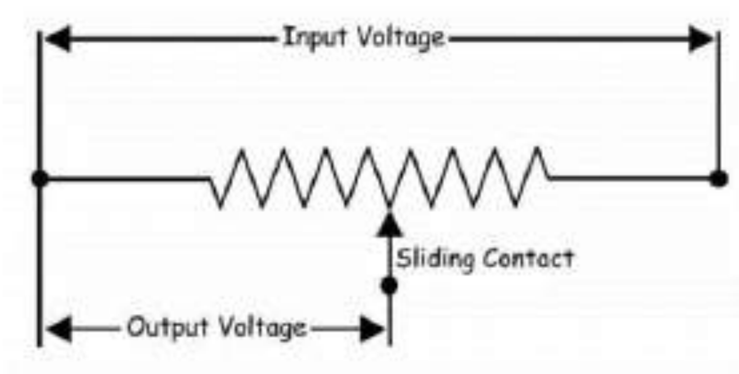
Video Link:

What is a Potentiometer?

A **potentiometer** (also known as a **pot** or **potmeter**) is defined as a 3 terminal variable resistor in which the resistance is manually varied to control the flow of electric current. A potentiometer acts as an adjustable voltage divider.

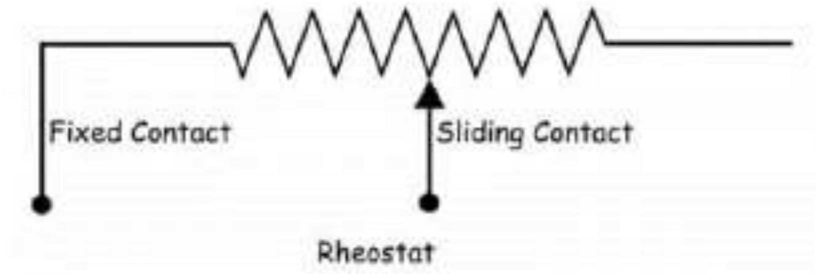
How Does a Potentiometer Work?

A potentiometer is a passive electronic component. Potentiometers work by varying the position of a sliding contact across a uniform resistance. In a potentiometer, the entire input voltage is applied across the whole length of the resistor, and the output voltage is the voltage drop between the fixed and sliding contact as shown below.

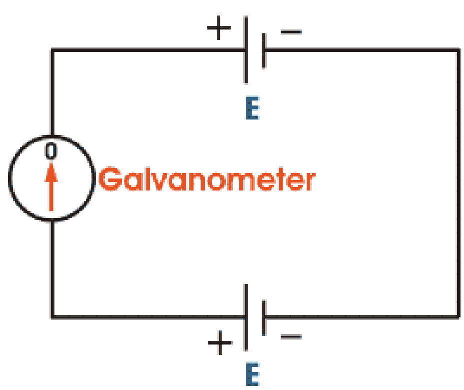


. A potentiometer has the two terminals of the input source fixed to the end of the resistor. To adjust the output voltage the sliding contact gets moved along the resistor on the output side.

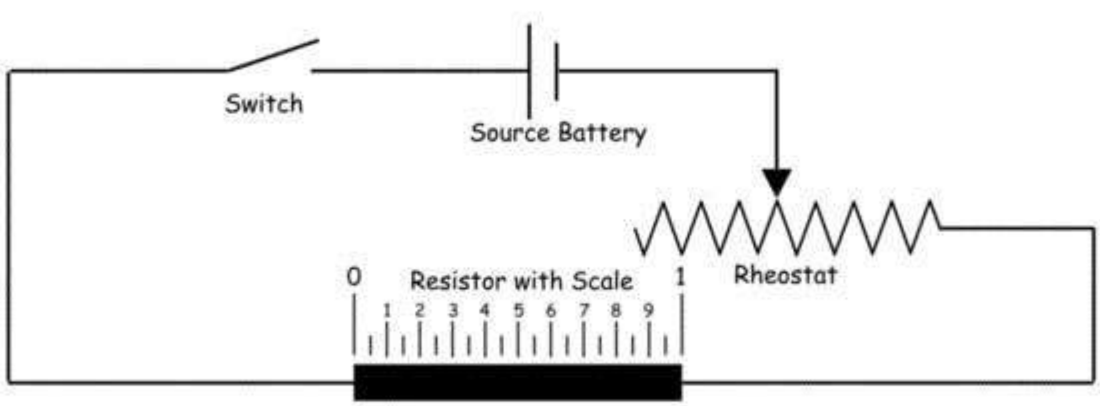
This is different to a rheostat, where here one end is fixed and the sliding terminal is connected to the circuit, as shown below.

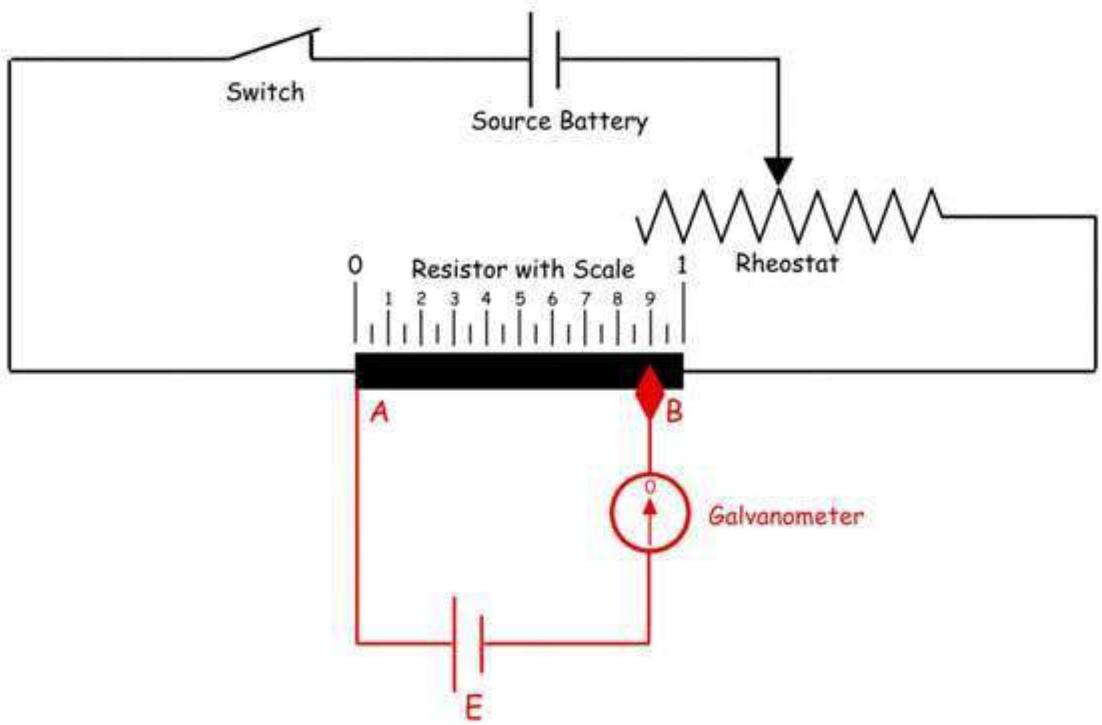


This is a very basic instrument used for comparing the emf of two cells and for calibrating ammeter, voltmeter, and watt-meter. The basic **working principle of a potentiometer** is quite simple. Suppose we have connected two batteries in parallel through a galvanometer. The negative battery terminals are connected together and positive battery terminals are also connected together through a galvanometer as shown in the figure below.



Here, if the electric potential of both battery cells is exactly the same, there is no circulating current in the circuit and hence the galvanometer shows null deflection. The **working principle of potentiometer** depends upon this phenomenon.





Now let's think about another circuit, where a battery is connected across a resistor via a switch and a rheostat as shown in the figure below.

The resistor has the uniform electrical resistance per unit length throughout its length. Hence, the voltage drop per unit length of the resistor is equal throughout its length. Suppose, by adjusting the rheostat we get v volt voltage drop appearing per unit length of the resistor.
Now, the positive terminal of a standard cell is connected to point A on the resistor and the negative terminal of the same is connected with a galvanometer. The other end of the galvanometer is in contact with the resistor via a sliding contact as shown in the figure above. By adjusting this sliding end, a point like B is found where there is no current through the galvanometer, hence no deflection in the galvanometer.

That means, emf of the standard cell is just balanced by the voltage appearing in the resistor across points A and B. Now if the distance between points A and B is L, then we can write emf of standard cell E = Lv volt.

Length

150-250 minutes depending on age group/prior knowledge

Reference Page:

https://www.google.com/search?q=Steady+current&source=lmns&bih=625&biw=1366&rlz=1C1CAFB_enPK904PK905&hl=en&ved=2ahUKEwivnIze8vjpAhXROewKHWSTBJUQ_AUoAHoECAEQAA

http://www-materials.eng.cam.ac.uk/mpsite/properties/non-IE/resistivity.html#:~:text=Restivity%20is%20affected%20by%20temperature,is%20measured%20by%20thermal%20conductivity.

https://www.physicsclassroom.com/class/circuits/Lesson-1/Electric-Potential-Difference

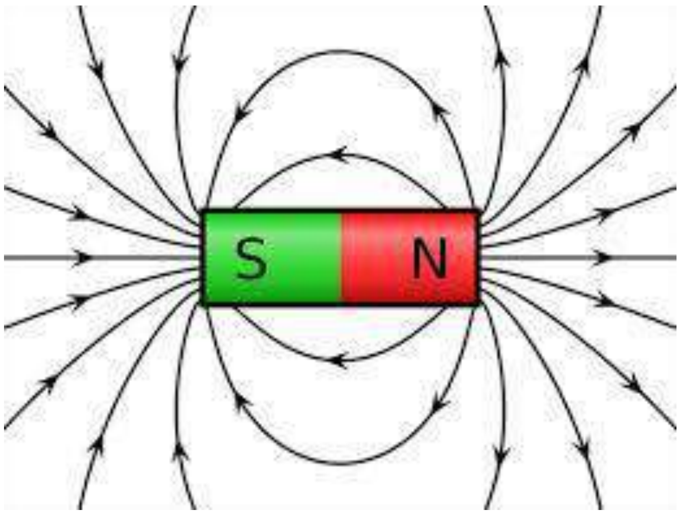
https://resources.pcb.cadence.com/blog/2020-power-dissipated-by-a-resistor-circuit-reliability-and-calculation-examples
CgZwc3ktYWIQAzICCAAyAggAMgIIADICCAAyAggAMgIIADICCAAyAggAMgIIADICCAA6BAgAEEdQgoUxWIKFMWDIkzFoAXAFeACAAfYCiAH2ApIBAzMtMZgBAKABAaABAqoBB2d3cy13aXqwAQA
https://www.electronics-tutorials.ws/dccircuits/dcp_4.html
https://kitronik.co.uk/blogs/resources/potential-divider-voltage-divider
https://en.wikipedia.org/wiki/Wheatstone_bridge#:~:text=A%20Wheatstone%20bridge%20is%20an,which%20includes%20the%20unknown%20component.

https://circuitglobe.com/wheatstone-bridge.html

https://www.electrical4u.com/potentiometer/

Unit - 13

Electromagnetism



Topics	Understandings	Skills
• Magnetic field of current –carrying conductor • Magnetic force on a current-carrying conductor • Magnetic flux density • Ampere's law and its application in solenoid • Force on a moving charged particle in a magnetic field • e/m of an electron • Torque on a current carrying coil in a magnetic field • Electro-mechanical instruments	The students will: • explain that magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets. • describe magnetic effect of current. • describe and sketch field lines pattern due to a long straight wire. • explain that a force might act on a current-carrying conductor placed in a magnetic field. • Investigate the factors affecting the force on a current carrying conductor in a magnetic field. • solve problems involving the use of F = BIL sin θ. • define magnetic flux density and its units. • describe the concept of magnetic flux (Ø) as scalar product of magnetic field (B) and area (A) using the relation ØB = B⊥ A=B.A. • state Ampere's law. • apply Ampere's law to find magnetic flux density around a wire and inside a solenoid. Conceptual linkage: [2]This chapter is built on Electromagnetism Physics X 39	• construct a simple electromagnet and investigate the factors which influence the strength of an electromagnet. • convert a galvanometer into voltmeter of range zero to 3 V. • interpret and illustrate on the basis of experimental data, the magnetic field produced by a current flowing in a coil is stronger than a straight conductor. • examine the motion of electrons in an electric field using a Cathode Ray tube. • examine the motion of electrons in a magnetic field using a Cathode Ray tube.

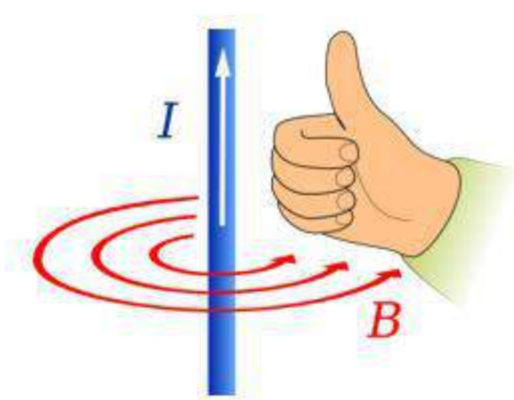
	• describe quantitatively the path followed by a charged particle shot into a magnetic field in a direction perpendicular to the field. • explain that a force may act on a charged particle in a uniform magnetic field. • describe a method to measure the e/m of an electron by applying magnetic field and electric field on a beam of electrons. • predict the turning effect on a current carrying coil in a magnetic field and use this principle to understand the construction and working of a galvanometer. • explain how a given galvanometer can be converted into a voltmeter or ammeter of a specified range. • describe the use of a vometer / multimeter (analogue and digital).	

Let us start with the very first theory of Electromagnetism

01.Magnetic field of current –carrying conductor

Current is generally defined as the rate of flow of charge. We already know that stationary charges produce an electric field which is proportional to the magnitude of the charge. The same principle can be applied here, moving charges produce magnetic fields which are proportional to the current and hence a current carrying conductor produces magnetic effect around it. This magnetic field is generally attributed to the sub-atomic particles in the conductor, for e.g. the moving electrons in the atomic orbitals.

Magnetic field has both magnitude and direction. Hence it is a vector quantity and is denoted by B (in the diagram given below). Magnetic field due to a current carrying conductor depends on the current in the conductor and distance of the point from the conductor. The direction of the magnetic field is perpendicular to the wire. If you wrap your right hand's fingers around the wire with your thumb pointing in the direction of the current, then the direction in which the fingers would curl will give the direction of the magnetic field. This will be clearer with the diagram shown below where the red lines represent the magnetic field lines.



Characteristics Of Magnetic Field Due To Current Carrying Conductor

The magnetic field produced due to a current carrying conductor has the following characteristics:

- It encircles the conductor.
- It lies in a plane perpendicular to the conductor.
- Reversal in direction of current flow reverses the direction of the field.
- Strength of the field is directly proportional to the magnitude of current.
- Strength of the field at any point is inversely proportional to the distance of the point from the wire.

It's difficult to comprehend the role of magnetism in our lives as we can't see them. Take a look around and the realization of its importance will not be as difficult. The motors that are used so extensively around the world whether it's a toy car or a bullet train or an aircraft or a spaceship they all use the same magnetic effect.

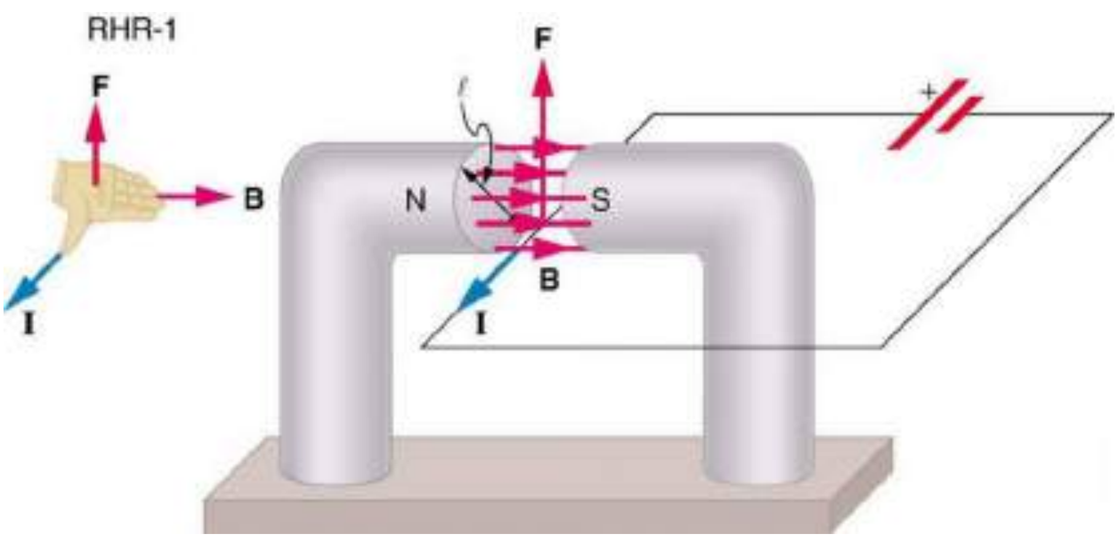


Figure 1. The magnetic field exerts a force on a current-carrying wire in a direction given by the right hand rule 1 (the same direction as that on the individual moving charges). This force can easily be large enough to move the wire, since typical currents consist of very large numbers of moving charges.

We can derive an expression for the magnetic force on a current by taking a sum of the magnetic forces on individual charges. (The forces add because they are in the same direction.) The force on an individual charge moving at the drift velocity v_d is given by F = $qv_dB \sin \theta$. Taking B to be uniform over a length of wire l and zero elsewhere, the total magnetic force on the wire is then F = $(qv_dB \sin \theta)(N)$, where N is the number of charge carriers in the section of wire of length l. Now, $N = nV$, where n is the number of charge carriers per unit volume and V is the volume of wire in the field. Noting that $V = Al$, where A is the cross-sectional area of the wire, then the force on the wire is F = $(qv_dB \sin \theta)(nAl)$. Gathering terms,

$$F = (nqAvd)\ lB\sin\theta F = (nqAvd)\ lB \sin\theta.$$

Because $nqAv_d = I$ (see **Current**),

$$F = IlB\sin\theta\ F = IlB\sin\theta$$

is the equation for *magnetic force on a length l of wire carrying a current I in a uniform magnetic field B*, as shown in Figure 2. If we divide both sides of this expression by l, we find that the magnetic force per unit length of wire in a uniform field is $Fl=IB\sin\theta Fl=IB\sin\theta$. The direction of this force is given by RHR-1, with the thumb in the direction of the current *I*. Then, with the fingers in the direction of *B*, a perpendicular to the palm points in the direction of *F*, as in Figure 2.

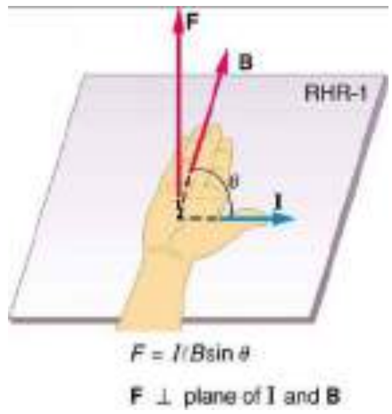


Figure 2. The force on a current-carrying wire in a magnetic field is $F = IlB \sin \theta$. Its direction is given by RHR-1.

EXAMPLE 1. CALCULATING MAGNETIC FORCE ON A CURRENT-CARRYING WIRE: A STRONG MAGNETIC FIELD

Calculate the force on the wire shown in Figure 1, given $B = 1.50$ T, $l = 5.00$ cm, and $I = 20.0$ A.

Strategy
The force can be found with the given information by using F=IlBsinθF=IlBsin θ and noting that the angle θ between I and B is 90º, so that $\sin \theta = 1$.

Solution
Entering the given values into $F = IlB \sin \theta$ yields

$$F = IlB \sin \theta = (20.0\text{ A})(0.0500\text{ m})(1.50\text{ T})(1).$$

The units for tesla are 1 T=NA·m1 T=NA·m; thus,

$$F = 1.50\text{ N}.$$

Discussion

This large magnetic field creates a significant force on a small length of wire.

Magnetic force on current-carrying conductors is used to convert electric energy to work. (Motors are a prime example—they employ loops of wire and are considered in the next section.) Magnetohydrodynamics (MHD) is the technical name given to a clever application where magnetic force pumps fluids without moving mechanical parts. (See Figure 3.)

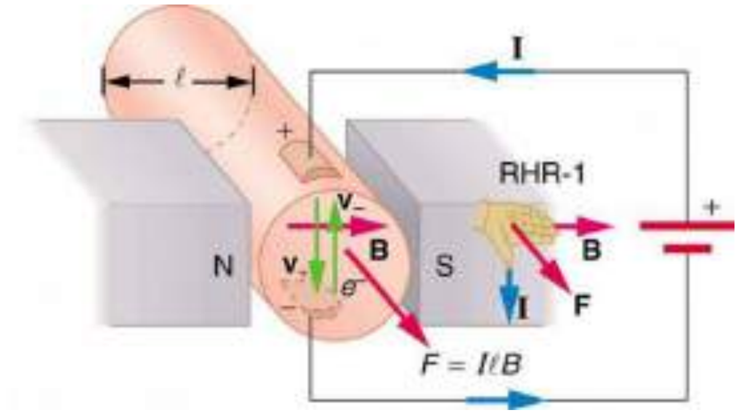
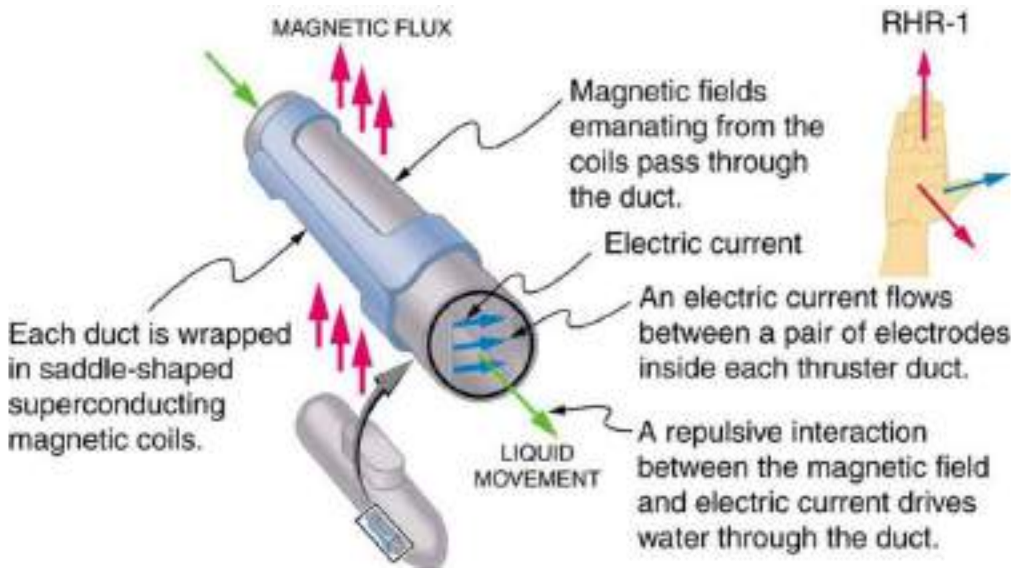


Figure 3. Magneto hydrodynamics. The magnetic force on the current passed through this fluid can be used as a no mechanical pump.

A strong magnetic field is applied across a tube and a current is passed through the fluid at right angles to the field, resulting in a force on the fluid parallel to the tube axis as shown. The absence of moving parts makes this attractive for moving a hot, chemically active substance, such as the liquid sodium employed in some nuclear reactors. Experimental artificial hearts are testing with this technique for pumping blood, perhaps circumventing the adverse effects of mechanical pumps. (Cell membranes, however, are affected by the large fields needed in MHD, delaying its practical application in humans.) MHD propulsion for nuclear submarines has been proposed, because it could be considerably quieter than conventional propeller drives. The deterrent value of nuclear submarines is based on their ability to hide and survive a first or second nuclear strike. As we slowly disassemble our nuclear weapons arsenals, the submarine branch will be the last to be decommissioned because of this ability (See Figure 4.) Existing MHD drives are heavy and inefficient—much development work is needed.



Section Summary

- The magnetic force on current-carrying conductors is given by

$$F=IlB\sin\theta$$

where I is the current, l is the length of a straight conductor in a uniform magnetic field B, and θ is the angle between I and B. The force follows RHR-1 with the thumb in the direction of I.

CONCEPTUAL QUESTIONS

1. Draw a sketch of the situation in Figure 1 showing the direction of electrons carrying the current, and use RHR-1 to verify the direction of the force on the wire.
2. Verify that the direction of the force in an MHD drive, such as that in Figure 3, does not depend on the sign of the charges carrying the current across the fluid.
3. Why would a magnetohydrodynamic drive work better in ocean water than in fresh water? Also, why would superconducting magnets be desirable?
4. Which is more likely to interfere with compass readings, AC current in your refrigerator or DC current when you start your car? Explain.

Assessment :

PROBLEMS & EXERCISES

1. What is the direction of the magnetic force on the current in each of the six cases in Figure 5?

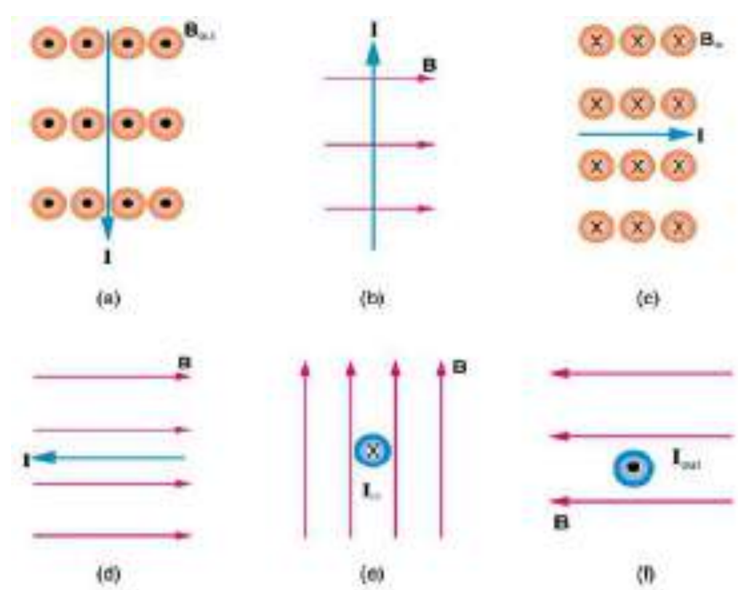


Figure 5.

2. What is the direction of a current that experiences the magnetic force shown in each of the three cases in Figure 6, assuming the current runs perpendicular to B?

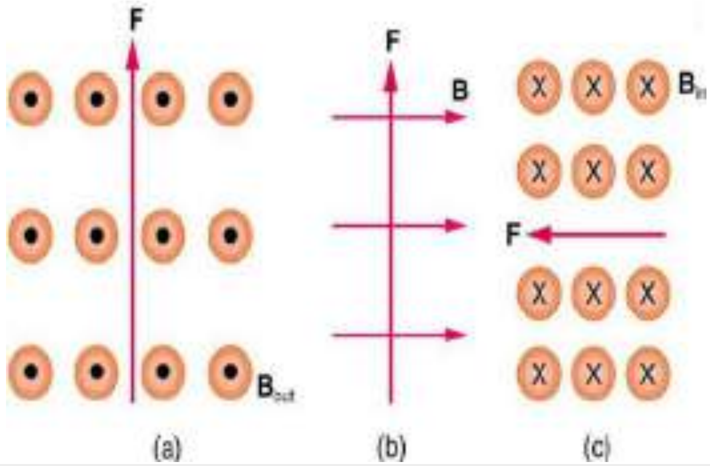


Figure 6.

03.Magnetic flux density

Magnetic flux is a measurement of the total magnetic field which passes through a given area. It is a useful tool for helping describe the effects of the magnetic force on something occupying a given area. The measurement of magnetic flux is tied to the particular area chosen. We can choose to make the area any size we want and orient it in any way relative to the magnetic field.

If we use the field-line picture of a magnetic field then every field line passing through the given area contributes some magnetic flux. The angle at which the field line intersects the area is also important. A field line passing through at a glancing angle will only contribute a small component of the field to the magnetic flux. When calculating the magnetic flux we include only the **component** of the magnetic field vector which is **normal** to our test area.

If we choose a simple flat surface with area AAA as our test area and there is an angle \theta$\theta$theta between the normal to the surface and a magnetic field vector (magnitude BBB) then the magnetic flux is,
[Explain]

$$\Phi = BA\cos\theta$$

In the case that the surface is perpendicular to the field then the angle is zero and the magnetic flux is simply B ABAB, A. Figure 1 shows an example of a flat test area at two different angles to a magnetic field and the resulting magnetic flux.

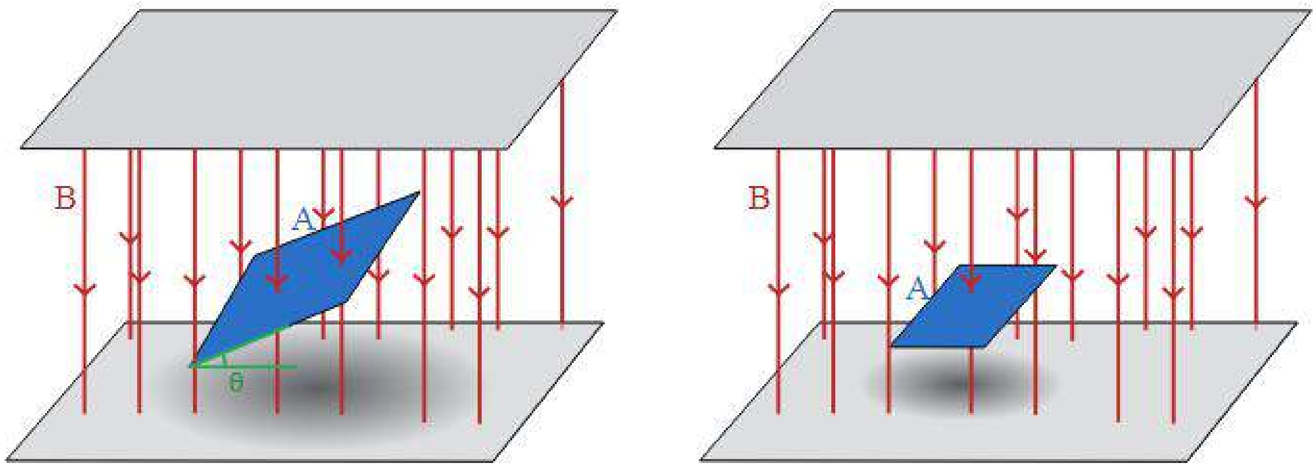


Figure 1: *Magnetic flux through given areas (blue) oriented at an angle (left) and normal to (right) the magnetic field.*

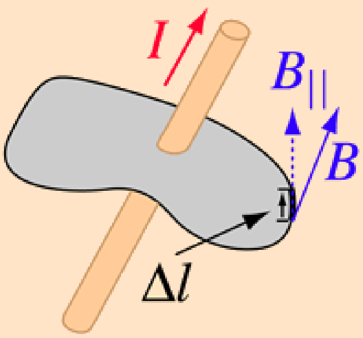
Video Link:

04.Ampere’s law and its application in solenoid:

Ampere's law can be applied to find the magnetic field inside of a long solenoid as a function of the number of turns per length N/L and the current I. ... The magnetic field inside a solenoid is proportional to both the applied current and the number of turns per unit length.

Ampere's Law

The magnetic field in space around an electric current is proportional to the electric current which serves as its source, just as the electric field in space is proportional to the charge which serves as its source. Ampere's Law states that for any closed loop path, the sum of the length elements times the magnetic field in the direction of the length element is equal to the permeability times the electric current enclosed in the loop.

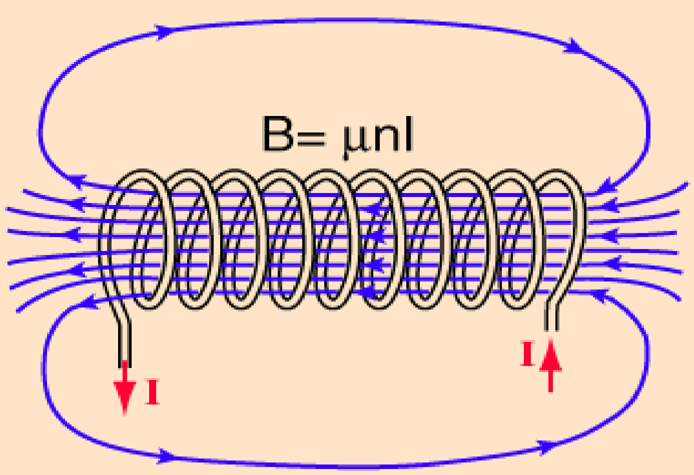


$$\sum B_{||}\Delta l = \mu_0 I$$

In the electric case, the relation of field to source is quantified in Gauss's Law which is a very powerful tool for calculating electric fields.

Solenoid

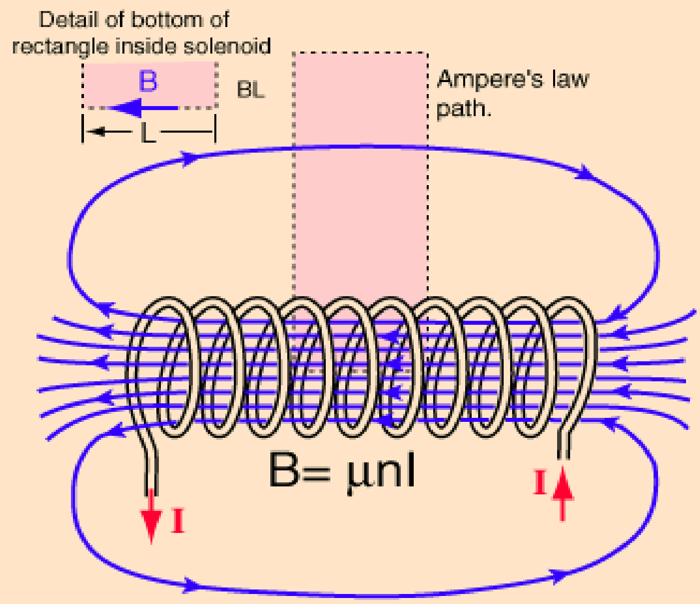
A long straight coil of wire can be used to generate a nearly uniform magnetic field similar to that of a bar magnet. Such coils, called solenoids, have an enormousnumber of practical applications. The field canbe greatly strengthenedby the addition ofan iron core.Such cores aretypical inelectromagnets.



The magnetic field is concentrated into a nearly uniform field in the center of a long solenoid. The field outside is weak and divergent.

Solenoid Field from Ampere's Law

Taking a rectangular path about which to evaluate Ampere's Law such that the length of the side parallel to the solenoid field is **L** gives a contribution **BL** inside the coil.The field is essentially perpendicular tothe sides of thepath, giving negligible contribution. If theend is taken so far from the coil that thefield is negligible, thenthe length inside the coilis the dominant contribution.



This admittedly idealized case for Ampere's Law gives

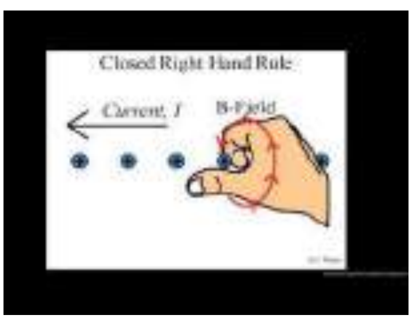
$$BL = \mu NI$$

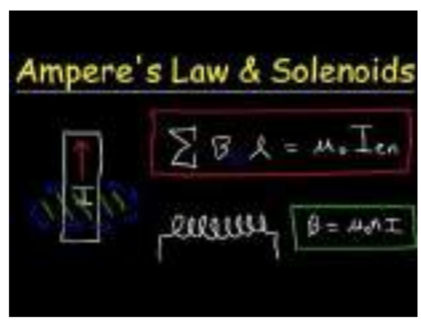
$$B = \mu \frac{N}{L} I$$

$$B = \mu n I$$

This turns out to be a good approximation for the solenoid field, particularly in the case of an iron core solenoid.

Video link:





05.Force on a moving charged particle in a magnetic field

Right Hand Rule 1

The magnetic force on a moving charge is one of the most fundamental known. Magnetic force is as important as the electrostatic or Coulomb force. Yet the magnetic force is more complex, in both the number of factors that affects it and in its direction, than the relatively simple Coulomb force. The magnitude of the magnetic force F on a charge q moving at a speed v in a magnetic field of strength B is given by

$$F = qvB \sin \theta,$$

where θ is the angle between the directions of v and B. This force is often called the *Lorentz force*. In fact, this is how we define the magnetic field strength B—in terms of the force on a charged particle moving in a magnetic field. The SI unit for magnetic field strength B is called the *tesla* (T) after the eccentric but brilliant inventor Nikola Tesla (1856–1943). To determine how the tesla relates to other SI units, we solve $F = qvB \sin \theta$ for B.

$$B = \frac{F}{qv \sin \theta}$$

Because $\sin \theta$ is unitless, the tesla is

$$1\ \mathrm{T} = \frac{1\ \mathrm{N}}{\mathrm{C} \cdot \mathrm{m/s}} = \frac{1\ \mathrm{N}}{\mathrm{A} \cdot \mathrm{m}}$$

(note that C/s = A). Another smaller unit, called the *gauss* (G), where 1 G = 10−4 T, is sometimes used. The strongest permanent magnets have fields near 2 T; superconducting electromagnets may attain 10 T or more. The Earth's magnetic field on its surface is only about 5×10^{-5} T, or 0.5 G.

The *direction* of the magnetic force **F** is perpendicular to the plane formed by **v** and **B**, as determined by the *right hand rule 1* (or **RHR-1**), which is illustrated in Figure 1. RHR-1 states that, to determine the direction of the magnetic force on a positive moving charge, you point the thumb of the right hand in the direction of **v**, the fingers in the direction of **B**, and a perpendicular to the palm points in the direction of **F**. One way to remember this is that there is one velocity, and so the thumb represents it. There are many field lines, and so the fingers represent them. The force is in the direction you would push with your palm. The force on a negative charge is in exactly the opposite direction to that on a positive charge.

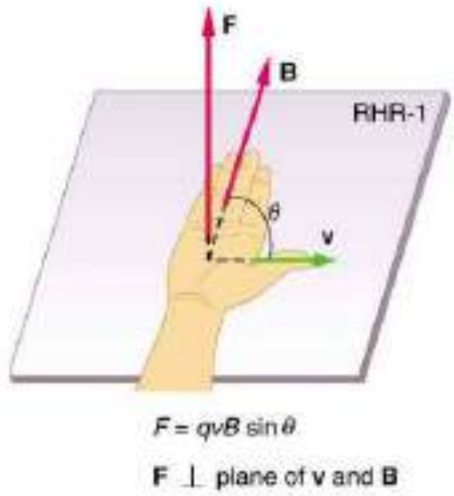


Figure 1. Magnetic fields exert forces on moving charges. This force is one of the most basic known. The direction of the magnetic force on a moving charge is perpendicular to the plane formed by v and B and follows right hand rule–1 (RHR-1) as shown. The magnitude of the force is proportional to q, v, B, and the sine of the angle between v and B.

MAKING CONNECTIONS: CHARGES AND MAGNETS

There is no magnetic force on static charges. However, there is a magnetic force on moving charges. When charges are stationary, their electric fields do not affect magnets. But, when charges move, they produce magnetic fields that exert forces on other magnets. When there is relative motion, a connection between electric and magnetic fields emerges—each affects the other.

EXAMPLE 1. CALCULATING MAGNETIC FORCE: EARTH’S MAGNETIC FIELD ON A CHARGED GLASS ROD

With the exception of compasses, you seldom see or personally experience forces due to the Earth’s small magnetic field. To illustrate this, suppose that in a physics lab you rub a glass rod with silk, placing a 20-nC positive charge on it. Calculate the force on the rod due to the Earth’s magnetic field, if you throw it with a horizontal velocity of 10 m/s due west in a place where the Earth’s field is due north parallel to the ground. (The direction of the force is determined with right hand rule 1 as shown in Figure 2.)

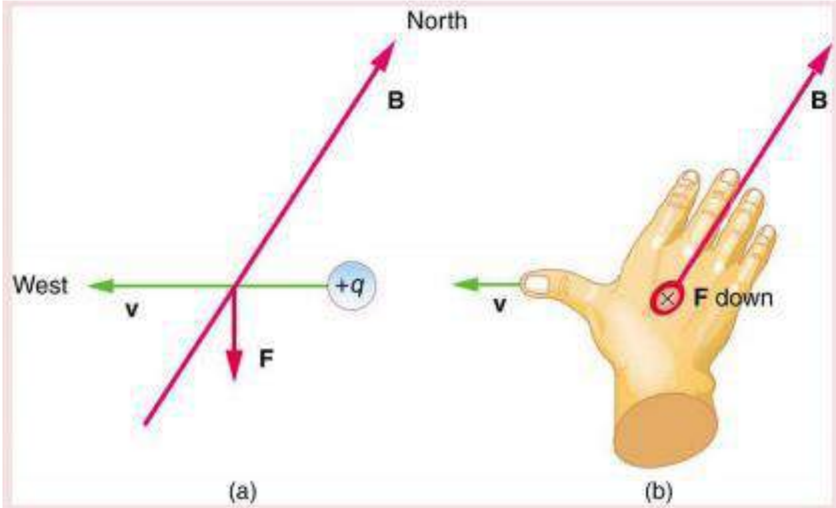


Figure 2. A positively charged object moving due west in a region where the Earth's magnetic field is due north experiences a force that is straight down as shown. A negative charge moving in the same direction would feel a force straight up.

Strategy
We are given the charge, its velocity, and the magnetic field strength and direction. We can thus use the equation $F = qvB \sin \theta$ to find the force.

Solution
The magnetic force is

$$F = qvB \sin \theta$$

We see that $\sin \theta = 1$, since the angle between the velocity and the direction of the field is 90º. Entering the other given quantities yields

$$F=(20\times10^{-9}\ C)(10\ m/s)(5\times10^{-5}\ T)=1\times10^{-11}(C\cdot m/s)(N\ C\cdot m/s)=1\times10^{-11}\ N F=(20\times10^{-9}\ C)(10\ m/s)(5\times10^{-5}\ T)=1\times10^{-11}(C\cdot m/s)(N\ C\cdot m/s)=1\times10^{-11}\ N.$$

Discussion
This force is completely negligible on any macroscopic object, consistent with experience. (It is calculated to only one digit, since the Earth's field varies with location and is given to only one digit.) The Earth's magnetic field, however, does produce very important effects, particularly on submicroscopic particles. Some of these are explored in **Force on a Moving Charge in a Magnetic Field: Examples and Applications**.

Section Summary

- Magnetic fields exert a force on a moving charge q, the magnitude of which is

  $$F = qvB \sin \theta,$$

  where θ is the angle between the directions of v and B.
- The SI unit for magnetic field strength B is the tesla (T), which is related to other units by

  $$1\ T=1\ N\ C\cdot m/s=1\ NA\cdot m 1\ T=1\ N\ C\cdot m/s=1\ NA\cdot m$$
- The *direction* of the force on a moving charge is given by right hand rule 1 (RHR-1): Point the thumb of the right hand in the direction of v, the fingers in the direction of B, and a perpendicular to the palm points in the direction of F.

- The force is perpendicular to the plane formed by ***v*** and ***B***. Since the force is zero if ***v*** is parallel to ***B***, charged particles often follow magnetic field lines rather than cross them.

CONCEPTUAL QUESTIONS

1. If a charged particle moves in a straight line through some region of space, can you say that the magnetic field in that region is necessarily zero?

Assessment :

PROBLEMS & EXERCISES

1. What is the direction of the magnetic force on a positive charge that moves as shown in each of the six cases shown in Figure 3?

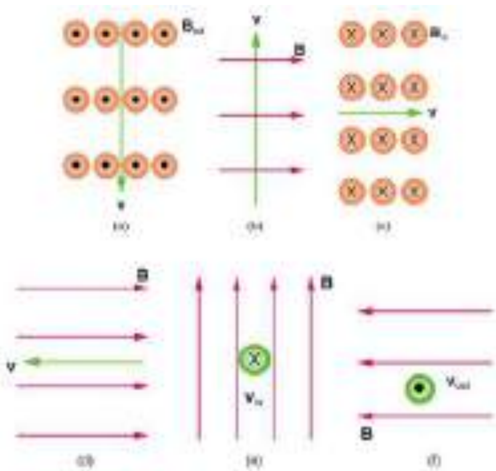


Figure 3.

. Repeat Exercise 1 for a negative charge.

3. What is the direction of the velocity of a negative charge that experiences the magnetic force shown in each of the three cases in Figure 4, assuming it moves perpendicular to **B**?

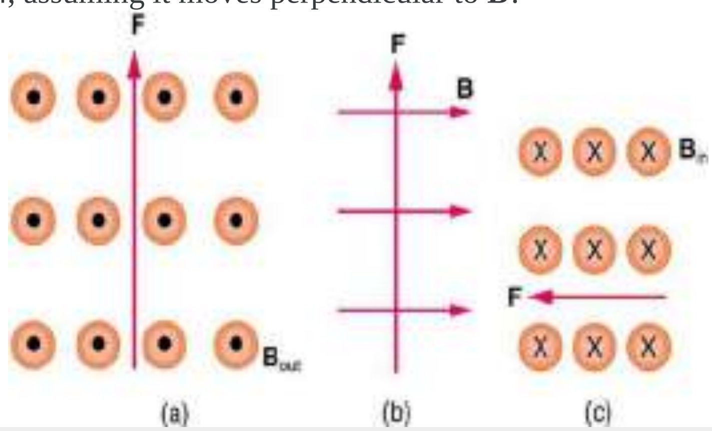


Figure 4.

4. Repeat Figure 4 for a positive charge.

5. What is the direction of the magnetic field that produces the magnetic force on a positive charge as shown in each of the three cases in the figure below, assuming **B** is perpendicular to **v**?

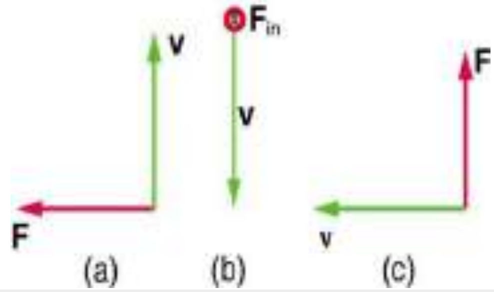


Figure 5.

6. Repeat Exercise 5 for a negative charge.

7. What is the maximum force on an aluminum rod with a 0.100-μC charge that you pass between the poles of a 1.50-T permanent magnet at a speed of 5.00 m/s? In what direction is the force?

8. (a) Aircraft sometimes acquire small static charges. Suppose a supersonic jet has a0.500-μC charge and flies due west at a speed of 660 m/s over the Earth's south magnetic pole, where the 8.00 × 10−5-T magnetic field points straight up. What are the direction and the magnitude of the magnetic force on the plane? (b) Discuss whether the value obtained in part (a) implies this is a significant or negligible effect.
9. (a) A cosmic ray proton moving toward the Earth at 5.00×10^{7} experiences a magnetic force of 1.70×10^{-16} N. What is the strength of the magnetic field if there is a 45º angle between it and the proton's velocity? (b) Is the value obtained in part (a) consistent with the known strength of the Earth's magnetic field on its surface? Discuss.
10. An electron moving at 4.00×10^{3} m/s in a 1.25-T magnetic field experiences a magnetic force of 1.40×10^{-16} N. What angle does the velocity of the electron make with the magnetic field? There are two answers.
11. (a) A physicist performing a sensitive measurement wants to limit the magnetic force on a moving charge in her equipment to less than 1.00×10^{-12} N. What is the greatest the charge can be if it moves at a maximum speed of 30.0 m/s in the Earth's field? (b) Discuss whether it would be difficult to limit the charge to less than the value found in (a) by comparing it with typical static electricity and noting that static is often absen

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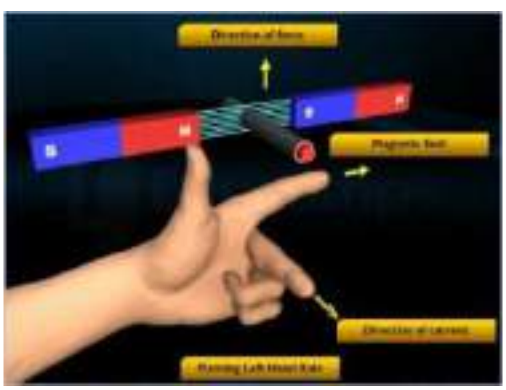
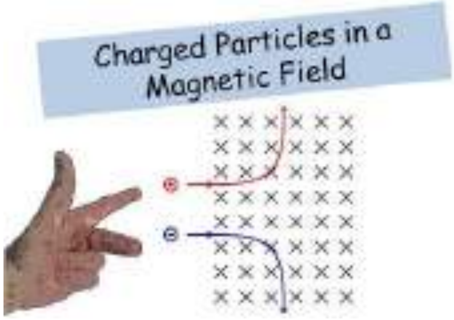
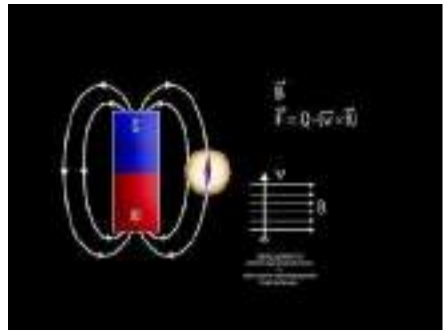






06.e/m of an electron

DETERMINATION OF e/m OF AN ELECTRON

INTRODUCTION

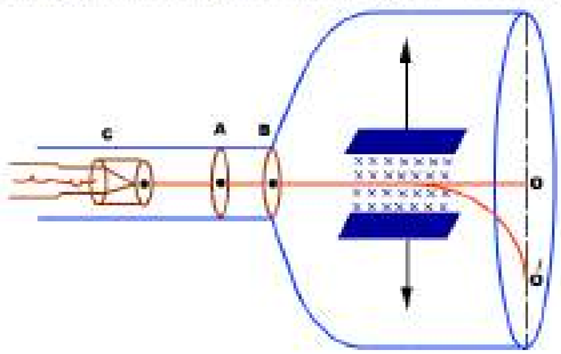
J.J Thomson was the first scientist who measured charge to mass ratio (e/m) of an electron.

PRINCIPLE

When a narrow beam of charged particles are projected at constant speed (v) across a magnetic field in a direction perpendicular to the field, the beam of particles experiences a force, which makes them move in a circular path.

APPARATUS

It consists of a highly evacuated glass tube, fitted with electrodes. Electrons are produced by heating a tungsten filament electrically. Electrons are made to accelerate and form a beam by passing through discs A and B. They are passed through electric and magnetic field. Finally they fall on zinc sulphide screen.



THEORY

Actually electrons moving side ways are also directed towards the screen by applying a -ve potential on a hollow cylinder (c) open on both sides surrounding the filament. Electrons are accelerated by applying a potential difference of above 1000 V between the filament and disc A. A further potential difference of 500 V is applied between the discs A and B. The arrangement focuses the beam to the hole of the disc B from where it is further proceeds to a straight line. When beam of electrons enters a magnetic field it moves in a circular track. The force experienced by the electron is

$$F_m = evB\text{--------}(1)$$

This magnetic field provides necessary centripetal force to electron so that it follows a circular path.

$$\text{i.e. } F_m = F_c$$

$$evB = mv^2/r$$

$$eB = mv/r$$

$$e/m = v/Br \text{ -----}(2)$$

By knowing the values of v, B and r, value of e/m can be determined.

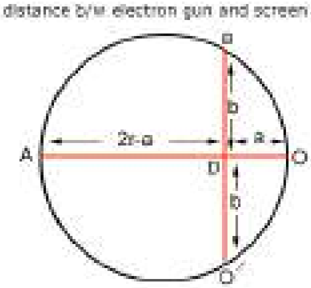
RADIUS OF CURVATURE OF PATH

If r is the radius of curvature of circular path, 'a' is the distance b/w 'O' and 'O'', and 'b' is the distance b/w electron gun and screen then by using the property of chord:

$$AD \times OD = BD \times DO$$

$$(2r-a)(a) = b.b$$

$$2ra-a^2 = b$$



Since 'a' is very small as compared to '2r', so we neglect 'a^2'.

$$2rx = b^2$$

$$r = b^2/2x$$

DETERMINATION OF THE VELOCITY (FIRST METHOD)

The electrons are first accelerated by applying a potential (V) b/w discs A and B before entering the magnetic field.

$$\mathbf{K.E = V.e}$$

Or

$$\mathbf{1/2mv^2 = Ve}$$

$$\mathbf{v = (2Ve/m)^{1/2}}$$

Putting the value of v in eq. (2)

$$\mathbf{e/m = v/Br}$$

$$\mathbf{e/m = (2Ve/m)^{1/2}/Br}$$

Squaring on both sides

$$\mathbf{e^2/m^2 = 2Ve/m/B^2r^2}$$

or

$$\mathbf{e/m = 2Ve/B^2r^2}$$

Since 'a' is very small as compared to '2r', so we neglect 'a^2'.

$$2rx = b^2$$

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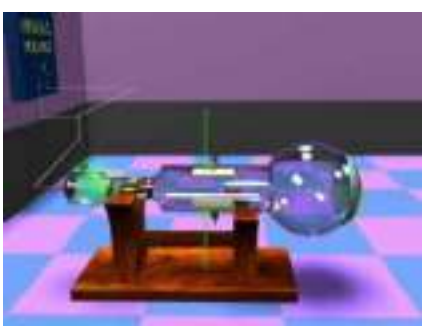
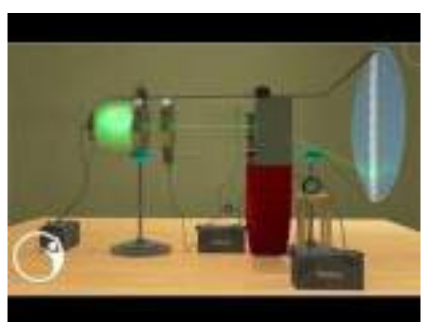
or

$$\mathbf{e/m = 2Ve/B^2r^2}$$

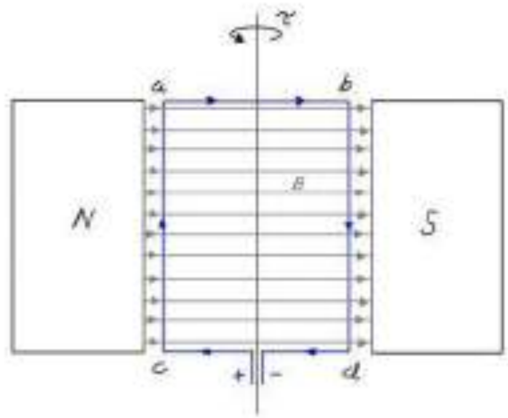
Video Link:





07.Torque on a current carrying coil in a magnetic field

CALCULATING THE TORQUE ON A CURRENT CARRYING LOOP IN A MAGNETIC FIELD:

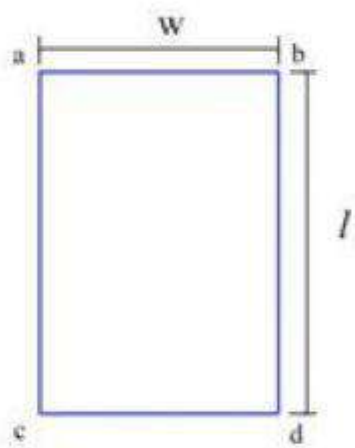


We can derive a formula for the torque on a current carrying loop in a magnetic field, which is free to turn about an axis, as shown in the diagram, by using the formulas for the force on a current carrying conductor in a magnetic field, and the formula for torque.

The ends of the loop, marked ab and cd, make no contribution to the torque, so we need only concern ourselves with the torque generated by the forces on the sides of the loop, marked ac and bd.

Let the sides ab and cd be equal to w, the width of the loop.

Let the sides ac and bd be equal to *l*, the length of the loop.



The magnitude of the forces acting on sides ac and bd will be equal, and are given by the formula:

$$F = BIl \sin\theta$$

As sides of the loop, ac and bd, are held at right angles to the magnetic field as the coil rotates, the magnitude of the forces are given by:

$$F = BIl \sin 90^0$$

$$F = BIl \times 1$$

$$F = BIl$$

These forces will be equal in magnitude, but opposite in direction and therefore sign, however as the forces act on opposite sides of the axis of rotation they will both tend to turn the coil in the same direction. Therefore, we need only concern ourselves with the magnitude, or absolute value, of these forces.

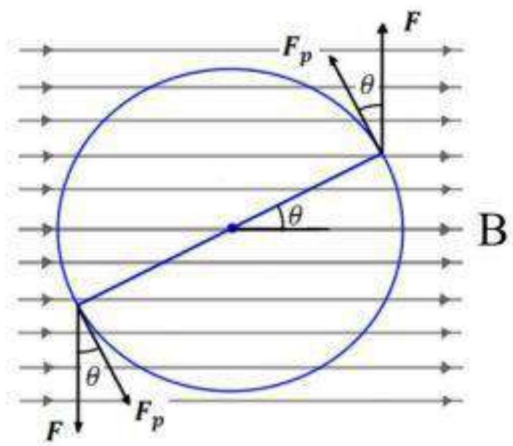
The formula for torque is:

$$\tau = F_p \times d$$

Or:

$$\tau = F \times d \cos\theta$$

Where θ is the angle between the normal to the straight line distance from the centre of rotation and the direction in which the force is acting, and is equal to the angle between the plane of the loop and the magnetic field direction.



The magnitude of the torque will therefore be given by the equation:

$$\tau = 2\,BIl \times d\cos\theta$$

The straight line distance from the axis of rotation to the point of action of the force for both of the sides ac and bd will be equal to w/2, half the width of the coil, substituting this for d we get:

$$\tau = 2\,BIl \times \frac{w}{2}\cos\theta$$

Or:

$$\tau = BIl \times w\cos\theta$$

The length of the loop multiplied by its width is equal to the area, A, of the loop, so that we can rewrite our equation as:

The torque on a coil made up of a number of loops, n, is simply the torque generated by a single current carrying loop in a magnetic field, multiplied by the number of loops making up the coil:

Where:

$$\tau = nBIA\cos\theta$$

Where:

τ = Torque (Nm)

B = Magnetic Field Strength (T)

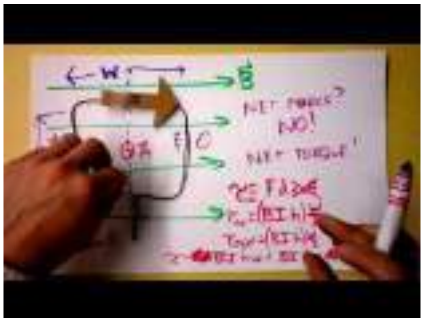
I = Current (A)

A = Area of the coil.

θ = Angle of Loop to Magnetic Field.

n = Number of Turns (or number of loops making up the coil).

Video Link:



08.Electro-mechanical instruments

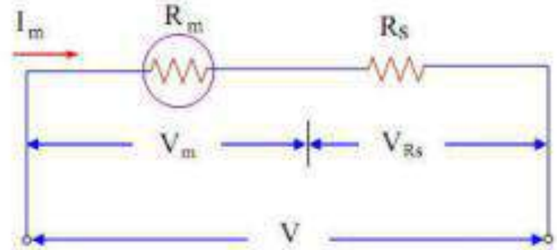
Introduction

PMMC instrument consists basically of a lightweight coil of copper wire suspended in the field of a permanent magnet. Current in the wire causes the coil to produce a magnetic field that interacts with the field from the Introduction magnet, resulting in partial rotation of the coil. A pointer connected to the coil deflects over a calibrated scale, indicating the level of current flowing in the wire.

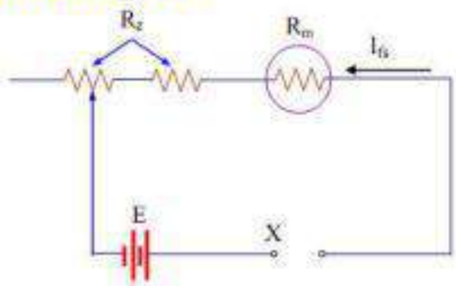
Electromechanical devices are ones which have both electrical and mechanical processes. Strictly speaking, a manually operated switch is an electromechanical component due to the mechanical movement causing an electrical output.

The PMMC instrument is essentially a low-level dc ammeter.

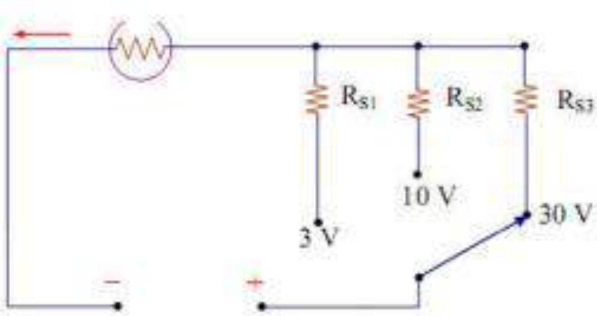
- The instrument may also be used as a dc voltmeter by connecting appropriate-value resistors in series with the coil.



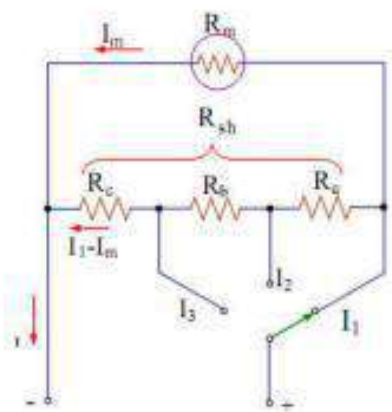
- Ohmmeters can be made from precision resistors, PMMC instrument, and batteries.



- Multirange meters are available that combine ammeter, voltmeter, and ohmmeter functions in one instrument

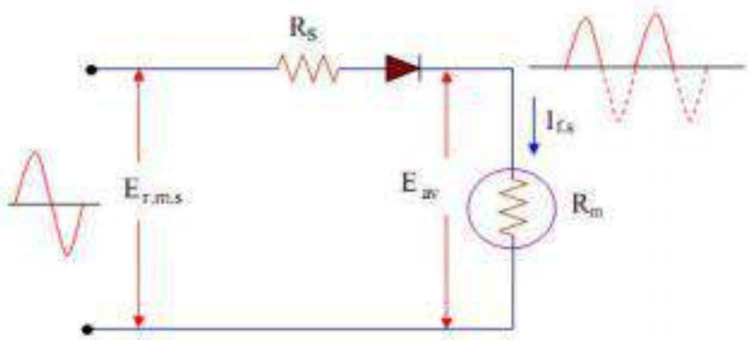


Mutlirange Voltmeter



Mutlirange Ammeter

- Ac ammeters and voltmeters can be constructed by using rectifier circuits with PMMC instruments.



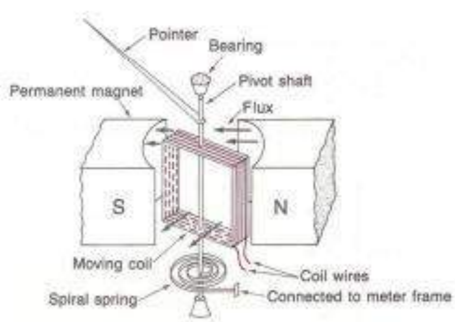
The Half wave rectifier

Deflection Instrument Fundamentals

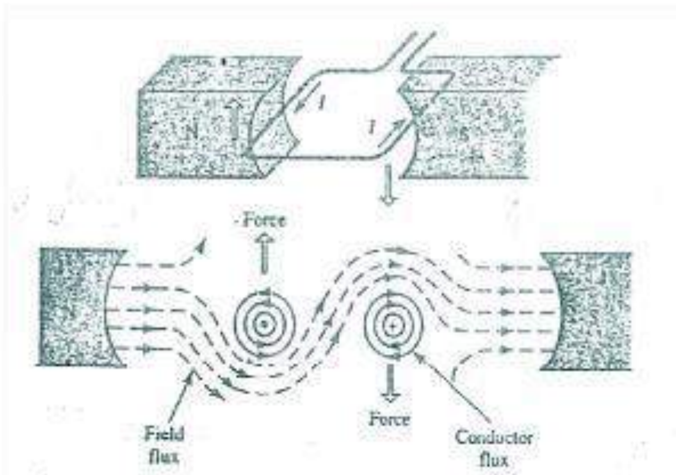
- A deflection instrument uses a pointer that moves over a calibrated scale to indicate a measured quantity.
- Three forces are operating in the electromechanical mechanism inside the instrument:
  - Deflecting force
  - Controlling force
  - Damping force

Deflecting Force

- The deflecting force causes the pointer to move from its zero position when a current flows.
- In the PMMC instrument, the deflecting force is magnetic.



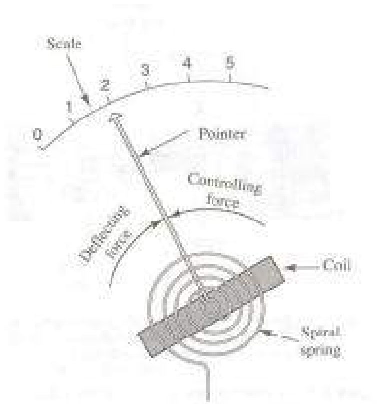
The pointer is fixed to the coil
So, it moves over the scale as
The coil rotates



The deflecting force in the PMMC instrument is provided by
A current-carrying coil pivoted in a magnetic field.

Controlling Force

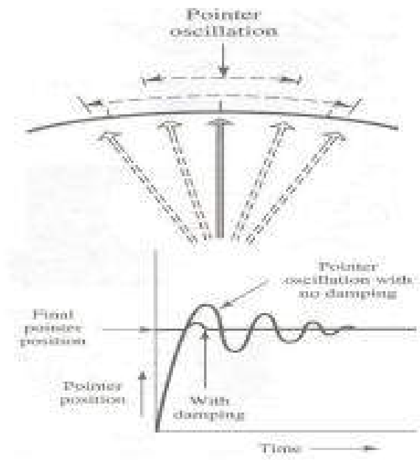
- The controlling force in the PMMC instrument is provided by spiral springs.
- The springs retain the coil & pointer at their zero position when no current is flowing.
- The coil and pointer stop rotating when the controlling force becomes equal to the deflecting force.
- The spring material must be nonmagnetic to avoid any magnetic field influence on the controlling force.



The controlling force from the springs balances the deflecting force.

- **The springs are also used to make electrical connection to the coil, they mush a low resistance(Phosphor bronze is the material usually employed).**

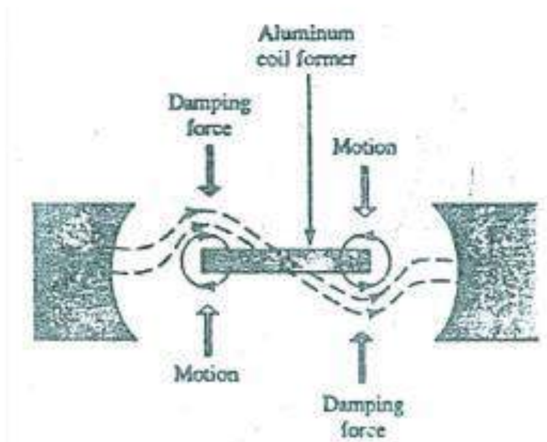
Damping Force



- The damping force is required to minimize (or damp out) oscillations of the pointer and coil before settling down at their final position.
- The damping force must be present only when the coil is in motion; thus it must be generated by the rotation of the coil.
- In PMMC instruments, the damping force is normally provided by eddy currents.
- Eddy currents induced in the coil set up a magnetic flux that opposes the coil motion, thus damping the oscillations of the coil.

Damping Force

- The damping force in a PMMC instrument is provided by eddy currents induced in the aluminum coil former as it moves through the magnetic field.

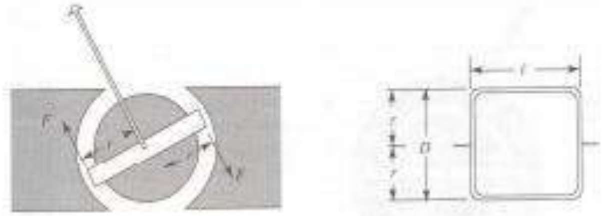


Torque Equation and Scale

- When a current I flows through a one-turn coil situated in a magnetic field, a force F is exerted on each side of the coil

  $F = (BIl) \times N$ newtons

  where N is the number of turns



(a) Force F acts on each side of the coil

(b) Area enclosed by coil is D X l

- Total force on each side of the coil of N turns:

$$F = 2BIlN \ \ newtons$$

- **The force on each side acts at a radius *r*, producing a deflecting torque:**

$$T_D = 2BlINr \ \ (N.m)$$
$$= BlIN(2r)$$
$$T_D = BlIND$$

$$T_D = BlIN\left(2r\right) = BlIND = BAIN$$

A=l.D, Where D is the coil diameter

- The controlling torque exerted by the spiral springs is directly proportional to the deformation or windup of the springs.

- Thus, the controlling torque is proportional to the actual angle of deflection of the pointer.

$$T_C = K\theta \quad \text{where } K \text{ is a constant}$$

- For a given deflection, the controlling and deflecting torques are equal:

$$K\theta = BlIND$$

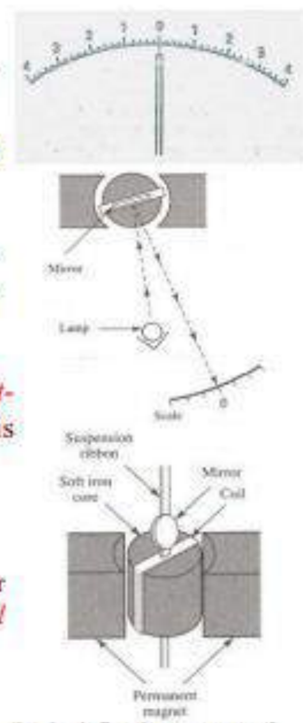
$$\theta = \frac{BlND}{K} I = CI \quad \text{where } C \text{ is a constant}$$

This equation shows that the pointer deflection is always proportional to the coil current.

Consequently, the scale of the instrument is linear, or uniformly divided.

Galvanometer

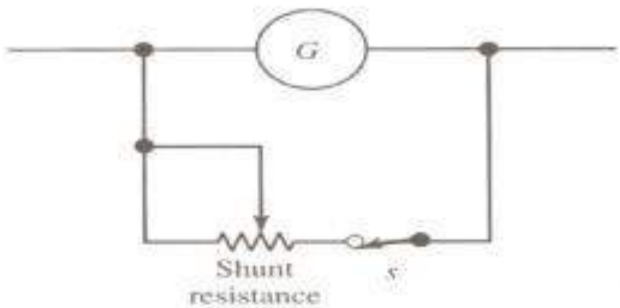
- It is a *PMMC instrument* designed to be sensitive to extremely low current levels.
- The simplest galvanometer is a very sensitive instrument with the type of ***center-zero scale.***
- Galvanometers are often employed *to detect zero* current or voltage in a circuit rather than to measure the actual level of current or voltage.
- The most sensitive moving-coil galvanometer use *taut-band suspension*, and the controlling torque is generated by the twist in the suspension ribbon.
- For the for greatest sensitivity, the weight of the pointer can create a problem. The solution is by *mounting a small mirror* on the moving coil instead of a pointer



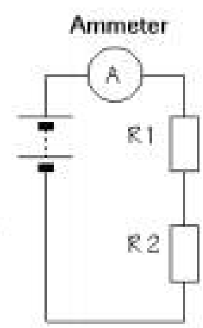
Basic deflection system of a galvanometer using a light beam

- An adjustable shunt resistor is employed to protect the coil of a galvanometer from destructively excessive current levels.

- The shunt resistance is initially set to zero, then gradually increased to divert current through the galvanometer.

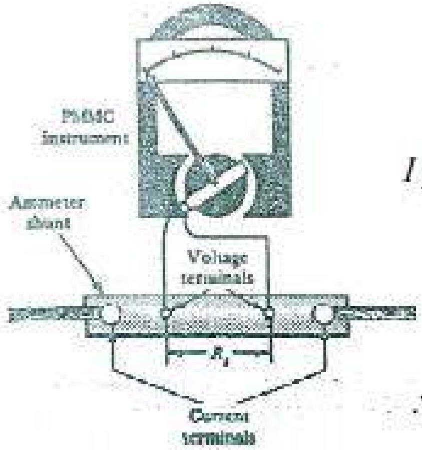


DC Ammeter



- An ammeter is always connected in series with a circuit in which current is to be measured.
- To avoid affecting the current level in the circuit, the ammeter must have a resistance much lower than the circuit resistance.
- For larger currents, the instrument must be modified so that most of the current to be measured is shunted *(a very low shunt resister)* around the coil of the meter.
- Only a small portion of the current passes through the moving coil.

- A dc ammeter consists of a PMMC instrument and a low-resistance shunt.



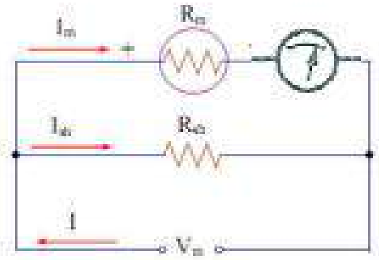
$$V_{sh} = V_m$$

$$I_{sh} R_{sh} = I_m R_m$$

$$R_{sh} = \frac{I_m R_m}{I_{sh}}$$

$$I_{sh} = I - I_m$$

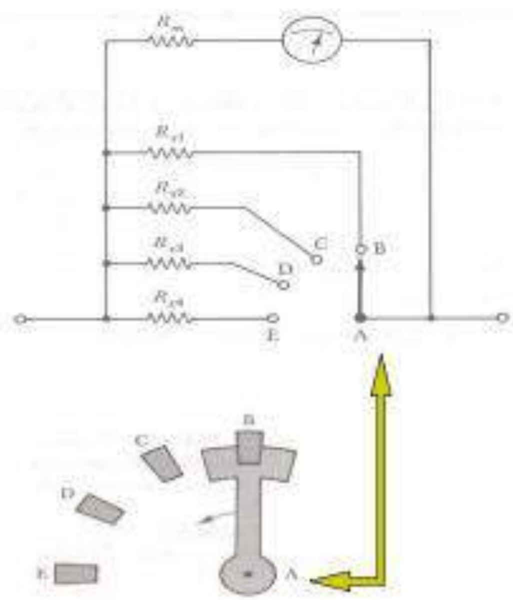
$$\therefore R_{sh} = \frac{I_m R_m}{I - I_m}$$



Multirange Ammeters

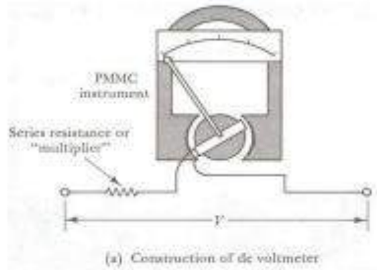
Make-before-break switch

- The instrument is not left without a shunt in parallel with it even for a brief instant. If this occurred, the high resistance of the instrument would affect the current flowing in the circuit.
- During switching there are actually two shunts in parallel with the instrument.



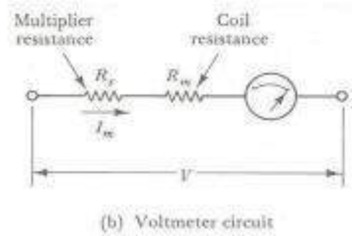
Make-before-break switch

DC Voltmeter



(a) Construction of dc voltmeter

- The deflection of a PMMC instrument is proportional to the current flowing through the moving coil. The coil current is directly proportional to the voltage across the coil.
- The coil resistance is normally quite small, and thus the coil voltage is also usually very small. Without any additional series (multiplier resistance) resistance the PMMC instrument would only measure very low voltage.
- The voltmeter range is easily increased by connecting a resistance in series with the instrument.



(b) Voltmeter circuit

- The meter current is directly proportional to the applied voltage, so that the meter scale can be calibrated to indicate the voltage.

- The voltmeter range is increased by connecting a multiplier resistance with the instrument (single or individual type of extension of range).

$$R_V = R_s + R_m$$

$$V = I_m R_V = I_m R_s + I_m R_m$$

$$R_s = \frac{1}{I_m} \times V - R_m$$

- Last equation can be used to select the multiplier resistance value (R_s) for certain voltage range (FSD). In this case I_m will be the full scale current.
- A multiplier resistance that is nine times the coil resistance will increase the voltmeter range by a factor of 10 (multiplier resistance + coil resistance)

- The *voltmeter sensitivity (S)* is defined as the total voltmeter resistance (*internal resistance R_{in}*) divided by the voltage range (full scale)

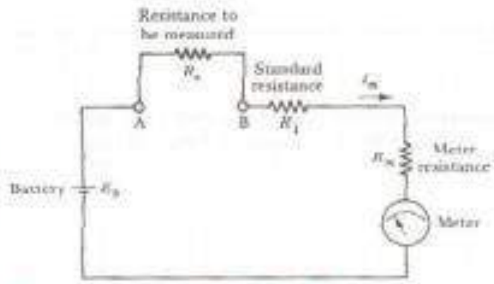
$$Sensitivity\ (S) = \frac{Total\ Resistance\ R_{in}}{Range} = \frac{1}{Full\ Scale\ Deflection\ Voltage\ (V_{FSD})} \quad K\Omega/V$$

Ohmmeter

A. Series Ohmmeter

- **Basic Circuit and Scale**

  - The simplest circuit consists of a voltage source (E_b) connected in series with a pair of terminals (A & B), a standard resistance (R_1), and a low-current PMMC instrument.



- The resistance to be measured (R_x) is connected across terminal A and B.
- *The meter current* $I_m = E_b/(R_x + R_1 + R_m)$
- When the ohmmeter terminals are shorted ($R_x = 0$) meter full-scale deflection occurs. $I_{FSD} = E_b/(R_1 + R_m)$
- At half-scale deflection $R_x = R_1 + R_m$
- At zero deflection the terminals are open-circuited ($R_x = \infty$).

Learning Outcomes:

• explain that magnetic field is an example of a field of force produced either by current-carrying conductors or by permanent magnets.

• describe magnetic effect of current.

• describe and sketch field lines pattern due to a long straight wire.

• explain that a force might act on a current-carrying conductor placed in a magnetic field.

• Investigate the factors affecting the force on a current carrying conductor in a magnetic field. • solve problems involving the use of F = BIL sin θ.

• define magnetic flux density and its units.

• describe the concept of magnetic flux (Ø) as scalar product of magnetic field (B) and area (A) using the relation ØB = B⊥ A=B.A.

• state Ampere's law.

• apply Ampere's law to find magnetic flux density around a wire and inside a solenoid. Conceptual linkage: [2]This chapter is built on Electromagnetism Physics X 39

• describe quantitatively the path followed by a charged particle shot into a magnetic field in a direction perpendicular to the field.

• explain that a force may act on a charged particle in a uniform magnetic field.

• describe a method to measure the e/m of an electron by applying magnetic field and electric field on a beam of electrons.

• predict the turning effect on a current carrying coil in a magnetic field and use this principle to understand the construction and working of a galvanometer.

• explain how a given galvanometer can be converted into a voltmeter or ammeter of a specified range.

• describe the use of avometer / multimeter (analogue and digital).

Reference Page:

https://byjus.com/physics/magnetic-field-current-conductor/#:~:text=Magnetic%20field%20due%20to%20a,is%20perpendicular%20to%20the%20wire.

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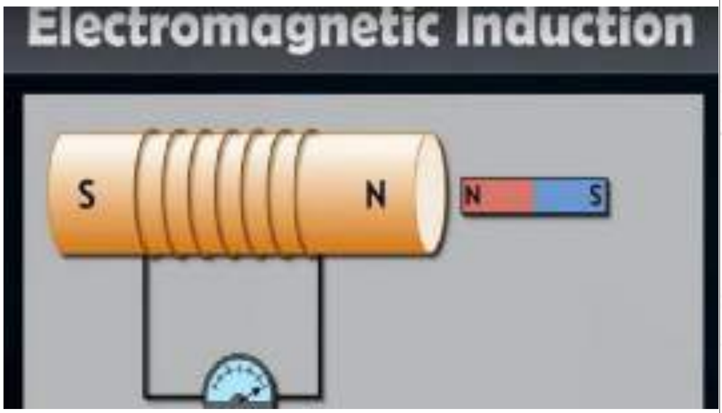
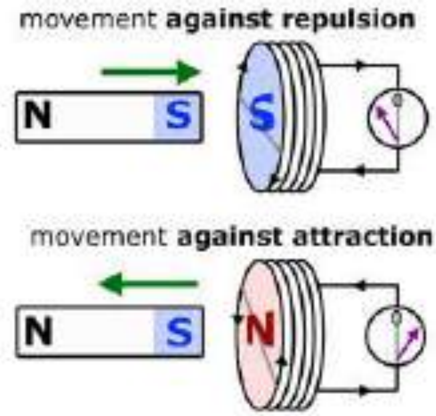
Unit#14

Electromagnetic Induction





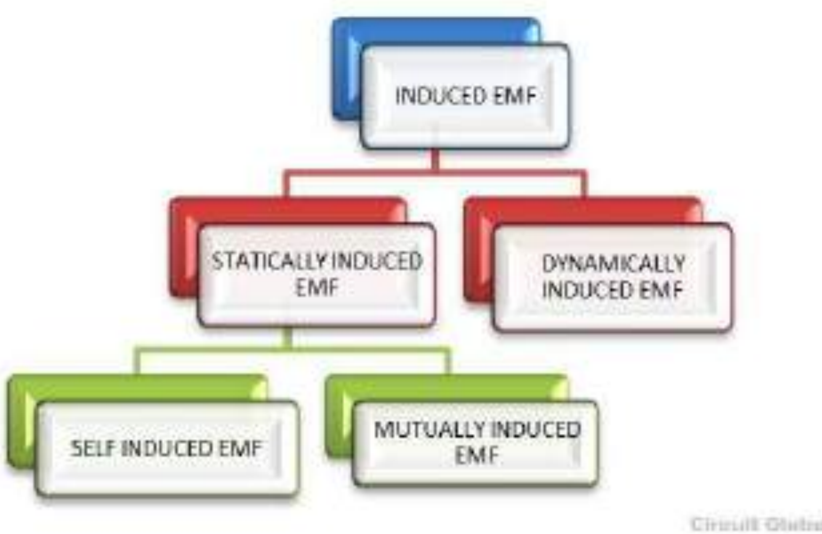
Topics	Understanding	Skill
• Induced Emf • Faraday's law • Lenz's law • Eddy currents • Mutual inductance • Self-inductance • Energy stored by an inductor • Motional emf,s • A.C. Generator • A.C. motor and Back emf • Transformer	• describe the production of electricity by magnetism. • explain that induced emf's can be generated in two ways. (i) by relative movement (the generator effect). (ii) by changing a magnetic field (the transformer effect). • infer the factors affecting the magnitude of the induced emf. • state Faraday's law of electromagnetic induction. • account for Lenz's law to predict the direction of an induced current and relate to the principle of conservation of energy. • apply Faraday's law of electromagnetic induction and Lenz's law to solve problems. • explain the production of eddy currents and identify their magnetic and heating effects. • explain the need for laminated iron cores in electric motors, generators and transformers. • explain what is meant by motional emf. Given a rod or wire moving through a magnetic field in a simple way, compute the potential difference across its ends. • define mutual inductance (M) and self-inductance (L), and their unit henry. Conceptual linkage: ²This chapter is built on Electromagnetism Physics X 41	• perform an investigation to predict and verify the effect on an electric current generated when: • the distance between the coil and magnet is varied. • the strength of the magnet is varied. • demonstrate electromagnetic induction by a permanent magnet, coil and demonstration galvanometer. • conduct a demonstration of step-up and step-down transformer by dissectible transformer. • demonstrate an improvised electric motor. • demonstrate the action of an induction coil by producing spark. • gather information and choose equipment to investigate "multiplier " effect (a small magnetic field created by current carrying loops of wire (wrapped around a piece of iron core lead to a large observed magnetic field)

	• describe the main components of an A.C generator and explain how it works. • describe the main features of an A.C electric motor and the role of each feature. • explain the production of back emf in electric motors. • describe the construction of a transformer and explain how it works. • identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltages. • describe how set-up and step-down transformers can be used to ensure efficient transfer of electricity along cables.	

Unit Overview

01.Induced Emf

An **Electromotive Force** or **EMF** is said to be induced when the flux linking with a conductor or coil changes.



This change in flux can be obtained in two different ways; that is by **statically** or by **dynamically** induced emf. They are explained below

Contents:

- Statically Induced Electromotive Force
- Dynamically Induced Electromotive Force

1. STATICALLY INDUCED EMF

This type of **EMF** is generated by keeping the coil and the magnetic field system, stationary at the same time; that means the change in flux linking with the coil takes place without either moving the conductor (coil) or the field system.

This change of flux produced by the field system linking with the coil is obtained by changing the electric current in the field system.

It is further divided in two ways

(i)Self-induced electromotive force (emf which is induced in the coil due to the change of flux produced by it

linking with its own turns.)

(ii)Mutually induced electromotive force(emf which is induced in the coil due to the change of flux produced

by another coil, linking with it.)

2. DYNAMICALLY INDUCED EMF

In dynamically **induced electromotive force** the magnetic field system is kept stationary, and the conductor is moving, or the magnetic field system is moving, and the conductor is stationary. Thus by following either of the two process the conductor cuts across the magnetic field and the emf is induced in the coil.

This phenomenon takes place in electric generators and back emf of motors and also in transformers.

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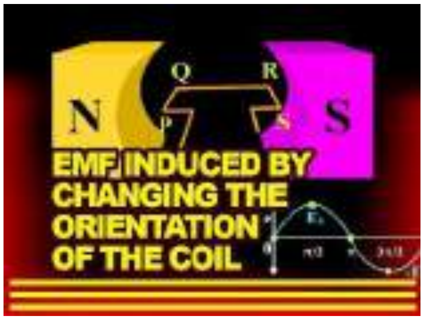
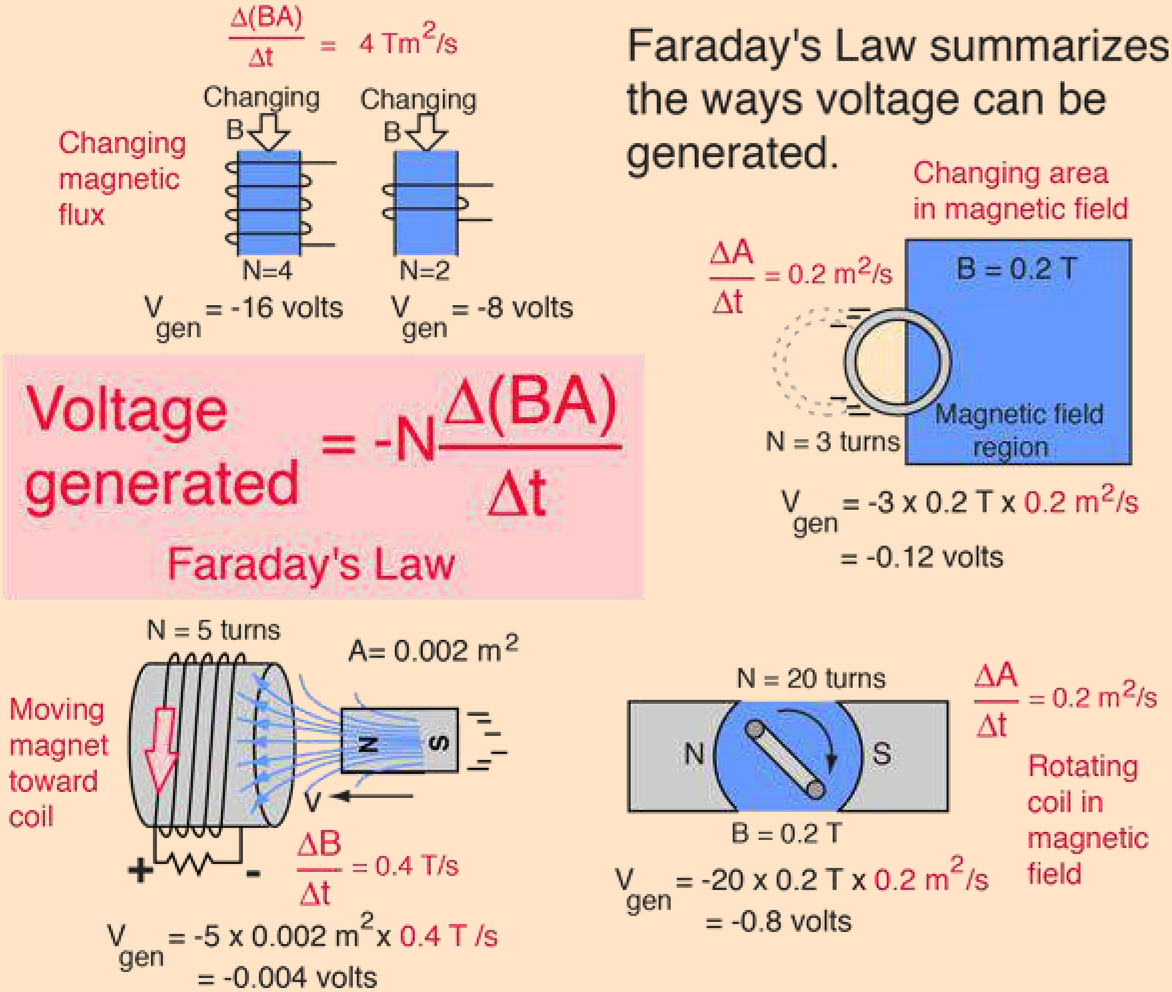


02.Fraday’s Law

Faraday's Law

Any change in the magnetic environment of a coil of wire will cause a voltage (emf) to be "induced" in the coil. No matter how the change is produced, the voltage will be generated. The change could be produced by changing the magnetic field strength, moving a magnet toward or away from the coil, moving the coil into or out of the magnetic field, rotating the coil relative to the magnet, etc.



Faraday's law is a fundamental relationship which comes from Maxwell's equations. It serves as a succinct summary of the ways a voltage (or emf) may be generated by a changing magnetic environment. The induced emf in a coil is equal to the negative of the rate of change of magnetic flux times the number of turns in the coil. It involves the interaction of charge with magnetic field.

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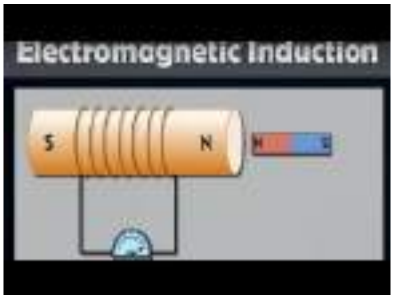
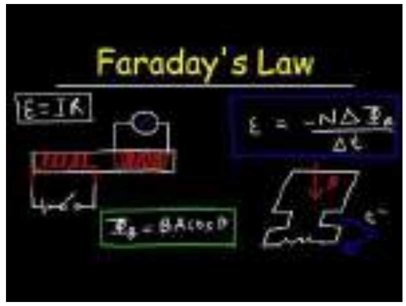
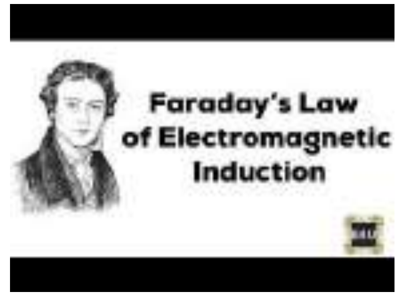
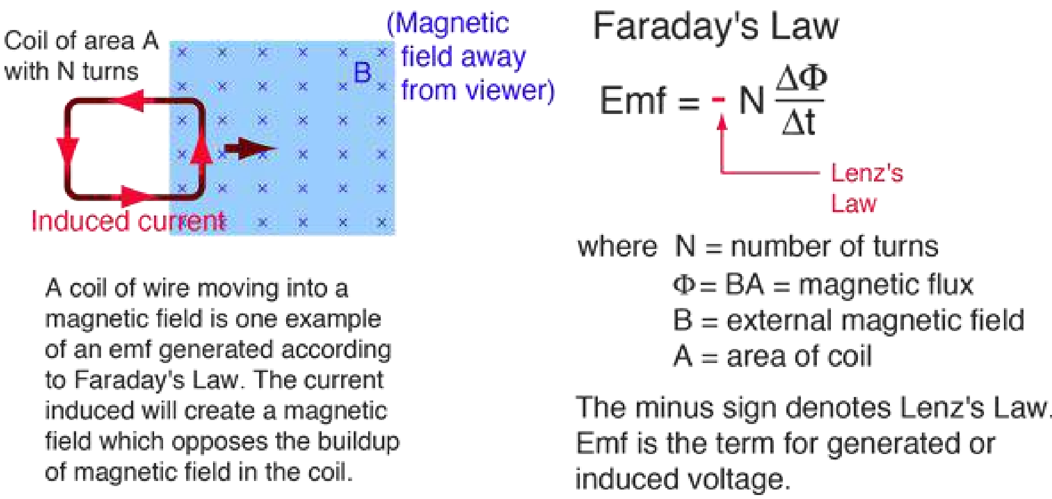




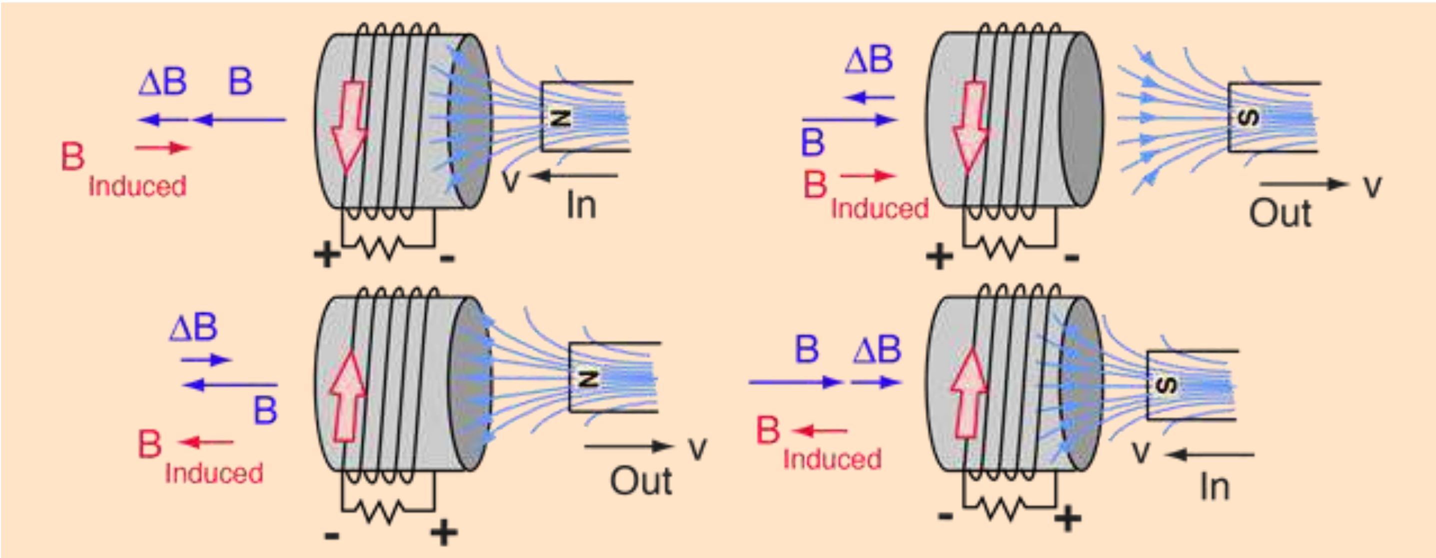




03.Lenz’s Law

Lenz's Law

When an emf is generated by a change in magnetic flux according to Faraday's Law, the polarity of the induced emf is such that it produces a current whose magnetic field opposes the change which produces it. The induced magnetic field inside any loop of wire always acts to keep the magnetic flux in the loop constant. In the examples below, if the B field is increasing, the induced field acts in opposition to it. If it is decreasing, the induced field acts in the direction of the applied field to try to keep it constant.



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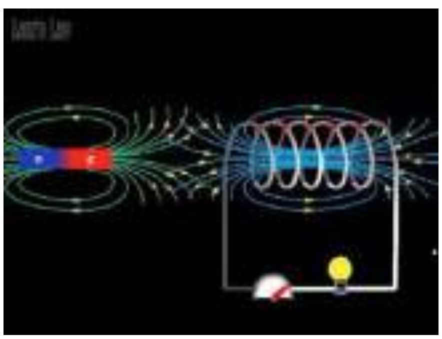
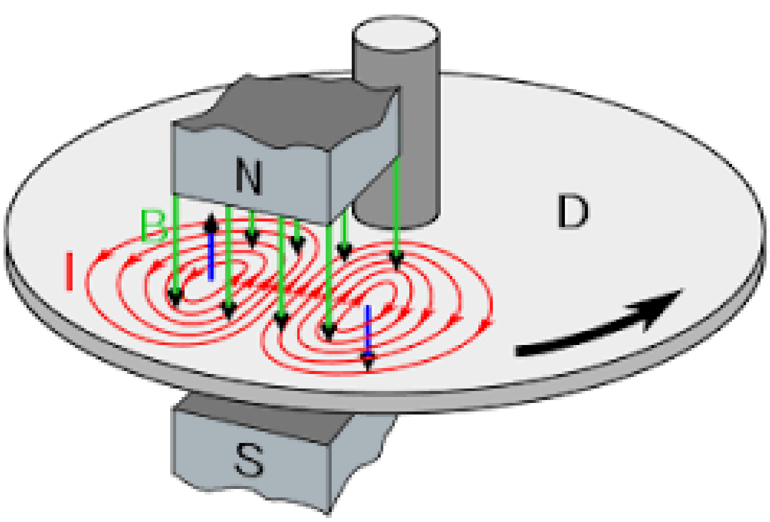
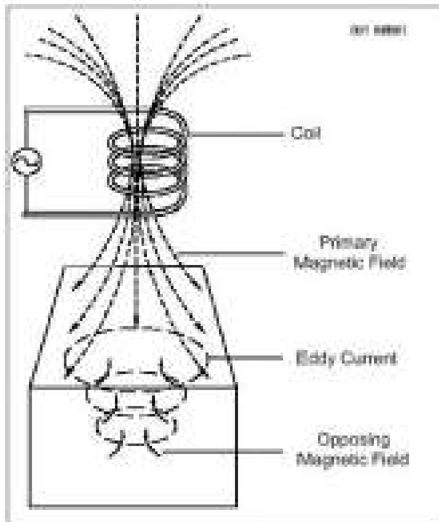


04.Eddy currents



An eddy current is a current set up in a conductor in response to a changing magnetic field. They flow in closed loops in a plane perpendicular to the magnetic field. By Lenz law, the current swirls in such a way as to create a magnetic field opposing the change; for this to occur in a conductor, electrons swirl in a plane perpendicular to the magnetic field.

Because of the tendency of eddy currents to oppose, eddy currents cause a loss of energy. Eddy currents transform more useful forms of energy, such as kinetic energy, into heat, which isn't generally useful.



Video Link:

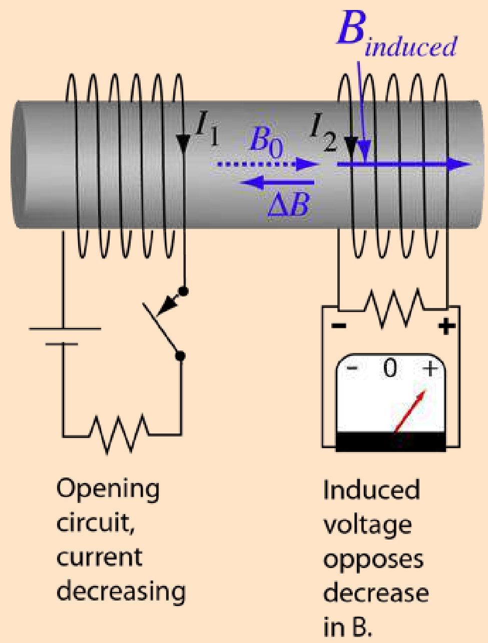
05.Mutual inductance

Mutual Inductance

When an emf is produced in a coil because of the change in current in a coupled coil , the effect is called mutual inductance. The emf is described by Faraday's law and it's direction is always opposed the change in the magnetic field produced in it by the coupled coil (Lenz's law). The induced emf in coil 1 is due to self inductance L.

The induced emf in coil #2 caused by the change in current I_1 can be expressed as

$$Emf_2 = -N_2 A \frac{\Delta B}{\Delta t} = -M \frac{\Delta I_1}{\Delta t}$$



The mutual inductance **M** can be defined as the proportionalitiy between the emf generated in coil 2 to the change in current in coil 1 which produced it.

The most common application of mutual inductance is the transformer.

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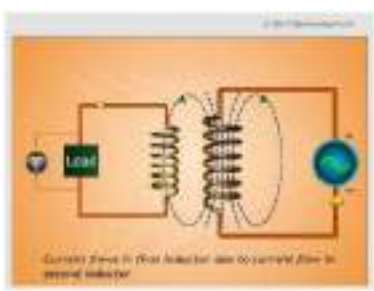
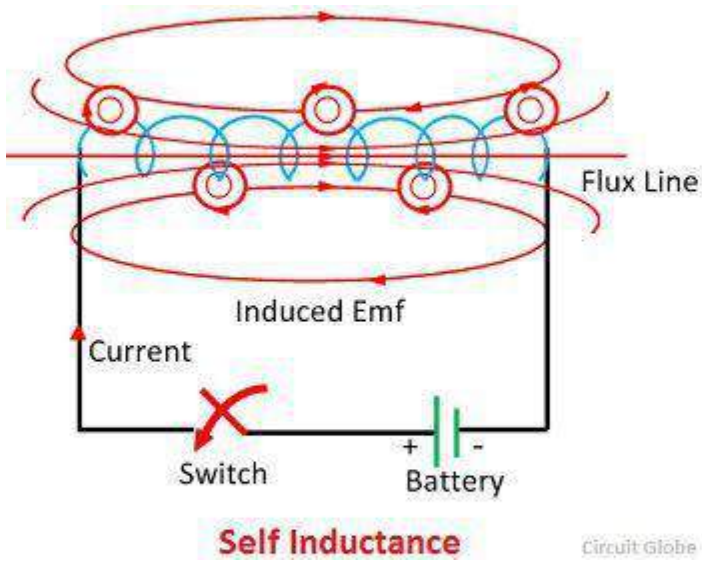


06.Self-inductance

Definition: Self-inductance or in other words inductance of the coil is defined as the property of the coil due to which it opposes the change of current flowing through it. Inductance is attained by a coil due to the self-induced emf produced in the coil itself by changing the current flowing through it.

If the current in the coil is increasing, the self-induced emf produced in the coil will oppose the rise of current, that means the direction of the induced emf is opposite to the applied voltage.



If the current in the coil is decreasing, the emf induced in the coil is in such a direction as to oppose the fall of current; this means that the direction of the self-induced emf is same as that of the applied voltage. Self-inductance does not prevent the change of current, but it delays the change of current flowing through it.

This property of the coil only opposes the changing current (alternating current) and does not affect the steady current that is (direct current) when flows through it. The unit of inductance is **Henry** (H).

Expression For Self Inductance

You can determine the self-inductance of a coil by the following expression

$$e = L\frac{dI}{dt}$$

Or

$$L = \frac{e}{dI/dt}$$

The above expression is used when the magnitude of self-induced emf (e) in the coil and the rate of change of current (dI/dt) is known.

Putting the following values in the above equations as e = 1 V, and dI/dt = 1 A/s then the value of Inductance will be L = 1 H.

Hence, from the above derivation, a statement can be given that a coil is said to have an inductance of 1 Henry if an emf of 1 volt is induced in it when the current flowing through it changes at the rate of 1 Ampere/second.

The expression for Self Inductance can also be given as:

$$e = L\frac{dI}{dt} = \frac{d}{dt}(LI) \text{ also } e = N\frac{d\varphi}{dt} = \frac{d}{dt}(N\varphi)$$

$$LI = N\varphi \text{ or } L = \frac{N\varphi}{I} \text{ Henry}$$

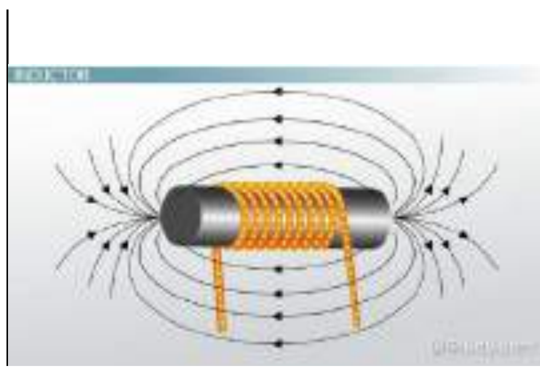
where,
N – number of turns in the coil
Φ – magnetic flux
I – current flowing through the coil

From the above discussion, the following points can be drawn about Self Inductance

- The value of the inductance will be high if the magnetic flux is stronger for the given value of current.
- The value of the Inductance also depends upon the material of the core and the number of turns in the coil or solenoid.
- The higher will be the value of the inductance in Henry, the rate of change of current will be lower.
- 1 Henry is also equal to 1 Weber/ampere

The solenoid has large self-inductance.

07. Energy stored by an inductor



Energy in an Inductor

When a electric current is flowing in an inductor, there is energy stored in the magnetic field. Considering a pure inductor L, the instantaneous power which must be supplied to initiate the current in the inductor is

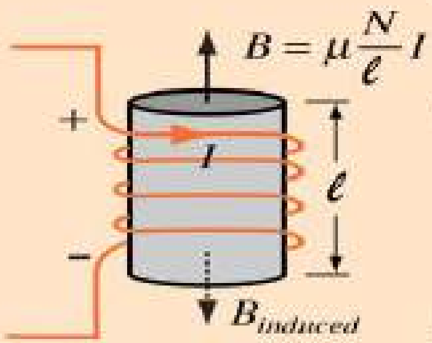
$$P = iv = Li\frac{di}{dt}$$

so the energy input to build to a final current i is given by the integral

$$\text{Energy stored} = \int_0^t P\,dt = \int_0^I Li'\,di' = \frac{1}{2}LI^2$$

Using the example of a solenoid, an expression for the energy density can be obtained.

Energy in Magnetic Field



Solenoid Field

Solenoid Inductance

From analysis of the energy stored in an inductor,

$$\text{Energy stored} = \frac{1}{2}LI^2$$

the energy density (energy/volume) is

$$\frac{\frac{1}{2}LI^2}{A\ell} = \frac{\frac{1}{2}\frac{\mu N^2 A}{\ell}\frac{B^2\ell^2}{\mu^2 N^2}}{A\ell}$$

so the energy density stored in the magnetic field is

$$\eta_B = \frac{energy}{volume} = \frac{1}{2}\frac{B^2}{\mu}$$

Video Link:

08.Motional emf

As we have seen, any change in magnetic flux induces an emf opposing that change—a process known as induction. Motion is one of the major causes of induction. For example, a magnet moved toward a coil induces an emf, and a coil moved toward a magnet produces a similar emf. In this section, we concentrate on motion in a magnetic field that is stationary relative to the Earth, producing what is loosely called *motional emf*. One situation where motional emf occurs is known as the Hall effect and has already been examined. Charges moving in a magnetic field experience the magnetic force $F = qvB \sin \theta$, which moves opposite charges in opposite directions and produces an em f = $B\ell v$. We saw that the Hall effect has applications, including measurements of B and v. We will now see that the Hall effect is one aspect of the broader phenomenon of induction, and we will find that motional emf can be used as a power source. Consider the situation shown in Figure 1. A rod is moved at a speed v along a pair of conducting rails separated by a distance ℓ in a uniform magnetic field B. The rails are stationary relative to B and are connected to a stationary resistor R. The resistor could be anything from a light bulb to a voltmeter. Consider the area enclosed by the moving rod, rails, and resistor. B is perpendicular to this area, and the area is increasing as the rod moves. Thus the magnetic flux enclosed by the rails, rod, and resistor is increasing. When flux changes, an emf is induced according to Faraday's law of induction.

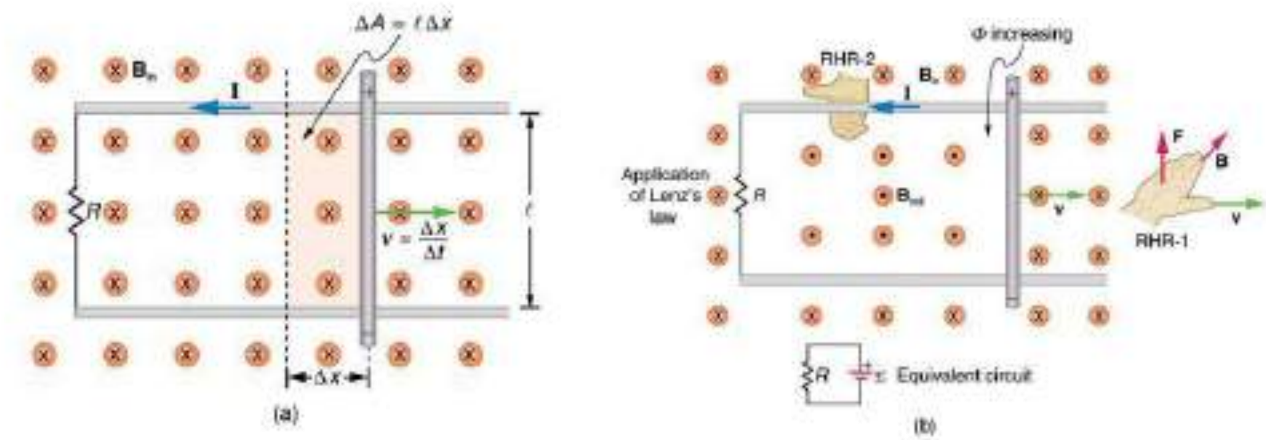


Figure 1. (a) A motional emf = $B\ell v$ is induced between the rails when this rod moves to the right in the uniform magnetic field. The magnetic field B is into the page, perpendicular to the moving rod and rails and, hence, to the area enclosed by them. (b) Lenz's law gives the directions of the induced field and current, and the polarity of the induced emf. Since the flux is increasing, the induced field is in the opposite direction, or out of the page. RHR-2 gives the current direction shown, and the polarity of the rod will drive such a current. RHR-1 also indicates the same polarity for the rod. (Note that the script E symbol used in the equivalent circuit at the bottom of part (b) represents emf.)

To find the magnitude of emf induced along the moving rod, we use Faraday's law of induction without the sign:

$$\mathrm{emf} = \mathrm{N}\frac{\Delta\Phi}{\Delta t}$$

Here and below, "emf" implies the magnitude of the emf. In this equation, $N = 1$ and the flux $\Phi = BA \cos \theta$. We have $\theta = 0^{\circ}$ and $\cos \theta = 1$, since B is perpendicular to A . Now $\Delta\Phi = \Delta(BA) = B\Delta A$, since B is uniform. Note that the area swept out by the rod is $\Delta A = \ell\Delta x$. Entering these quantities into the expression for emf yields

$$\text{emf} = \frac{B\Delta A}{\Delta t} = B\frac{\ell\Delta x}{\Delta t}$$

Finally, note that $\Delta x/\Delta t = v$, the velocity of the rod. Entering this into the last expression shows that

$$\text{emf} = B\ell v \quad (B, \ell, \text{ and } v \text{ perpendicular})$$

the motional emf. This is the same expression given for the Hall effect previously.

MAKING CONNECTIONS: UNIFICATION OF FORCES

There are many connections between the electric force and the magnetic force. The fact that a moving electric field produces a magnetic field and, conversely, a moving magnetic field produces an electric field is part of why electric and magnetic forces are now considered to be different manifestations of the same force. This classic unification of electric and magnetic forces into what is called the electromagnetic force is the inspiration for contemporary efforts to unify other basic forces.

To find the direction of the induced field, the direction of the current, and the polarity of the induced emf, we apply Lenz's law as explained in **Faraday's Law of Induction: Lenz's Law**. (See Figure 1(b).) Flux is increasing, since the area enclosed is increasing. Thus the induced field must oppose the existing one and be out of the page. And so the RHR-2 requires that *I* be counterclockwise, which in turn means the top of the rod is positive as shown.

Motional emf also occurs if the magnetic field moves and the rod (or other object) is stationary relative to the Earth (or some observer). We have seen an example of this in the situation where a moving magnet induces an emf in a stationary coil. It is the relative motion that is important. What is emerging in these observations is a connection between magnetic and electric fields. A moving magnetic field produces an electric field through its induced emf. We already have seen that a moving electric field produces a magnetic field—moving charge implies moving electric field and moving charge produces a magnetic field.

Motional emfs in the Earth's weak magnetic field are not ordinarily very large, or we would notice voltage along metal rods, such as a screwdriver, during ordinary motions. For example, a simple calculation of the motional emf of a 1 m rod moving at 3.0 m/s perpendicular to the Earth's field gives emf = $B\ell v = (5.0 \times 10^{-5}\ \text{T})(1.0\ \text{m})(3.0\ \text{m/s}) = 150\ \mu\text{V}$. This small value is consistent with experience. There is a spectacular exception, however. In 1992 and 1996, attempts were made with the space shuttle to create large motional emfs. The Tethered Satellite was to be let out on a 20 km length of wire as shown in Figure 2, to create a 5 kV emf by moving at orbital speed through the Earth's field. This emf could be used to convert some of the shuttle's kinetic and potential energy into electrical energy if a complete circuit could be made. To complete the circuit, the stationary ionosphere was to supply a return path for the current to flow. (The ionosphere is the rarefied and partially ionized atmosphere at orbital altitudes. It conducts because of the ionization. The ionosphere serves the same function as the stationary rails and connecting resistor in Figure 1, without which there would not be a complete circuit.) Drag on the current in the cable due to the magnetic force $F = I\ell B \sin \theta$ does the work that reduces the shuttle's kinetic and potential energy and allows it to be converted to electrical energessy. The tests were both unsuccessful. In the first, the cable hung up and could only be extended a couple of hundred meters; in the second, the cable broke when almost fully extended. The following example indicates feasibility in principle.

Assessment :

EXAMPLE 1. CALCULATING THE LARGE MOTIONAL EMF OF AN OBJECT IN ORBIT

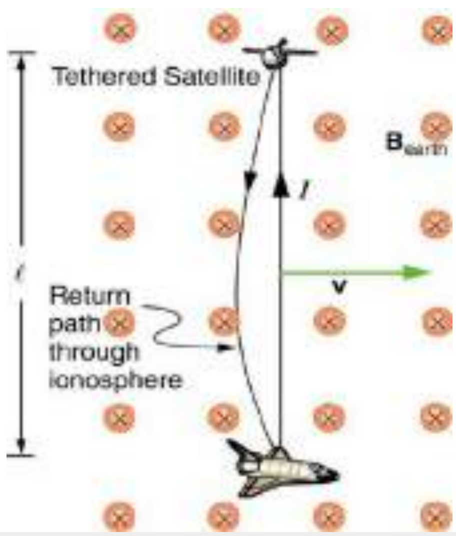


Figure 2. Motional emf as electrical power conversion for the space shuttle is the motivation for the Tethered Satellite experiment. A 5 kV emf was predicted to be induced in the 20 km long tether while moving at orbital speed in the Earth's magnetic field. The circuit is completed by a return path through the stationary ionosphere.

Calculate the motional emf induced along a 20.0 km long conductor moving at an orbital speed of 7.80 km/s perpendicular to the Earth's 5.00×10^{-5} T magnetic field.

Strategy
This is a straightforward application of the expression for motional emf — emf = $B\ell v$.

Solution
Entering the given values into emf = $B\ell v$ gives

emf=Bℓv=(5.00×10−5 T)(2.0×104 m)(7.80×103 m/s)=7.80×103 Vemf=Bℓv=(5.00×10−5 T)(2.0×104 m)(7.80×103 m/s)=7.80×103 V.

Discussion
The value obtained is greater than the 5 kV measured voltage for the shuttle experiment, since the actual orbital motion of the tether is not perpendicular to the Earth's field. The 7.80 kV value is the maximum emf obtained when $\theta = 90^\circ$ and $\sin\theta = 1$.

CONCEPTUAL QUESTIONS

1. Why must part of the circuit be moving relative to other parts, to have usable motional emf? Consider, for example, that the rails in Figure 1 are stationary relative to the magnetic field, while the rod moves.
2. A powerful induction cannon can be made by placing a metal cylinder inside a solenoid coil. The cylinder is forcefully expelled when solenoid current is turned on rapidly. Use Faraday's and Lenz's laws to explain how this works. Why might the cylinder get live/hot when the cannon is fired?
3. An induction stove heats a pot with a coil carrying an alternating current located beneath the pot (and without a hot surface). Can the stove surface be a conductor? Why won't a coil carrying a direct current work?
4. Explain how you could thaw out a frozen water pipe by wrapping a coil carrying an alternating current around it. Does it matter whether or not the pipe is a conductor? Explain.

PROBLEMS & EXERCISES

1. Use Faraday's law, Lenz's law, and RHR-1 to show that the magnetic force on the current in the moving rod in Figure 1 is in the opposite direction of its velocity.

2. If a current flows in the Satellite Tether shown in Figure 2, use Faraday's law, Lenz's law, and RHR-1 to show that there is a magnetic force on the tether in the direction opposite to its velocity.

3. (a) A jet airplane with a 75.0 m wingspan is flying at 280 m/s. What emf is induced between wing tips if the vertical component of the Earth's field is 3.00×10^{-5} T? (b) Is an emf of this magnitude likely to have any consequences? Explain.

4. (a) A nonferrous screwdriver is being used in a 2.00 T magnetic field. What maximum emf can be induced along its 12.0 cm length when it moves at 6.00 m/s? (b) Is it likely that this emf will have any consequences or even be noticed?

5. At what speed must the sliding rod in Figure 1 move to produce an emf of 1.00 V in a 1.50 T field, given the rod's length is 30.0 cm?

6. The 12.0 cm long rod in Figure 1 moves at 4.00 m/s. What is the strength of the magnetic field if a 95.0 V emf is induced?

7. Prove that when B, ℓ, and v are not mutually perpendicular, motional emf is given by emf = $B\ell v \sin\theta$. If v is perpendicular to B, then θ is the angle between ℓ and B. If ℓ is perpendicular to B, then θ is the angle between v and B.

8. In the August 1992 space shuttle flight, only 250 m of the conducting tether considered in Example 1 (above) could be let out. A 40.0 V motional emf was generated in the Earth's 5.00×10^{-5} T field, while moving at 7.80×10^{3} m/s. What was the angle between the shuttle's velocity and the Earth's field, assuming the conductor was perpendicular to the field?

9. Integrated Concepts Derive an expression for the current in a system like that in Figure 1, under the following conditions. The resistance between the rails is R, the rails and the moving rod are identical in cross section A and have the same resistivity ρ. The distance between the rails is l, and the rod moves at constant speed v perpendicular to the uniform field B. At time zero, the moving rod is next to the resistance R.

10. Integrated Concepts The Tethered Satellite in Figure 2 has a mass of 525 kg and is at the end of a 20.0 km long, 2.50 mm diameter cable with the tensile strength of steel. (a) How much does the cable stretch if a 100 N force is exerted to pull the satellite in? (Assume the satellite and shuttle are at the same altitude above the Earth.) (b) What is the effective force constant of the cable? (c) How much energy is stored in it when stretched by the 100 N force?

11. Integrated Concepts The Tethered Satellite discussed in this module is producing 5.00 kV, and a current of 10.0 A flows. (a) What magnetic drag force does this produce if the system is moving at 7.80 km/s? (b) How much kinetic energy is removed from the system in 1.00 h, neglecting any change in altitude or velocity during that time? (c) What is the change in velocity if the mass of the system is 100,000 kg? (d) Discuss the long term consequences (say, a week-long mission) on the space shuttle’s orbit, noting what effect a decrease in velocity has and assessing the magnitude of the effect.

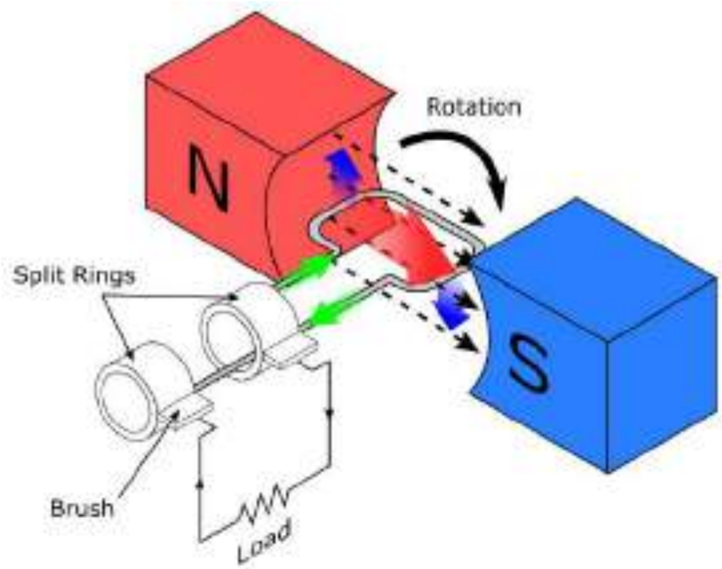
SELECTED SOLUTIONS TO PROBLEMS & EXERCISES

1. (a) 0.630 V (b) No, this is a very small e m f.

5. 2.22 m/s

11.(a) 10.0 N (b) 2.81×10^{8} J (c) 0.36 m/s (d) For a week-long mission (168 hours), the change in velocity will be 60 m/s, or approximately 1%. In general, a decrease in velocity would cause the orbit to start spiraling inward because the velocity would no longer be sufficient to keep the circular orbit. The long-term consequences are that the shuttle would require a little more fuel to maintain the desired speed, otherwise the orbit would spiral slightly inward.

09.A.C. Generator



DEFINITION

A Generator is a device which converts mechanical energy into electrical energy.

WORKING PRINCIPLE

A.C Generator works on the principle of electromagnetic induction (motional e m f). In generator an induced emf is produced by rotating a coil in a magnetic field. The flux linking the coil changes continuously hence a continuous fluctuating emf is obtained.

CONSTRUCTION

A.C Generator consists of the following parts.

Powerful field magnet with concave poles.

Armature:

It is a rectangular coil of large number of turns of wire wound on laminated soft-iron core of high permeability and low hysteresis loss.

Slip rings:

The ends of the coil are joined to two separate copper rings fixed on the axle (S1 & S2).

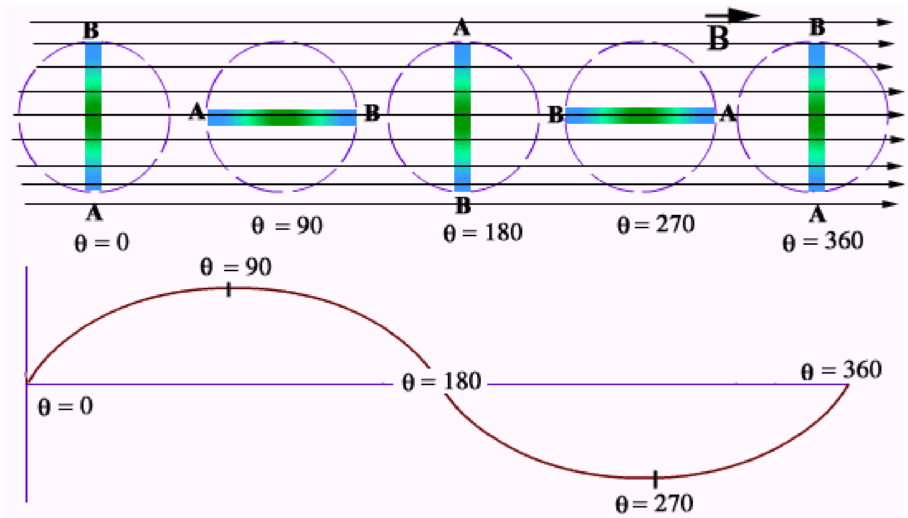
Carbon brushes:

Two carbon brushes remain pressed against each of the rings which form the terminals of the external circuit.

Diagram.

WORKING

In order to determine the magnitude and direction of induced e.m.f, let us consider the different positions of the coil which has ‘N’ turns of wire. In one revolution following positions can be considered.



When initially coil is vertical, the length arms AC and BD are moving parallel to the lines of force maximum number of lines link the coil, but rate of change of flux is zero, hence emf is zero.

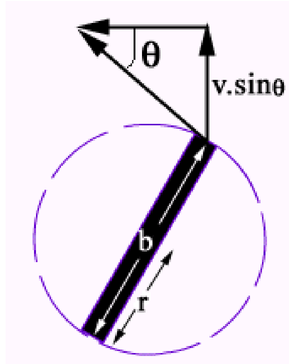
As the coil moves from this position, sides AC and BD begin to cut the lines of force and induced emf is setup till it is maximum when the coil is horizontal. It has rotated 90^o, 1st quarter is completed.

Further rotation decreases the value of emf, until at the end of 2^{nd} quarter, when coil is vertical, it has rotated 180^o, the emf is again zero.

As the coil rotates further from position 3 to position 4, an emf is again induced, but in reverse direction, because AC and BD are cutting the magnetic lines in opposite direction. The reverse emf reaches to –ve peak value at the end of 3^{rd} quarter. The coil is horizontal and angle of rotation is 270^o.

On further rotation, the emf again decreases and becomes zero when the coil returns back to its original position after rotating 360^o.

This shows that the coil of generator produces induced emf which reverse its direction 2*f times in one cycle. Where f = frequency of rotation of coil.



EXPRESSION FOR EMF IN A.C. GENERATOR

Consider a coil ABCDA of 'N' turns rotating in a uniform magnetic field B with a constant angular speed 'ω'. Let the length of the coil is 'l' and its breadth is 'b'.

To calculate emf in sides AC and BD we proceed as follows:

$$\text{Motional emf} = B\,v\,l\,\sin\theta$$

$$\text{Emf in side AC} = B\,v\,l\,\sin\theta = \xi_1$$

$$\text{Emf in side BD} = B\,v\,l\,\sin\theta = \xi_2$$

$$\text{Emf induced in the coil} = \xi_1 + \xi_2$$

$$= B\,v\,l\,\sin\theta + B\,v\,l\,\sin\theta$$

$$\xi = 2\,B\,v\,l\,\sin\theta$$

If coil has 'N' turns, emf will increase N times

$$\xi = 2\,B\,v\,l\,N\,\sin\theta \text{ -----(1)}$$

If angular velocity of coil is 'ω' and it takes time 't' to cover angle θ then

$$\theta = \omega t \text{ also}$$

$$V = r\omega \text{ and } r = b/2$$

$$V = b/2\omega$$

Putting the value of q and V in eq. (1)

$$\xi = 2B\,(b/2\omega)\,l\,N\,\sin(\omega t)$$

$$\xi = \omega B(b*l)\sin(\omega t)$$

$$\xi = NB\omega(b.l)\sin\omega t$$

$$\xi = N\,B\,\omega\,A\,\sin\omega t \text{ –(2)}$$

this is the expression for the induced emf in the coil of an A.C generator at any instant.

If f = no. of rotation per sec. Then we have $\omega=2\pi f$

$$\xi = V = N B \omega A \sin(2\pi ft) \quad (3)$$

for maximum emf $\theta = 90^o$ or 270^o

or $2\pi ft = \pi/2$ or $3\pi/2$

and $\sin 90^o = \sin\pi/2 = +1$

$\sin 270^o = \sin 3\pi/2 = -1$

$$\xi_o = V_o = NB\omega A(1)$$

$$\xi_o = V_o = \pm NB\omega A$$

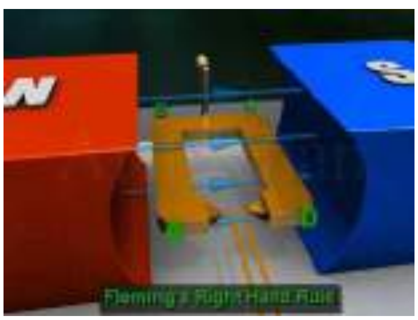
+- = shows direction of induced current

Relation b/w ξ and ξ_o

$$\xi = N B \omega A \sin(2\pi ft)$$

$$\xi = \xi_o \sin(2\pi ft)$$

Video Link:



10. A.C. motor and Back emf

When something like a refrigerator or an air conditioner (anything with a motor) first turns on in your house, the lights often dim momentarily. To understand this, realize that a spinning motor also acts like a generator. A motor has coils turning inside magnetic fields, and a coil turning inside a magnetic field induces an emf. This emf, known as the back emf, acts against the applied voltage that's causing the motor to spin in the first place, and reduces the current flowing through the coils of the motor.

At the motor's operating speed, enough current flows to overcome any losses due to friction and other sources and to provide the necessary energy required for the motor to do work. This is generally much less current than is required to get the motor spinning in the first place.

If the applied voltage is DV, then the initial current flowing through a motor with coils of resistance R is:

$$I = \frac{\Delta V}{R}$$

Assessment:

For example, $I = \dfrac{120\ V}{6\ \Omega} = 20\ A$

A device drawing that much current reduces the voltage and current provided to other electrical equipment in your house, causing lights to dim.

When the motor is spinning and generating a back emf ε, the current is reduced to:

$$I = \frac{(\Delta V - \varepsilon)}{R}$$

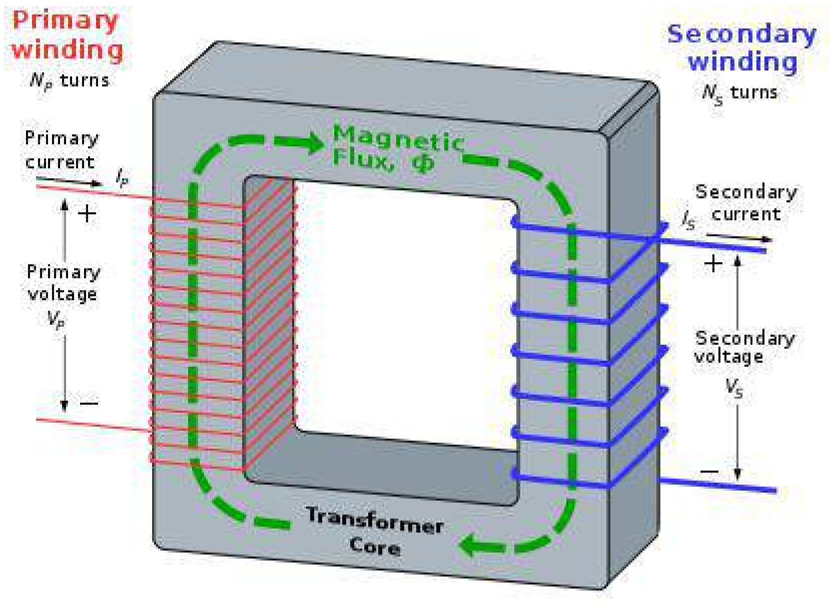
If the back emf is ε = 108 V, we get:

$$I = \frac{(120 - 108)}{6} = \frac{12}{6} = 2\ A$$

It takes very little time for the motor to reach operating speed and for the current to drop from its high initial value. This is why the lights dim only briefly.

Video Link:

11.Transformer



A transformer is a device which is use to convert high alternatic voltage to a low alternatic voltage and vice versa.

WORKING PRINCIPLE

Transformer works on the principle of mutual induction of two coils. When current in the primary coil is changed the flux linked to the secondary coil also changes. Consequently an EMF is induced in the secondary coil.

CONSTRUCTION

A transformer consists of a rectangular core of soft iron in the form of sheets insulated from one another. Two separate coils of insulated wires, a primary coil and a secondary coil are wound on the core. These coils are well insulated from one another and from the core. The coil on the input side is called Primary coil and the coil on the output side is called Secondary coil.

WORKING

Suppose an alternatic voltage source Vp is connected to primary coil. Current in primary will produce magnetic flux which is linked to secondary. When current in primary changes, flux in secondary also changes which results an EMF Vs in secondary. According to Faradays law EMF

induced in a coil depends upon the rate of change of magnetic flux in the coil. If resistance of the coil is small then the induced EMF will be equal to voltage applied.
According to Faradays law

$$V_p = N_p \, \Delta\Phi / \Delta t \text{ ------------ } (1)$$

Where Np = Number of turns in primary coil.

Similarly, for secondary coil.

$$V_s = N_s \, \Delta\Phi / \Delta t \text{ ------------ } (2)$$

Dividing equation (1) by equation (2)

$$\mathbf{V_p / V_s = N_p / N_s}$$

This expression shows that the magnitude of EMF depends upon the number of turns in the coil

TYPES OF TRANSFORMER

There are two types of transformer:
Step up transformer
Step down transformer

STEP UP TRANSFORMER

A transformer in which Ns>Np is called a step up transformer. A step up transformer is a transformer which converts low alternate voltage to high alternate voltage.

STEP DOWN TRANSFORMER

A transformer in which Np>Ns is called a step down transformer. A step down transformer is a transformer which converts high alternate voltage to low alternate voltage.

Learning Outcomes

• describe the production of electricity by magnetism.
• explain that induced e m f can be generated in two ways. (i) by relative movement (the generator effect). (ii) by changing a magnetic field (the transformer effect).
• infer the factors affecting the magnitude of the induced emf.
• state Faraday's law of electromagnetic induction.
• account for Lenz's law to predict the direction of an induced current and relate to the principle of conservation of energy.
• apply Faraday's law of electromagnetic induction and Lenz's law to solve problems.
• explain the production of eddy currents and identify their magnetic and heating effects.
• explain the need for laminated iron cores in electric motors, generators and transformers.
• explain what is meant by motional emf. Given a rod or wire moving through a magnetic field in a simple way, compute the potential difference across its ends.
• define mutual inductance (M) and self-inductance (L), and their unit henry. Conceptual linkage: This chapter is built on Electromagnetism Physics

• describe the main components of an A.C generator and explain how it works.
• describe the main features of an A.C electric motor and the role of each feature.
• explain the production of back emf in electric motors.
• describe the construction of a transformer and explain how it works.
• identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltages.
• describe how set-up and step-down transformers can be used to ensure efficient transfer of electricity along cables.

Reference Page:

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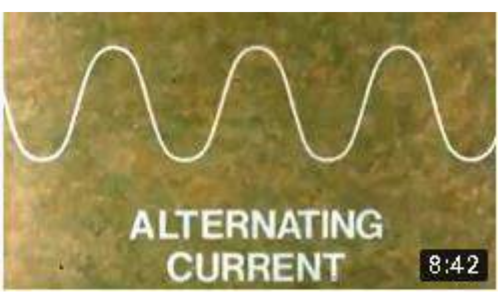
Unit # 15 ALTERNATING CURRENT

Chapter	Skills	Understanding
ALTERNATING CURRENT : Topics according to national curriculum. • Alternating current (AC) • Instantaneous, peak and rms values of AC • Phase, phase lag and phase lead in AC • AC through a resistor • AC through a capacitor • AC through an inductor • Impedance • RC series circuit • RL series circuit • Power in AC circuits • Resonant circuits • Electrocardiography • Principle of metal detectors • Maxwell's equations and electromagnetic waves	The students will: • determine the relation between current and capacitance when different capacitors are used in AC circuit using series and parallel combinations. • measure DC and AC voltages by a CRO. • determine the impedance of RL circuit at 50Hz and hence find inductance. • determine the impedance of RC circuit at 50Hz and hence find capacitance.	The students will: • describe the terms time period, frequency, instantaneous peak value and root mean square value of an alternating current and voltage. • represent a sinusoidally alternating current or voltage by an equation of the form x = xo sin wt. • describe the phase of A.0 and how phase lags and leads in A.0 Circuits. • identify inductors as important components of A.0 circuits termed as chokes (devices which present a high resistance to alternating current). • explain the flow of A.0 through resistors, capacitors and inductors. • apply the knowledge to calculate the reactance's of capacitors and inductors. • describe impedance as vector summation of resistances and reactance's. • construct phasor diagrams and carry out calculations on circuits including resistive and reactive components in series. • solve the problems using the formulae of A.0 Power. • explain resonance in an A.0 circuit and carry out calculations using the resonant frequency formulae.

		• describe that maximum power is transferred when the impedances of source and load match to each other. • describe the qualitative treatment of Maxwell's equations and production of electromagnetic waves. • become familiar with electromagnetic spectrum (ranging from radio waves to y-rays). • identify that light is a part of a continuous spectrum of electromagnetic waves all of which travel in vacuum with same speed. • describe that the information can be transmitted by radio waves. • identify that the microwaves of a certain frequency cause heating when absorbed by water and cause burns when absorbed by body tissues. • describe that ultra violet radiation can be produced by special lamps and that prolonged exposure to the Sun may cause skin cancer from ultra violet radiation.

VIDEOS		



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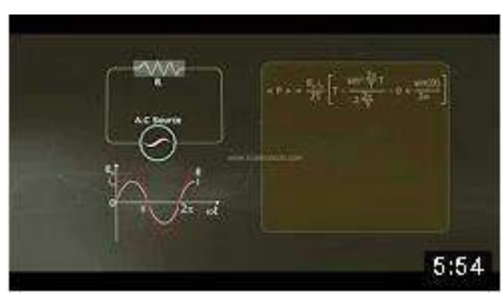

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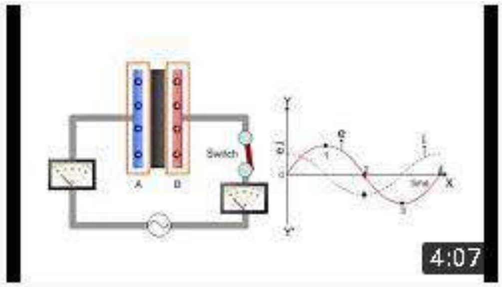

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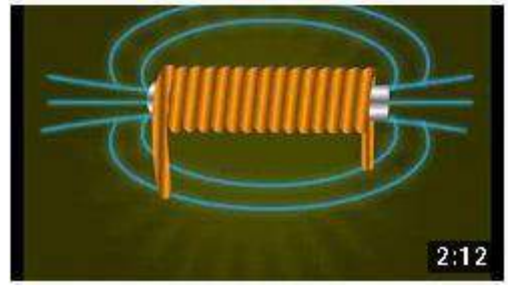

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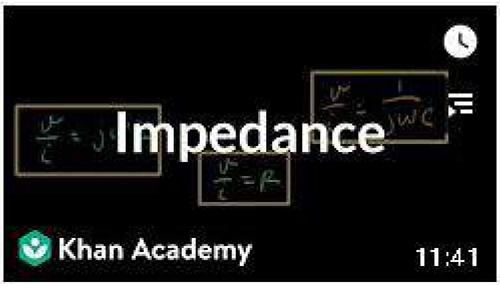

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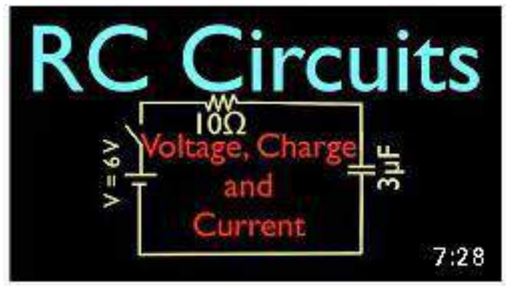

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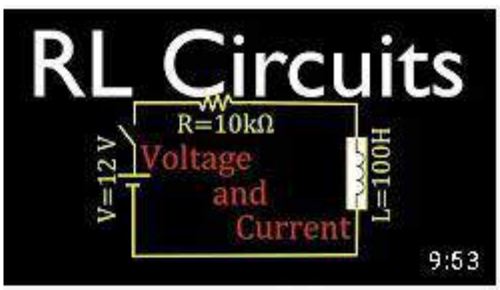

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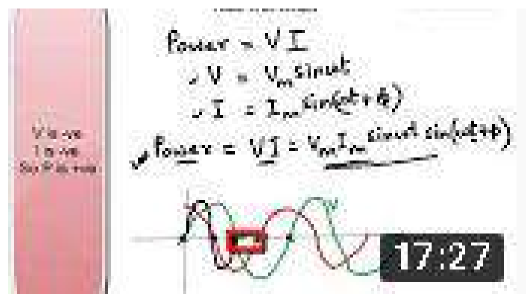

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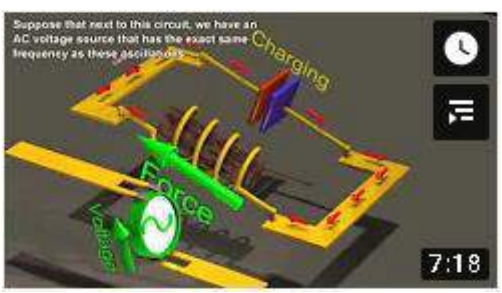

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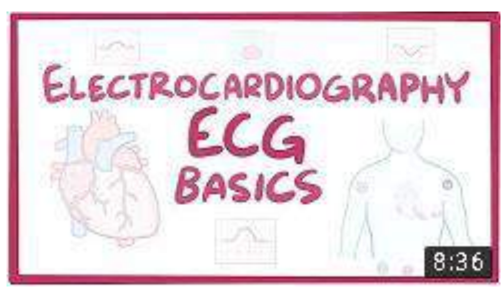

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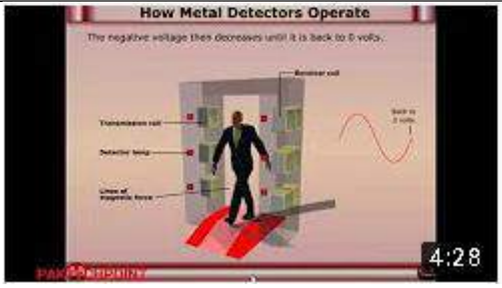

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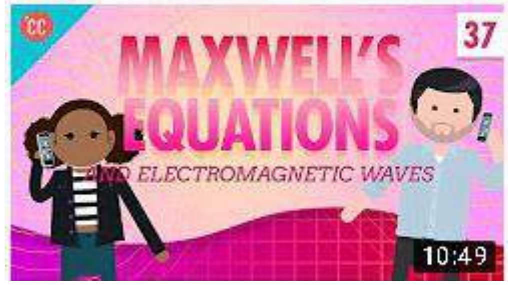

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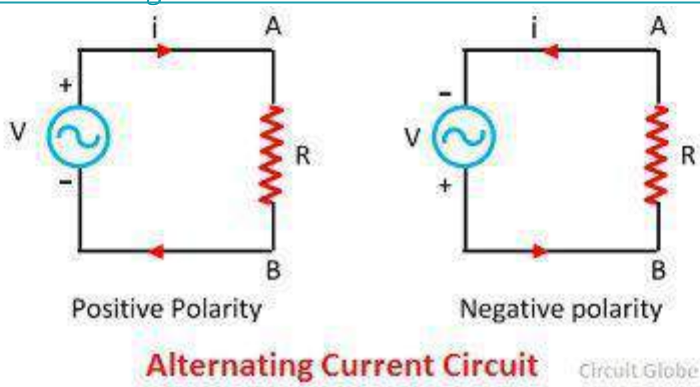
Chapter overview

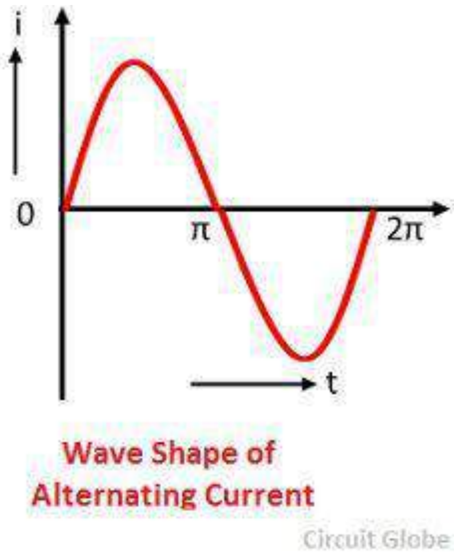
Alternating Current (AC)

Definition: The current that changes its magnitude and polarity at regular intervals of time is called an alternating current .The major advantage of using the alternating current instead of direct current is that the alternating current is easily transformed from higher voltage level to lower voltage level.

When the resistive load R is connected across the alternating source shown in the figure below, the current flows through it. The alternating current flows in one direction and then in the opposite direction when the polarity is reversed.

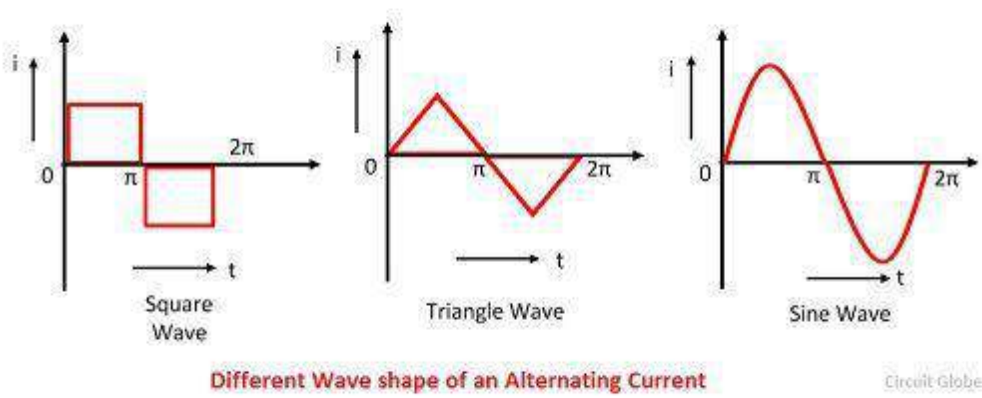


The wave shape of the source voltage and the current flow through the circuit (i.e., load resistor) is shown in the figure below.



The graph which represents the manner in which an alternating current changes with respect to time is known as wave shape or waveform. Usually, the alternating value is taken along the y-axis and the time taken to the x-axis.

The alternating current varies in a different manner as shown in the figure below. Accordingly, their wave shapes are named in different ways, such as irregular wave, a triangular wave, square wave, periodic wave, sawtooth wave, the sine wave.



An alternating current which varies according to the sine of angle θ is known as sinusoidal alternating current. The alternating current is generated in the power station because of the following reasons.

1. The alternating current produces low iron and copper losses in AC rotating machine and transformer because it improves the efficiency of AC machines.
2. The alternating current offer less interference to the nearby communication system (telephone lines etc.).
3. They produce the least disturbance in the electrical circuits

The alternating supply is always used for domestic and industrial applications.

Instantaneous, Average, And Rms Values

INSTANTANEOUS VALUE

The instantaneous value is “the value of an alternating quantity (it may ac voltage or ac current or ac power) at a particular instant of time in the cycle”. There are uncountable number of instantaneous values that exist in a cycle.

AVERAGE VALUE:

The average value is defined as “the average of all instantaneous values during one alternation”. That is, the ratio of the sum of all considered instantaneous values to the number of instantaneous values in one alternation period.
Whereas the average value for the entire cycle of alternating quantity is zero. Because the average value obtained for one alteration is a positive value and for another alternation is a negative value. The average values of these two alternations (for entire cycle) cancel each other and the resultant average value is zero.
Consider the single cycle alternating current wave in Figure 1

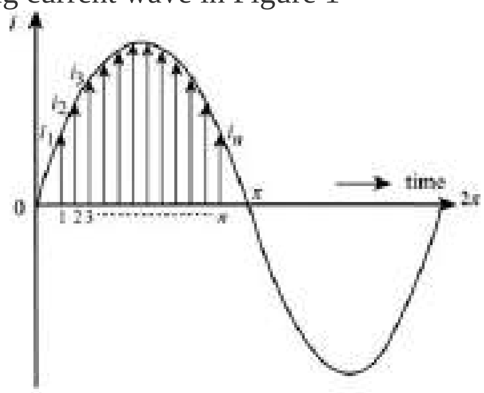


Figure 1

The instantaneous value at $t=1$ is i_1
At $t = n$ is, i_n
The average value for one alternation (0 to π) is

$$i_{avg} = \frac{i_1 + i_2 + i_3 + ... + i_n}{n}$$

RMS (ROOT MEAN SQUARE) VALUE:

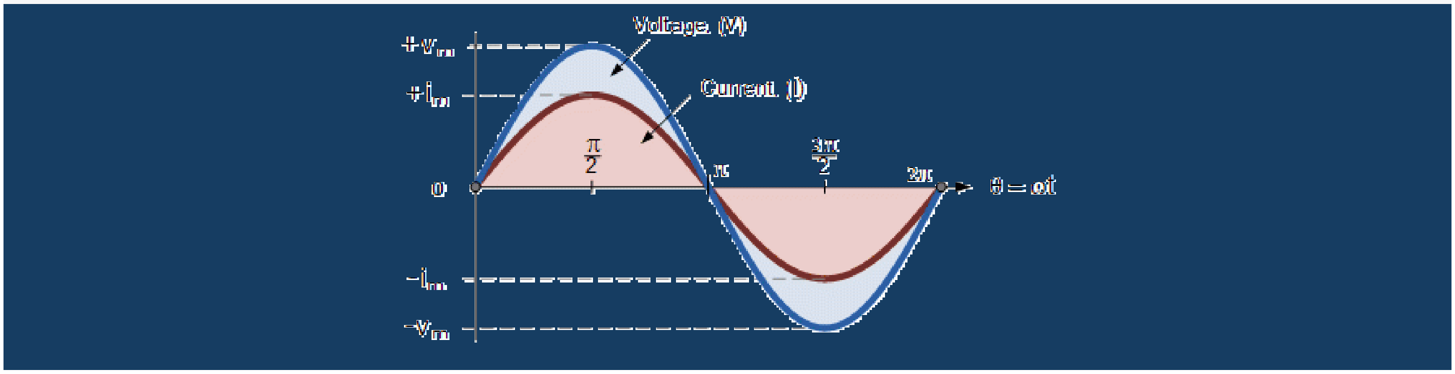
The Root Mean Square (RMS) value is “the square root of the sum of squares of means of an alternating quantity”.
It can also express as “the effect that produced by a certain input of AC quantity which is equivalent to an effect produced by the equal input of DC quantity”.
Consider one example, the heat produced by a resistor when one ampere direct current (DC) passed through it, is not an equal amount of heat produced when one ampere of alternating current (AC) passed through the same resistor. Since the AC current is not constant value rather than it is varying with the time. The heat produced by AC quantity (equal amount of DC quantity) is nothing but RMS value of an alternating parameter or quantity.

$$i_{rms} = \sqrt{i_1^2 + i_2^2 + ...i_n^2}$$

Here, $i_1, i_2, \ldots i_n$ are mean values

$$i_{rms} = \frac{i_{max}}{\sqrt{2}}$$

Home / AC Circuits / Phase Difference and Phase Shift



Phase Difference and Phase Shift

Phase Difference is used to describe the difference in degrees or radians when two or more alternating quantities reach their maximum or zero values

The **phase difference** or phase shift as it is also called of a Sinusoidal Waveform is the angle Φ (Greek letter Phi), in degrees or radians that the waveform has shifted from a certain reference point along the horizontal zero axis. In other words phase shift is the lateral difference between two or more waveforms along a common axis and sinusoidal waveforms of the same frequency can have a phase difference.

The phase difference, Φ of an alternating waveform can vary from between 0 to its maximum time period, T of the waveform during one complete cycle and this can be anywhere along the horizontal axis between, Φ = 0 to 2π (radians) or Φ = 0 to 360^o depending upon the angular units used.

Phase difference can also be expressed as a *time shift* of τ in seconds representing a fraction of the time period, T for example, +10mS or – 50uS but generally it is more common to express phase difference as an angular measurement.

Then the equation for the instantaneous value of a sinusoidal voltage or current waveform we developed in the previous Sinusoidal Waveform will need to be modified to take account of the phase angle of the waveform and this new general expression becomes.

Phase Difference Equation

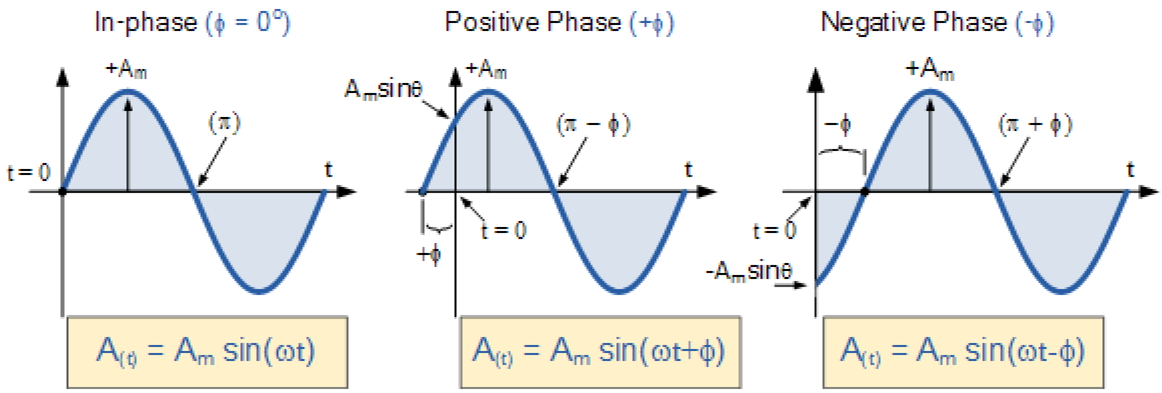
$$A_{(t)} = A_{max} \times \sin(\omega t \pm \Phi)$$

- Where:
- A_m – is the amplitude of the waveform.
- ωt – is the angular frequency of the waveform in radian/sec.
- Φ (phi) – is the phase angle in degrees or radians that the waveform has shifted either left or right from the reference point.

If the positive slope of the sinusoidal waveform passes through the horizontal axis "before" t = 0 then the waveform has shifted to the left so Φ >0, and the phase angle will be positive in nature, +Φ giving a leading phase angle. In other words it appears earlier in time than 0^o producing an anticlockwise rotation of the vector.

Likewise, if the positive slope of the sinusoidal waveform passes through the horizontal x-axis some time "after" t = 0 then the waveform has shifted to the right so $\Phi < 0$, and the phase angle will be negative in nature $-\Phi$ producing a lagging phase angle as it appears later in time than 0^o producing a clockwise rotation of the vector. Both cases are shown below.

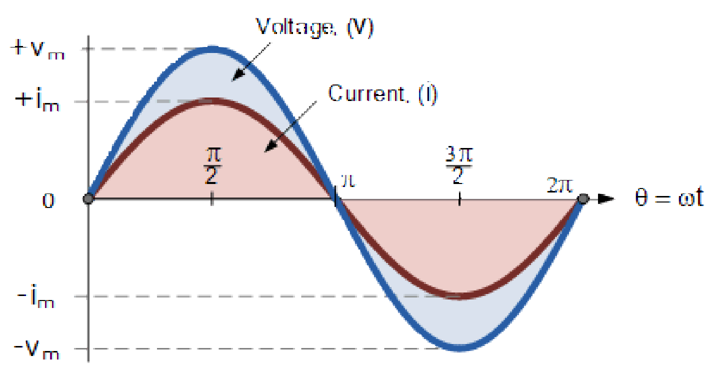
Phase Relationship of a Sinusoidal Waveform



Firstly, lets consider that two alternating quantities such as a voltage, v and a current, i have the same frequency f in Hertz. As the frequency of the two quantities is the same the angular velocity, ω must also be the same. So at any instant in time we can say that the phase of voltage, v will be the same as the phase of the current, i.

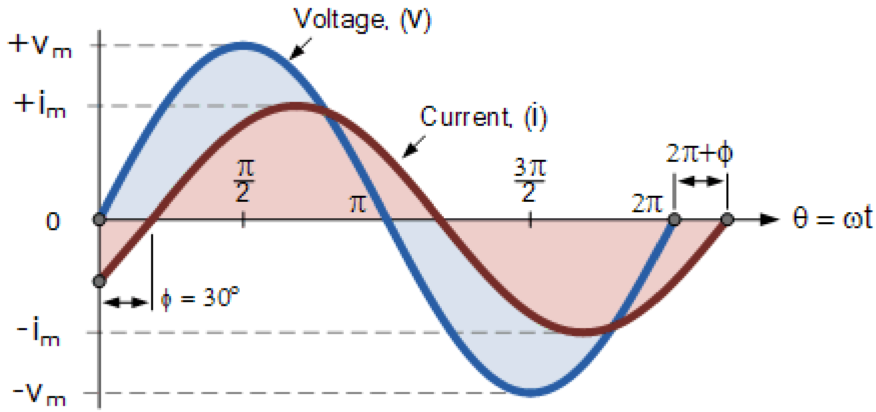
Then the angle of rotation within a particular time period will always be the same and the phase difference between the two quantities of v and i will therefore be zero and $\Phi = 0$. As the frequency of the voltage, v and the current, i are the same they must both reach their maximum positive, negative and zero values during one complete cycle at the same time (although their amplitudes may be different). Then the two alternating quantities, v and i are said to be "in-phase".

Two Sinusoidal Waveforms – "in-phase"



Now lets consider that the voltage, v and the current, i have a phase difference between themselves of 30^o, so ($\Phi = 30^o$ or $\pi/6$ radians). As both alternating quantities rotate at the same speed, i.e. they have the same frequency, this phase difference will remain constant for all instants in time, then the phase difference of 30^o between the two quantities is represented by phi, Φ as shown below.

Phase Difference of a Sinusoidal Waveform



The voltage waveform above starts at zero along the horizontal reference axis, but at that same instant of time the current waveform is still negative in value and does not cross this reference axis until 30^o later. Then there exists a **Phase difference** between the two waveforms as the current cross the horizontal reference axis reaching its maximum peak and zero values after the voltage waveform.

As the two waveforms are no longer "in-phase", they must therefore be "out-of-phase" by an amount determined by phi, Φ and in our example this is 30^o. So we can say that the two waveforms are now 30^o out-of phase. The current waveform can also be said to be "lagging" behind the voltage waveform by the phase angle, Φ. Then in our example above the two waveforms have a **Lagging Phase Difference** so the expression for both the voltage and current above will be given as.

$$\text{Voltage}, (v_t) = V_m \sin\omega t$$

$$\text{Current}, (i_t) = I_m \sin(\omega t - \theta)$$

where, i lags v by angle Φ

Likewise, if the current, i has a positive value and crosses the reference axis reaching its maximum peak and zero values at some time before the voltage, v then the current waveform will be "leading" the voltage by some phase angle. Then the two waveforms are said to have a **Leading Phase Difference** and the expression for both the voltage and the current will be.

$$\text{Voltage}, (v_t) = V_m \sin\omega t$$

$$\text{Current}, (i_t) = I_m \sin(\omega t + \theta)$$

where, i leads v by angle Φ

The phase angle of a sine wave can be used to describe the relationship of one sine wave to another by using the terms "Leading" and "Lagging" to indicate the relationship between two sinusoidal waveforms of the same frequency, plotted onto the same reference axis. In our example above the two waveforms are *out-of-phase* by 30^o. So we can correctly say that i lags v or we can say that v leads i by 30^o depending upon which one we choose as our reference.

The relationship between the two waveforms and the resulting phase angle can be measured anywhere along the horizontal zero axis through which each waveform passes with the "same slope" direction either positive or negative.

In AC power circuits this ability to describe the relationship between a voltage and a current sine wave within the same circuit is very important and forms the bases of AC circuit analysis.

The Cosine Waveform

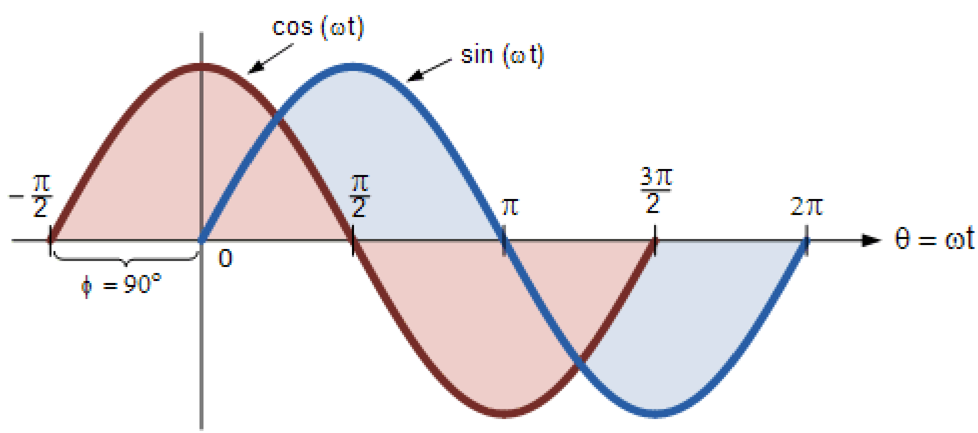
So we now know that if a waveform is "shifted" to the right or left of 0^o when compared to another sine wave the expression for this waveform becomes $A_m \sin(\omega t \pm \Phi)$. But if the waveform crosses the horizontal zero axis with a positive going slope 90^o or $\pi/2$ radians **before** the reference waveform, the waveform is called a **Cosine Waveform** and the expression becomes.

Cosine Expression

$$\sin(\omega t + 90^o) = \sin\left(\omega t + \frac{\pi}{2}\right) = \cos(\omega t)$$

The **Cosine Wave**, simply called "cos", is as important as the sine wave in electrical engineering. The cosine wave has the same shape as its sine wave counterpart that is it is a sinusoidal function, but is shifted by $+90^o$ or one full quarter of a period ahead of it.

Phase Difference between a Sine wave and a Cosine wave



Alternatively, we can also say that a sine wave is a cosine wave that has been shifted in the other direction by -90^o. Either way when dealing with sine waves or cosine waves with an angle the following rules will always apply.

Sine and Cosine Wave Relationships

$$\cos(\omega t + \phi) = \sin\left(\omega t + \phi + 90^o\right)$$

$$\sin(\omega t + \phi) = \cos\left(\omega t + \phi - 90^o\right)$$

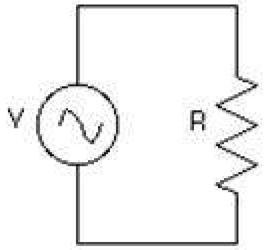
When comparing two sinusoidal waveforms it more common to express their relationship as either a sine or cosine with positive going amplitudes and this is achieved using the following mathematical identities.

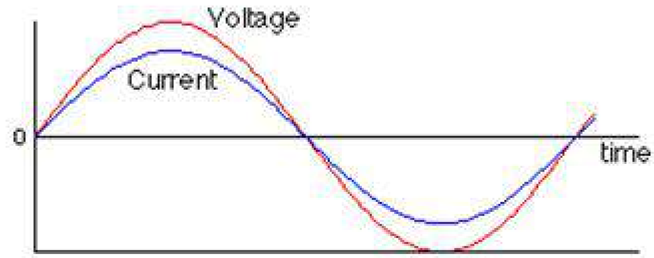
$$-\sin(\omega t) = \sin(\omega t \pm 180^\circ)$$
$$-\cos(\omega t) = \cos(\omega t + 180^\circ)$$
$$-\cos(\omega t) = \sin(\omega t + 270^\circ)$$
$$\pm\sin(\omega t) = \cos(\omega t \pm 90^\circ)$$
$$+\cos(\omega t) = \sin(\omega t + 90^\circ)$$
$$-\sin(\omega t) = \sin(-\omega t)$$
$$\cos(\omega t) = \cos(-\omega t)$$

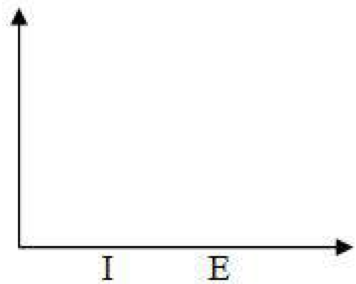
By using these relationships above we can convert any sinusoidal waveform with or without an angular or phase difference from either a sine wave into a cosine wave or vice versa.

Ac through Resistor

Ad by Value impression







Let an alternating emf be applied to a circuit containing resistor R only such type of circuit is called resistive circuit.

Let the emf applied to the circuit is $E = E_o sinwt - - - - - - - (i)$ Let I be the current in the circuit then potential difference across the resistor is

$$E = IR$$

$$I = \frac{E}{R}$$

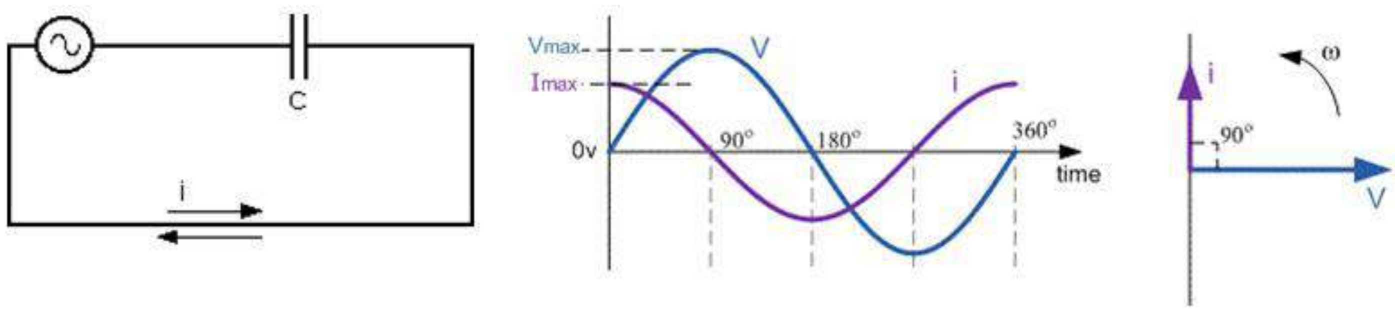
$$I = \frac{E_o sinwt}{R}$$

$$I = I_o sinwt$$

$$where\ I_o = \frac{E_o}{R}\ is\ the\ form\ of\ alternating\ current\ developed\ in\ the\ resistive\ circuit$$

Comparing $I_o = \frac{E_o}{R}$. with ohm's law, we see that current is equal to voltage/resistance
This means the resistance R is resistance for ac which is in fact the resistance for dc. Therefore the behavior of R is same for ac and dc.

Ac through Capacitor



Let an alternating emf be applied to a circuit containing capacitor only such type of circuit is called capacitive circuit.

Let the emf applied to the circuit is $E = E_o sinwt - - - - - - - - (i)$
Let q be the charge in the capacitor of capacitance C then the potential developed in the capacitor is

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

if V=E then

$$E = \frac{q}{C}$$

$$q = CE$$

$$q = CE_o sinwt$$

taking derivative,

$$\frac{dq}{dt} = CE_o \frac{d}{dt} sinwt$$

$$I = C\,E_o \omega cos\omega t$$

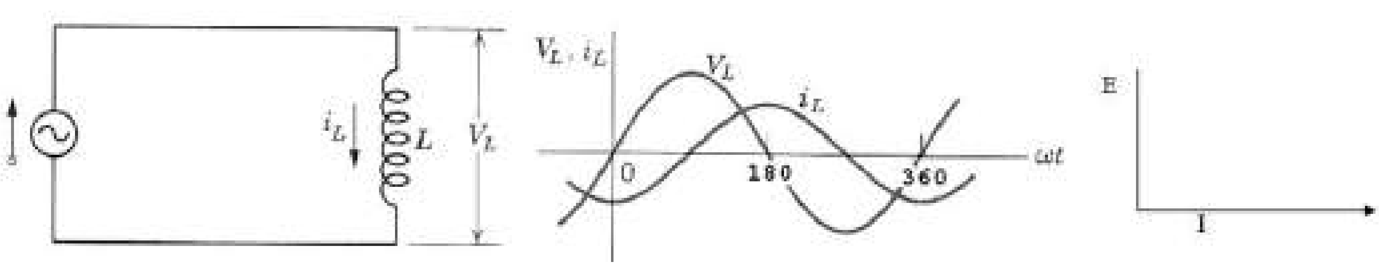
$$I = \frac{E_o}{\frac{1}{C\omega}} \sin\left(\omega t + \frac{\pi}{2}\right)$$

$$I = I_o \sin\left(\omega t + \frac{\pi}{2}\right) - - - - - - - - -(ii)$$

Equation ii is the type of current developed in the purely capacitive circuit.
Comparing equation i and ii we see that the alternating current leads to the alternating emf by π/2 as shown in fig.

Ac through inductor only

Ad by Value impression



Let an alternating emf be applied to a circuit containing inductor only such type of circuit is called inductive circuit.
Let the emf applied to the circuit is

$E = E_o sinwt - - - - - - - - (i)$ then the induced emf across the inductor is

$$-L\frac{dI}{dt}$$

This emf opposes the growth of current in the circuit.
Applying Kirchhoff's voltage law in the loop of fig a

$$E + \left(-L\frac{dI}{dt}\right) = 0$$

$$E = L\frac{dI}{dt}$$

$$dI = \frac{E}{L}dt$$

$$dI = \frac{E_o}{L}sinwtdt$$

integrating above expression we get

$$\int dI = \frac{E_o}{L}\int sinwtdt$$

$$I = \frac{E_o}{L}\left(\frac{-cos\omega t}{\omega}\right)$$

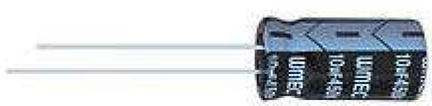
$$I = \frac{E_o}{L\omega}(-cos\omega t)$$

$$I = \frac{E_o}{L\omega}sin\left(\omega t - \frac{\pi}{2}\right)$$

$$I = I_o sin\left(\omega t - \frac{\pi}{2}\right) - - - - - - - - (ii)$$

This is the form of alternating current developed in the purely inductive circuit. equation i and ii shows that in a purely inductive circuit alternating emf leads the alternating current by π/2

What is Impedance?



Impedance is the amount of resistance that a component offers to current flow in a circuit at a specific frequency.

How to Calculate Impedance

Now we will go over how to calculate the impedance of the 2 main reactive components, capacitors and inductor.

The impedance of capacitors and inductors each have separate formulas, so the correct formula needs to be applied for each one.

Capacitor Impedance

To calculate the impedance of a capacitor, the formula to do so is:

$$X_C = \frac{1}{2\pi f C}$$

where XC is the impedance in unit ohms, f is the frequency of the signal passing through the capacitor, and C is the capacitance of the capacitor.
To use our online calculator that will calculate capacitor impedance automatically for you, visit the resource Capacitor Impedance Calculator.

Inductor Impedance

To calculate the impedance of an inductor, the formula to do so is:

$$X_L = 2\pi f L$$

where XL is the impedance in unit ohms, f is the frequency of the signal passing through the inductor, and L is the inductance of the inductor.
To use our online calculator that will calculate inductor impedance automatically for you, visit the resource Inductor Impedance Calculator.

If there are both capacitors and inductors present in a circuit, the total amount of impedance can be calculated by adding all of the individual impedances:

XTotal= XC + XL

Resistors and Capacitors in Series

An RC circuit has a resistor and a capacitor and when connected to a DC voltage source, and the capacitor is charged exponentially in time.

LEARNING OBJECTIVES

Describe the components and function of an RC circuit, noting especially the time-dependence of the capacitor's charge

KEY TAKEAWAYS

Key Points

- In an RC circuit connected to a DC voltage source, the current decreases from its initial value of I_0=emf/R to zero as the voltage on the capacitor reaches the same value as the emf.
- In an RC circuit connected to a DC voltage source, voltage on the capacitor is initially zero and rises rapidly at first since the initial current is a maximum: V(t)=emf(1−et/RC)V(t)=emf(1−et/RC).
- The time constant τ for an RC circuit is defined to be RC. It's unit is in seconds and shows how quickly the circuit charges or discharges.

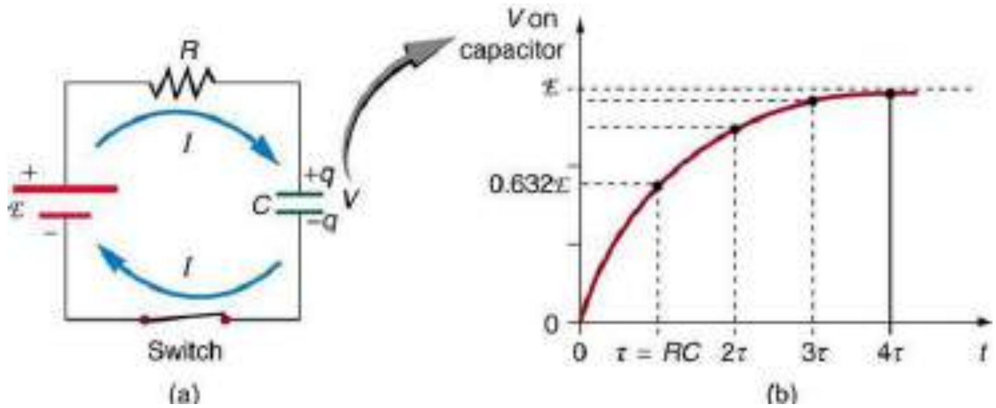
Key Terms

- **DC**: Direct current; the unidirectional flow of electric charge.
- **capacitor**: An electronic component capable of storing an electric charge, especially one consisting of two conductors separated by a dielectric.
- **differential equation**: An equation involving the derivatives of a function.

An RC circuit is one containing a resistor R and a capacitor C. The capacitor is an electrical component that houses electric charge. In this Atom, we will study how a series RC circuit behaves when connected to a DC voltage source. (In subsequent Atoms, we will study its AC behavior.)

Charging

Fig 1 shows a simple RC circuit that employs a DC voltage source. The capacitor is initially uncharged. As soon as the switch is closed, current flows to and from the initially uncharged capacitor. As charge increases on the capacitor plates, there is increasing opposition to the flow of charge by the repulsion of like charges on each plate.



Charging an RC Circuit: (a) An RC circuit with an initially uncharged capacitor. Current flows in the direction shown as soon as the switch is closed. Mutual repulsion of like charges in the capacitor progressively slows the flow as the capacitor is charged, stopping the current when the capacitor is fully charged and Q=C·emf. (b) A graph of voltage across the capacitor versus time, with the switch closing at time t=0. (Note that in the two parts of the figure, the capital script E stands for emf, q stands for the charge stored on the capacitor, and τ is the RC time constant.)

In terms of voltage, across the capacitor voltage is given by V_c=Q/C, where Q is the amount of charge stored on each plate and C is the capacitance. This voltage opposes the battery, growing from zero to the maximum emf when fully charged. Thus, the current decreases from its initial value of I_0=emf/R to zero as the voltage on the capacitor reaches the same value as the emf. When there is no current, there is no IR drop, so the voltage on the capacitor must then equal the emf of the voltage source.

Initially, voltage on the capacitor is zero and rises rapidly at first since the initial current is a maximum. Fig 1 (b) shows a graph of capacitor voltage versus time (t) starting when the switch is closed at t=0. The voltage approaches emf asymptotically since the closer it gets to emf the less current flows. The equation for voltage versus time when charging a capacitor C through a resistor R, is:

$V(t)=emf(1-et/RC)V(t)=emf(1-et/RC)$,

where V(t) is the voltage across the capacitor and emf is equal to the emf of the DC voltage source. (The exact form can be derived by solving a linear differential equation describing the RC circuit, but this is slightly beyond the scope of this Atom.) Note that the unit of RC is second. We define the time constant τ for an RC circuit as $\tau=RC\tau=RC$. τ shows how quickly the circuit charges or discharges.

Discharging

Discharging a capacitor through a resistor proceeds in a similar fashion, as illustrates. Initially, the current is $I_0=V_0/R$, driven by the initial voltage V_0 on the capacitor. As the voltage decreases, the current and hence the rate of discharge decreases, implying another exponential formula for V. Using calculus, the voltage V on a capacitor C being discharged through a resistor R is found to be

$$V(t)=V0e-t/RCV(t)=V0e-t/RC.$$

Impedance

Impedance is the measure of the opposition that a circuit presents to the passage of a current when a voltage is applied.

LEARNING OBJECTIVES

Express the relationship between the impedance, the resistance, and the capacitance of a series RC circuit in a form of equation

KEY TAKEAWAYS

Key Points

- The advantage of assuming that sources have complex exponential form is that all voltages and currents in the circuit are also complex exponentials, having the same frequency as the source.
- The major consequence of assuming complex exponential voltage and currents is that the ratio (Z = V/I) for each element does not depend on time, but does depend on source frequency.
- For a series RC circuit, the impedance is given as $Z=\sqrt{R2+(1\omega C)2}Z=R2+(1\omega C)2$.

Key Terms

- **impedance**: A measure of the opposition to the flow of an alternating current in a circuit; the aggregation of its resistance, inductive and capacitive reactance. Represented by the symbol Z.
- **AC**: Alternating current.
- **capacitor**: An electronic component capable of storing an electric charge, especially one consisting of two conductors separated by a dielectric.
- **resistor**: An electric component that transmits current in direct proportion to the voltage across it.

Rather than solving the differential equation relating to circuits that contain resistors and capacitors, we can imagine all sources in the circuit are complex exponentials having the same frequency. This technique is useful in solving problems in which phase relationship is important. The phase of the complex impedance is the phase shift by which the current is ahead of the voltage.

Complex Analysis

For an RC circuit in, the AC source driving the circuit is given as:

Series RC Circuit: Series RC circuit.

sin(t)= sin (ω t), sin(t)=sin(ω t),

where V is the amplitude of the AC voltage, j is the imaginary unit (j^2=-1), and ω ω is the angular frequency of the AC source. Two things to note:

1. We use lower case alphabets for voltages and sources to represent that they are alternating (i.e., we use $v_{in}(t)$ instead of $V_{in}(t)$).
2. The imaginary unit is given the symbol “j”, not the usual “i”. “i” is reserved for alternating currents.

Complex Impedance

The major consequence of assuming complex exponential voltage and currents is that the ratio Z=VIZ=VI for rather than depending on time each element depends on source frequency. This quantity is known as the element’s (complex) impedance. The magnitude of the complex impedance is the ratio of the voltage amplitude to the current amplitude. Just like resistance in DC cases, impedance is the measure of the opposition that a circuit presents to the passage of a current when a voltage is applied. The impedance of a resistor is R, while that of a capacitor (C) is 1jωC1jωC. In the case of the circuit in, to find the complex impedance of the RC circuit, we add the impedance of the two components, just as with two resistors in series: Z=R+1jωCZ=R+1jωC.

• Power in AC circuits

Learning Objectives

By the end of the section, you will be able to:

- Describe how average power from an ac circuit can be written in terms of peak current and voltage and of rms current and voltage

- Determine the relationship between the phase angle of the current and voltage and the average power, known as the power factor

A circuit element dissipates or produces power according to where I is the current through the element and V is the voltage across it. Since the current and the voltage both depend on time in an ac circuit, the instantaneous power is also time dependent. A plot of $p(t)$ for various circuit elements is shown in . For a resistor, $i(t)$ and $v(t)$ are in phase and therefore always have the same sign , For a capacitor or inductor, the relative signs of $i(t)$ and $v(t)$ vary over a cycle due to their phase differences (see and . Consequently, $p(t)$ is positive at some times and negative at others, indicating that capacitive and inductive elements produce power at some instants and absorb it at others.

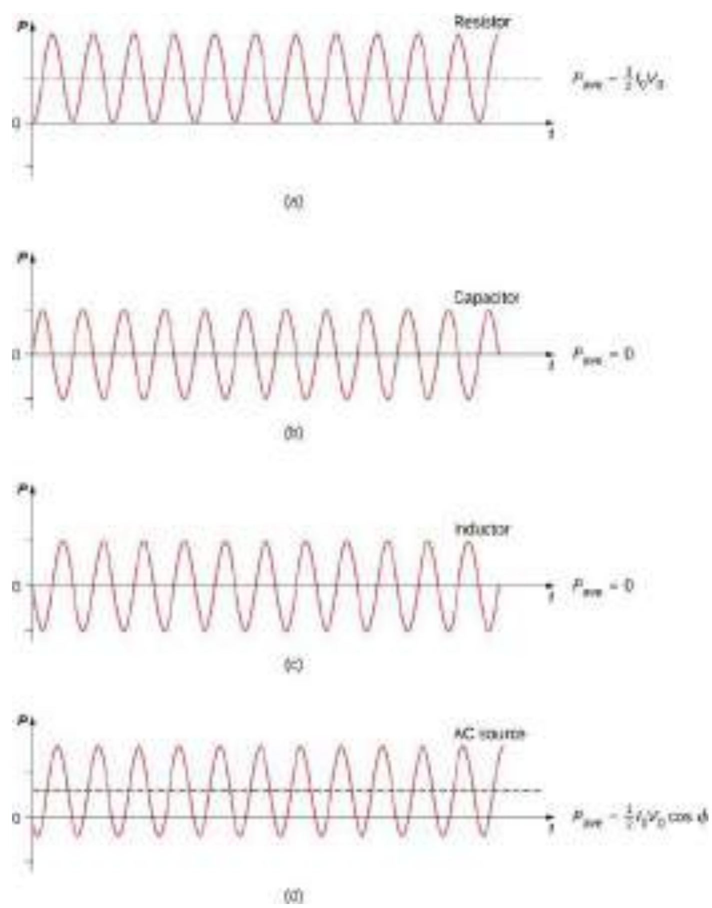
Graph of instantaneous power for various circuit elements.

(a) For the resistor, whereas for

(b) the capacitor and

(c) the inductor,

(d) For the source, which may be positive, negative, or zero, depending on



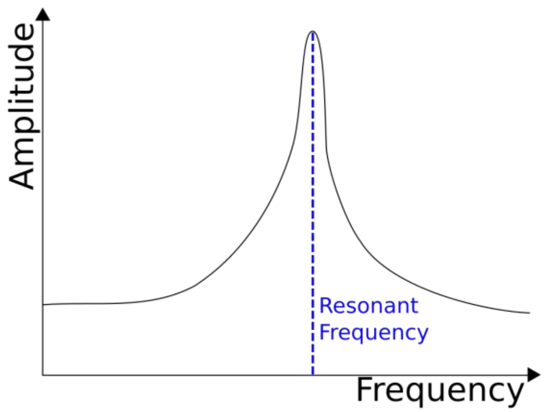
Because instantaneous power varies in both magnitude and sign over a cycle, it seldom has any practical importance. What we’re almost always concerned with is the power averaged over time, which we refer to as the average power. It is defined by the time average of the instantaneous power over one cycle.

Resonant circuits

Resonance occurs in a circuit when the reactances within a circuit cancel one another out. As a result, the impedance is at a *minimum* and the current is at a *maximum*. Mathematically, the condition for resonance is

X_L = X_C.$X_L = X_C$.

Resonance allows for the maximum power output of an RLC circuit**.**



The current in a circuit peaks at the resonant frequency.

Electrocardiogram (ECG or EKG)

What is it?

An electrocardiogram — abbreviated as EKG or ECG — is a test that measures the electrical activity of the heartbeat. With each beat, an electrical impulse (or “wave”) travels through the heart. This wave causes the muscle to squeeze and pump blood from the heart. A normal heartbeat on ECG will show the timing of the top and lower chambers.

The right and left atria or upper chambers make the first wave called a “P wave" — following a flat line when the electrical impulse goes to the bottom chambers. The right and left bottom chambers or ventricles make the next wave called a “QRS complex." The final wave or “T wave” represents electrical recovery or return to a resting state for the ventricles.

Why is it done?

An ECG gives two major kinds of information. First, by measuring time intervals on the ECG, a doctor can determine how long the electrical wave takes to pass through the heart. Finding out how long a wave takes to travel from one part of the heart to the next shows if the electrical activity is normal or slow, fast or irregular. Second, by measuring the amount of electrical activity passing through the heart muscle, a cardiologist may be able to find out if parts of the heart are too large or are overworked.

Does it hurt?

No. There’s no pain or risk associated with having an electrocardiogram. When the ECG stickers are removed, there may be some minor discomfort.

How Do Metal Detectors Work?

Metal detectors work by transmitting an electromagnetic field from the search coil into the ground. Any metal objects (targets) within the electromagnetic field will become energised and retransmit an electromagnetic field of their own. The detector's search coil receives the retransmitted field and alerts the user by producing a target response. Minelab metal detectors are capable of discriminating between different target types and can be set to ignore unwanted targets.

1. Battery

The battery provides power to the detector.

2. Control Box

The control box contains the detector's electronics. This is where the transmit signal is generated and the receive signal is processed and converted into a target response.

3. Search Coil

The detector's search coil transmits the electromagnetic field into the ground and receives the return electromagnetic field from a target.

4. Transmit Electromagnetic Field *(visual representation only - blue)*

The transmit electromagnetic field energises targets to enable them to be detected.

5. Target

A target is any metal object that can be detected by a metal detector. In this example, the detected target is treasure, which is a good (accepted) target.

6. Unwanted Target

Unwanted targets are generally ferrous (attracted to a magnet), such as nails, but can also be non-ferrous, such as bottle tops. If the metal detector is set to reject unwanted targets then a target response will not be produced for those targets.

7. Receive Electromagnetic Field *(visual representation only - yellow)*

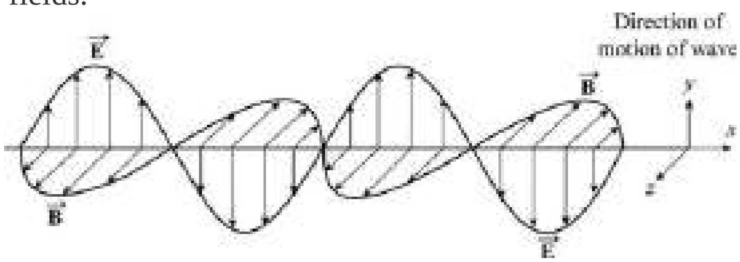
The receive electromagnetic field is generated from energised targets and is received by the search coil.

8. Target Response *(visual representation only - green)*

When a good (accepted) target is detected the metal detector will produce an audible response, such as a beep or change in tone. Many Minelab detectors also provide a visual display of target information.

Maxwell's Equations And Electromagnetic Waves

Electromagnetic waves are waves travelling in vacuum which are a couple of electric as well as magnetic fields. An ideal electromagnetic wave can be represented in three-directional space as a magnetic field in *x* direction and an electric field in *y* direction.
Hence, the direction of motion of the wave will be in *z* direction. Maxwell's equations are best way to represent electromagnetic waves. These are partial differential equations which represent the electric and magnetic fields in term of charge and fields.



The equations are,

1. Gauss' law of electricity is about the electric field and the charge enclosed. This is about the surface integral of electric field.

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\varepsilon_0}$$

The differential form will give

$$\nabla \cdot E = \frac{\rho}{\varepsilon_0}$$

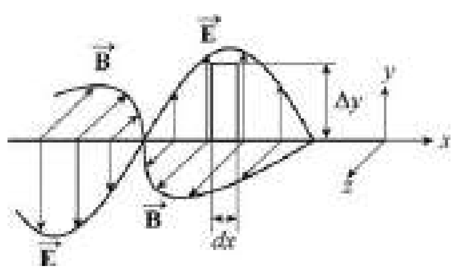
2. Gauss' law of magnetism tells about the magnetic flux. This says about the surface integral of magnetic field.

$$\oint \vec{B} \cdot d\vec{A} = 0$$

The differential form will give

$$\nabla \cdot B = 0$$

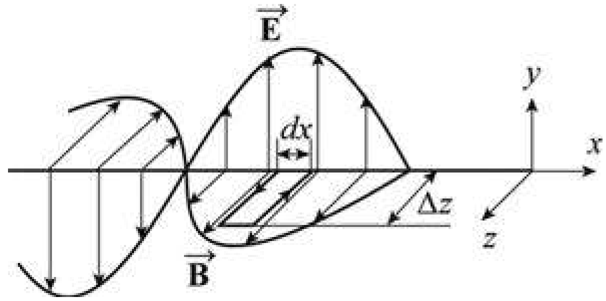
3. Using **Faraday's law**, the relationship between the electric field and magnetic field can be determined. According to Faraday's law



$$\oint E \cdot ds = -\frac{d\phi_B}{dt}$$

$$\nabla \times \vec{E} = -\frac{d\vec{B}}{dt}$$

4. According to **Ampere's law**



$$\oint B \cdot ds = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

To modify amperes law, Maxwell considered if the equation has to be correct, then there must be a displacement current between the capacitor plates since there is electric field between the capacitor plates and outside the plates the field is zero.

The Ampere law can hence be replaced as

$$\oint B \cdot dl = \mu_0 i + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

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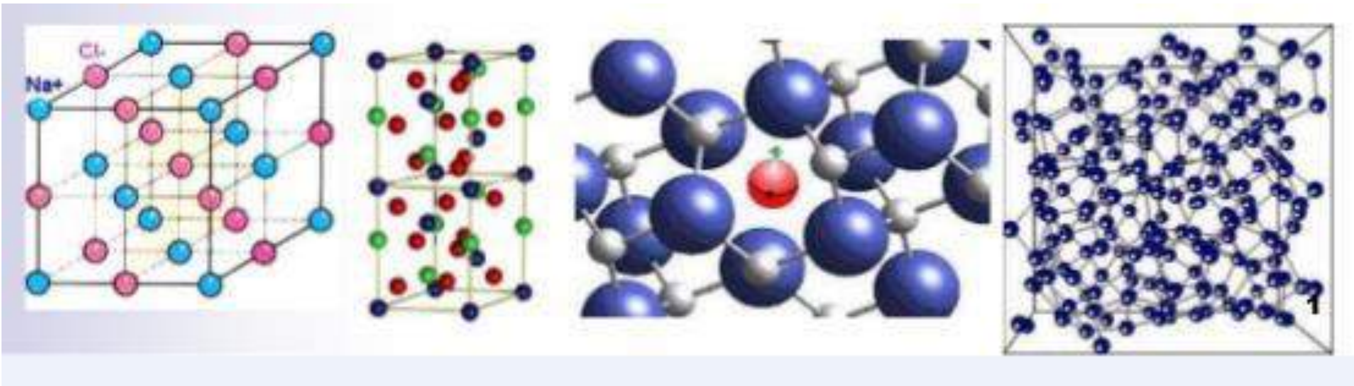
Unit#16

Physics of Solids



Topic	**skills**	**understanding**
Physics of Solids. Topics according to national curriculum. Classification of solids • Mechanical properties of solids • Elastic limit and yield strength • Electrical properties of solids • Superconductors • Magnetic properties of solids	Students will be able to: • determine Young's modulus of the material of a given wire using Searle's apparatus. • determine the energy stored in a spring. • describe the applications of superconductors in magnetic resonance imaging (MRI), magnetic levitation trains, powerful but small electric motors and faster computer chips. • identify the importance of hysteresis loop to select materials for their use to make them temporary magnets or permanent magnets.	Students will be able to: distinguish between the structure of crystalline, glassy, amorphous and polymeric solids. • describe that deformation in solids is caused by a force and that in one dimension, the deformation can be tensile or compressive. • describe the behavior of springs in terms of load-extension, Hooke's law and the spring constant. • define and use the terms Young's modulus, bulk modulus and shear modulus. • demonstrate knowledge of the force-extension graphs for typical ductile, brittle and polymeric materials. • become familiar of ultimate tensile stress, elastic deformation and plastic deformation of a material. • describe the idea about energy bands in solids. • classify insulators, conductors, semiconductors on the basis of energy bands. • become familiar with the behavior of superconductors and their potential uses. • distinguish between dia, para and ferro magnetic materials.

		• describe the concepts of magnetic domains in a material. • explain the Curie point. • classify hard and soft ferromagnetic substances. • describe hysteresis loss. • synthesise from hysteresis loop how magnetic field strength varies with magnetizing current.

VIDEOS		

https://www.youtube.com/watch?v=fTbNwKC3jfg

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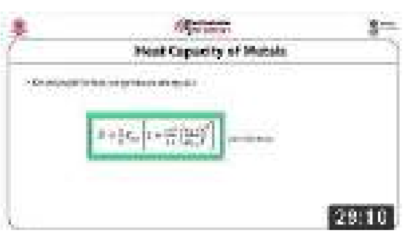

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Unit overview

Mechanical Properties of Solids

A material is said to be in the solid state if all the atoms of that matter are densely packed together. A solid material has a definite shape and size. In order to change the shape and size of the solid object, an external force needs to be applied. In this chapter, we will learn about the Mechanical Properties of Solids.

- Elasticity and Plasticity
- Applications of Elastic Behavior of Materials
- Stress and Strain
- Elastic Moduli
- Hooke's Law and Stress-strain Curve

Elasticity and Plasticity

Elasticity is the property of a body to recover its original configuration (shape and size) when you remove the deforming forces. Plastic bodies do not show a tendency to recover to their original configuration when you remove the deforming forces. Plasticity is the property of a body to lose its property of elasticity and acquire a permanent deformation on the removal of deforming force.

Applications of Elastic Behaviour of Materials

Have you seen a stretched slingshot? You surely must have played with it, haven't you? What happens when you release it? This is an important concept of elasticity and the Elastic behaviour of substances. It finds various applications in our day to day lives. Let us look at this concept in a greater detail.

Stress and Strain

You must have noticed that there are certain objects that you can stretch easily. Let's say a rubber band. However, can you stretch an iron rod? Sound's impossible right? Why? In this chapter, we will look at these properties of solids in greater detail. We will see how quantities like stress can help us guess the strength of solids.

Elastic Moduli

In the stress-strain curve given below, the region within the elastic limit (region OA) is of importance to structural and manufacturing sectors since it describes the maximum stress a particular material can take before being permanently deformed. The modulus of elasticity is simply the ratio between stress and strain. Elastic Moduli can be of three types, Young's modulus, Shear modulus, and Bulk modulus. In this article, we will understand elastic moduli in detail.

Hooke's Law and Stress-strain Curve

By now, we know that the stress and strain take different forms in different situations. In this article, we will understand the relationship between stress and strain by looking at the Hooke's law and the stress-strain curve.

What is elastic limit?

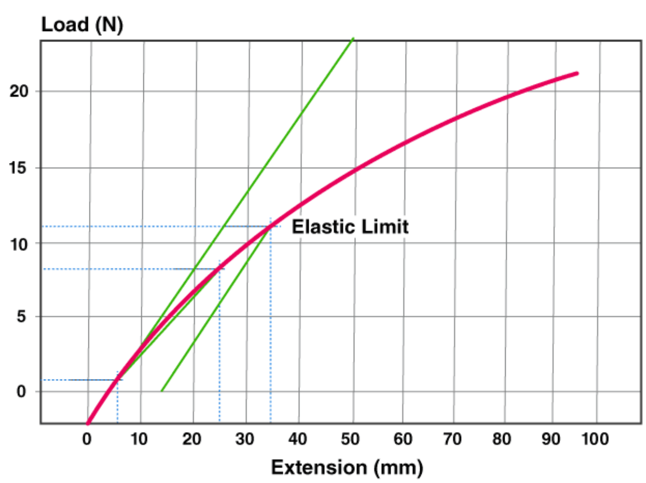
Elastic limit is defined as the maximum stress that a material can withstand before the permanent deformation. It is the highest limit of the material before plastic deformation of the material can occur. Once the stress or force is removed from the material, the material comes back to its original shape. Elastomers like rubber have the highest elastic limit. The behavior can be explained by Hooke's law.

Elastic Limit Testing

Elastic limit can be determined by measuring the greatest stress that can be applied to a given sample without causing any permanent deformation. For metals or any other rigid materials have the stress-strain curve as a straight line as the elastic limit is approximately equal to the proportional limit. Materials like rubber and plastic are called an apparent elastic limit as their stress-strain curve is not significantly straight..

Electrical Properties of Solids

We are aware of the physical properties of solids. Like the fact that they have a definite shape and volume. But the electrical properties of solids vary largely based on their composition and chemical structure. They are divided into three groups – conductors, semiconductors, and insulators. Let us study these further.



Conductors – Insulators – Semiconductors

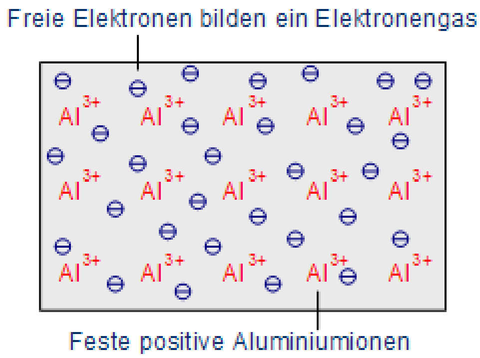
Conductors

Conductors are generally substances which have the property to pass different types of energy. In the following, the conductivity of electricity is the value of interest.

Metals

The conductivity of metals is based on the free electrons (so-called Fermi gas) due to the metal bonding. Already with low energy electrons become sufficiently detached from the atoms and a conductivity is achieved.

Metallic bonding: fixed ions and free valence electrons (Fermi gas)



The conductivity depends, inter alia, on the temperature. If the temperature rises, the metal atoms swing ever stronger, so that the electrons are constrained in their movements. Consequence, the resistance increases. The best conductors, gold and silver, are used relatively rare because of the high costs (gold e.g. for the contacting of the finished chips). The alternatives in the semiconductor technology for the wiring of the individual components of microchips are aluminum and copper.

Salts

In addition to metals, salts can also conduct electricity. There are no free electrons, so the conductivity depends on ions which can be solved when a salt is melting or dissolving, so that the ions are free to move (see chapter chemical bonds for details).

Insulators

Insulators possess no free charge carriers and thus are non-conductive.

The atomic bond

The atomic bond is based on shared electron pairs of nonmetals. The elements which behave like nonmetals have the desire to catch electrons, thus there are no free electrons which might serve as charge carriers.

The ionic bond

In the solid state, ions are arranged in a grid network. By electrical forces, the particles are held together. There are no free charge carriers to enable a current flow. Thus substances composed of ions can be both conductor and insulator.

Semiconductors

Semiconductors are solids whose conductivity lies between the conductivity of conductors and insulators. Due to exchange of electrons - to achieve the noble gas configuration - semiconductors arrange as lattice structure. Unlike metals, the conductivity increases with increasing temperature.

Increasing temperatures leads to broken bonds and free electrons are generated. At the location at which the electron was placed, a so-called defect electron ("hole") remains.

Cut-out of a silicon lattice

The electron flow is based on the conductivity properties of semiconductors. The electronic band structure illustrates why semiconductors behave like this.

Superconductors

Superconductors are materials that offer no resistance to electrical current. Prominent examples of superconductors include aluminium, niobium, magnesium diboride, cuprates such as yttrium barium copper oxide and iron pnictides. These materials only become superconducting at temperatures below a certain value, known as the critical temperature.

Magnetic Properties Of Solids

Every substance around us has some magnetic properties in it. Different types of materials show different properties in the presence of a magnetic field. The magnetic properties of a substance originate from the electrons present in the atoms or molecules. Every electron in an atom behaves like a small magnet. Electrons can also be referred to as small loops of current which retain their magnetic moment.

Magnetic properties

These magnetic moments come from two types of motion of electrons:

1. The orbital movement around the nucleus of an atom.
2. When the electron spins around its own axis.

On the basis of the magnetic properties solids can be classified as follows:

Properties	**Description**	**Alignment of magnetic dipoles**	**Examples**	**Application**
Diamagnetic	They are weakly repelled by the magnetic fields	All the electrons in the orbitals are paired and are completely filled.	NaCl, Benzene	Behaves like an insulator.
Paramagnetic	They are weakly attracted by the magnetic fields.	Contains at least one unpaired electron in the orbital.	O_2, Cu^{2+} etc.	Electronic appliances
Ferromagnetic	Strongly attracted by the magnetic field. The can be magnetised permanently	Consists of unpaired electrons, all having the same direction	Cobalt, nickel, CrO_2 etc.	CrO_2 is commonly used in making cassette recorder.
Antiferromagnetic	Net magnetic moment is zero.	Dipole moments are arranged in a	NiO, MnO, V_2O_3 etc.	–

		compensatory way		
Ferrimagnetic	Possess small net magnetic moments	Unequal number of parallel and antiparallel arrangement of magnetic moments	Fe_3O_4	–

Graphs showing the variation of magnetic properties on changing temperature:

In paramagnetic material, with the increase in the magnetic field, the magnetization of the material increases. When the material is heated the magnetization starts decreasing, so the magnetization of the material is inversely proportional to temperature. This relationship is known as Curie's law.

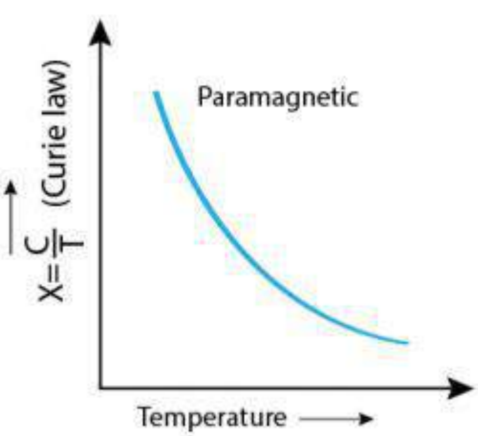
M = C×(B/T)

Where, M = magnetization of the material

C= Curie's constant

B= applied magnetic field

T= Temperature



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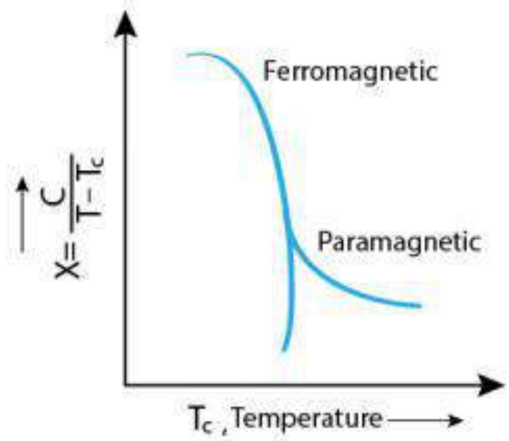

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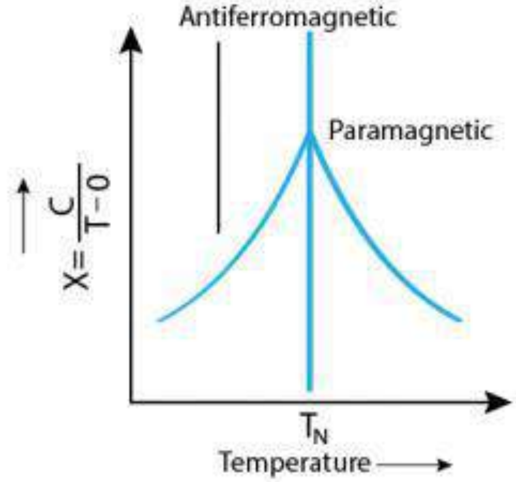

(c)

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Unit#17

Electronics

Topics	skills	understanding
Electronics. Topics according to national curriculum. • Intrinsic and extrinsic semiconductors • P & N type substances • Electrical conductivity by electrons and holes • PN Junction • Forward and reverse biased PN junction characteristics • Half and full wave rectification • Uses of specially designed PN junctions • Transistor and its characteristics • Transistor as an amplifier (C-E configuration)	Students will be able to: • distinguish between intrinsic and extrinsic semiconductors. • distinguish between P & N type substances. • explain the concept of holes and electrons in semiconductors. • explain how electrons and holes flow across a junction. • describe a PN junction and discuss its forward and reverse biasing. • define rectification and describe the use of diodes for half and full wave rectifications. • distinguish PNP & NPN transistors. • describe the operations of transistors. • deduce current equation and apply it to solve problems on transistors. • explain the use of transistors as a switch and an amplifier.	Students will be able to: draw characteristics of semiconductor diode and calculate forward and reverse current resistances. • study the half and full waver rectification by semiconductor diodes by displaying on C.R.O. • use multimeter to (i) identify base of transistor (ii) distinguish between NPN and PNP transistor (iii) see the unidirectional flow of current in case of diode and an lED. (iv) to check whether a given electric component e.g. diode or transistor is in working order. • demonstrate the amplification action of a transistor graphically by CRO Science, Technology and Society Connections • describe the function and use of LED, Photodoide and Photo voltaic cell. • analyze that the modern world is the world of digital electronics. • analyze that the computers are the forefront of electronic technology.

		• realize that electronics is shifting low-tech electrical appliances to high-tech electronic appliances.

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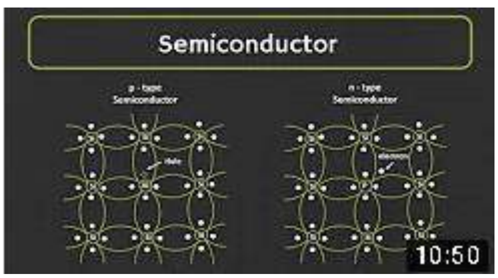

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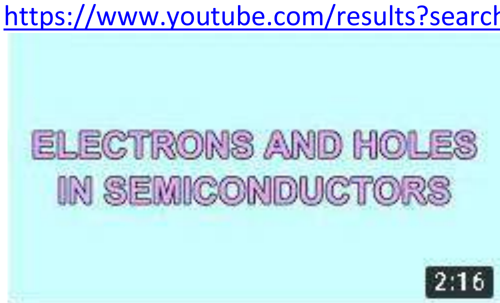
https://www.youtube.com/results?search_query=P+%26+N+type+substances



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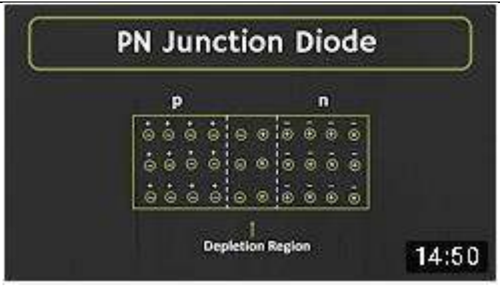

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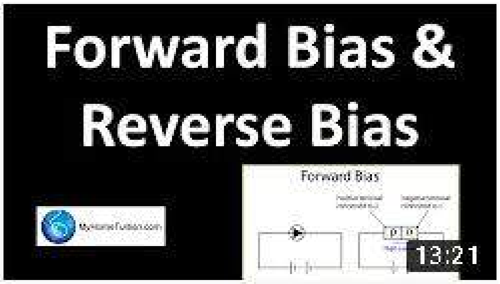

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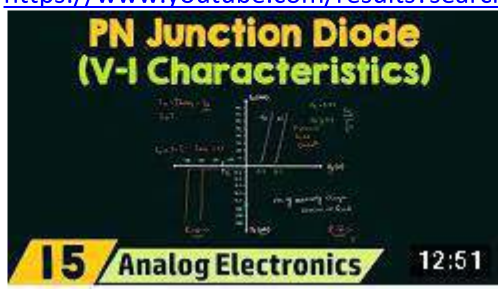

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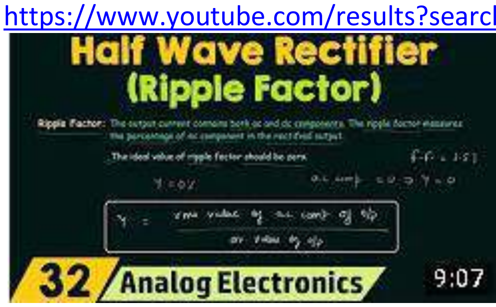

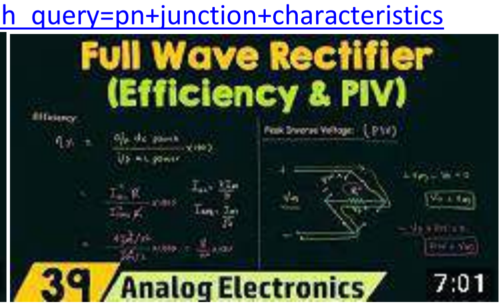

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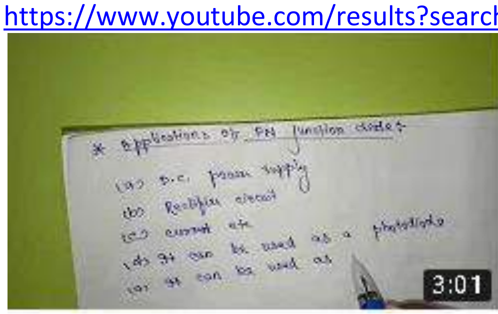

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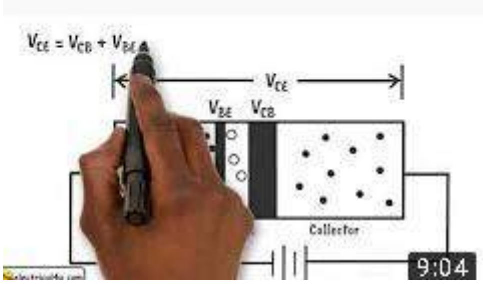

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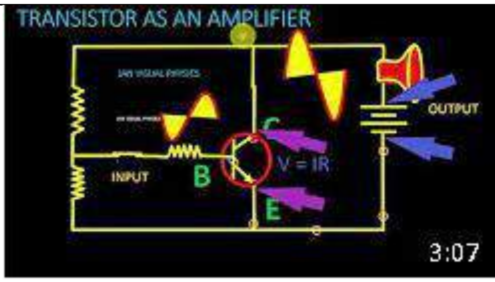


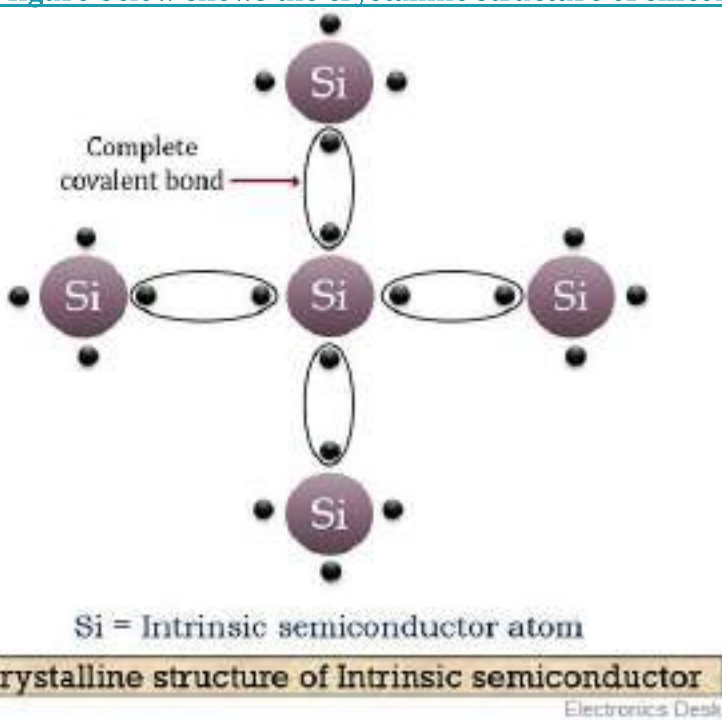
https://www.youtube.com/results?search_query=transistor+as+an+amplifier+%28C-E+Configuration%29

Chapter overview

INTRINSIC & EXTRINSIC SEMICONDUCTOR

Definition of Intrinsic Semiconductor

An intrinsic semiconductor is formed from a **highly pure semiconductor** material thus also known as pure semiconductors. These are basically undoped semiconductors that do not have doped impurity in it.
At room temperature, intrinsic semiconductors exhibit almost **negligible conductivity**. As no any other type of element is present in its crystalline structure.
The group IV elements of the periodic table form an intrinsic semiconductor. However, mainly **silicon and germanium** are widely used. This is so because in their case only small energy is needed in order to break the covalent bond.
The figure below shows the crystalline structure of silicon:



Crystalline structure of Intrinsic semiconductor

The figure above clearly shows that silicon consists of 4 electrons in the valence shell. Here, 4 covalent bonds are formed between the electrons of the silicon atom.

When the temperature of the crystal is increased then the electrons in the covalent bond gain kinetic energy and after breaking the covalent bond it gets free. Thus, the movement of free electrons generates current.

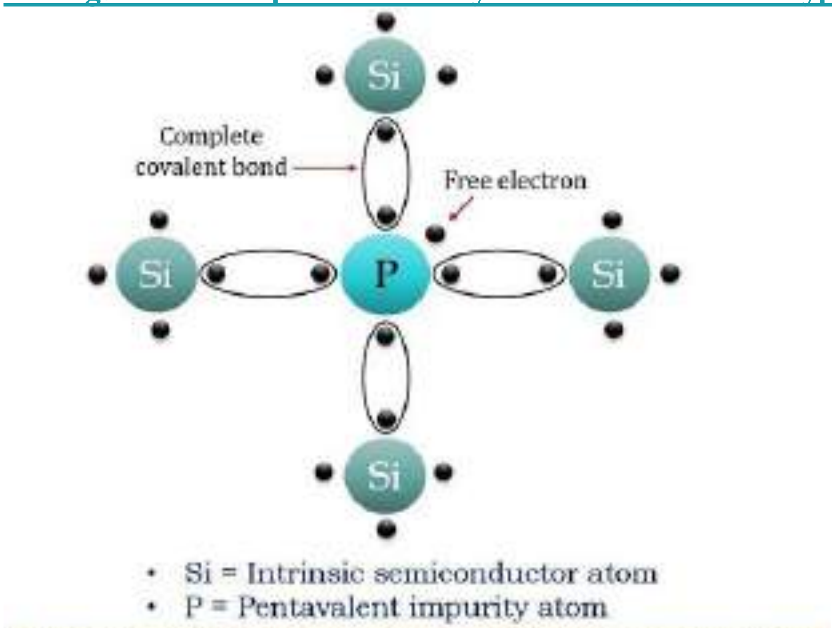
The rise in temperature somewhat increases the number for free electrons for conduction.

Definition of Extrinsic Semiconductor

Extrinsic Semiconductors are those that are the result of adding an impurity to a pure semiconductor. These are basically termed as an impure form of semiconductors.

The process by which certain amount of impurity is provided to a pure semiconductor is known as **doping**. So, we can say a pure semiconductor is doped to generate an extrinsic semiconductor.
These are **highly conductive in nature**. However, unlike intrinsic semiconductor, extrinsic semiconductors are of two types **p-type** and an **n-type** semiconductor.
It is noteworthy here that the classification of the extrinsic semiconductor depends on the type of element doped to the pure semiconductor.

The p-type semiconductors are formed by introducing group III elements or trivalent impurity into the pure semiconductor. These are also known as an **acceptor impurity**, as a trivalent impurity has only 3 electrons in the valence shell.
The n-type semiconductors are formed by the addition of group V elements or pentavalent impurity to a pure semiconductor. These are termed as **donor impurity**, as a pentavalent impurity holds 5 electrons in its valence shell.
The figure below represents the crystalline structure of n-type semiconductor:



Crystalline structure of n type extrinsic semiconductor

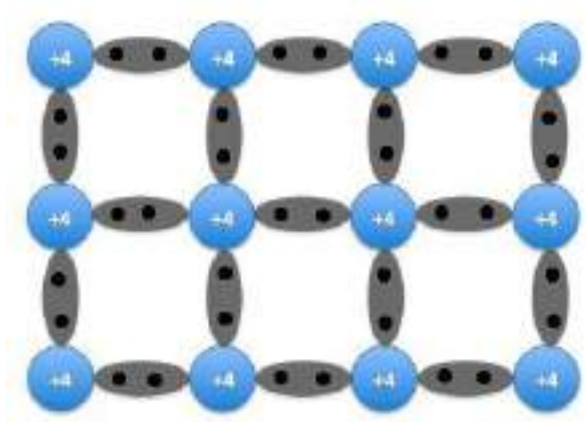
Here, the above figure clearly shows that a pentavalent impurity is doped to a pure silicon crystal. In this case, 4 electrons of phosphorus are covalently bonded with the adjacent silicon atom. But, still, a free electron is left in this case.

Thus, the movement of these free electrons generates high conduction. Also, when the temperature is increased then it causes the covalent bond to get a breakdown. Hence generating more free electrons.

So, this is the reason why an n-type extrinsic semiconductor has electrons as the majority charge carrier.

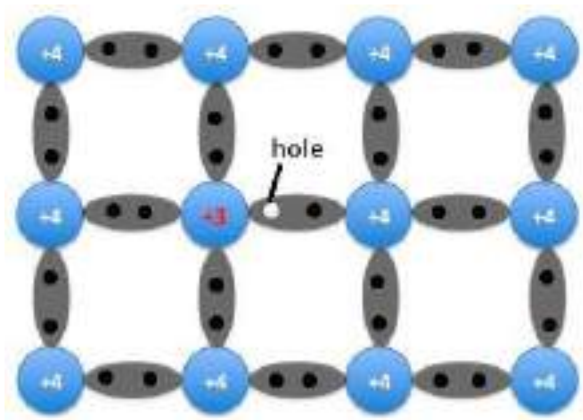
p-type

In a pure (intrinsic) Si or Ge semiconductor, each nucleus uses its four valence electrons to form four covalent bonds with its neighbors (see figure below). Each ionic core, consisting of the nucleus and non-valent electrons, has a net charge of +4, and is surrounded by 4 valence electrons. Since there are no excess electrons or holes In this case, the number of electrons and holes present at any given time will always be equal.



An intrinsic semiconductor. Note each +4 ion is surrounded by four electrons.

Now, if one of the atoms in the semiconductor lattice is replaced by an element with three valence electrons, such as a Group 3 element like Boron (B) or Gallium (Ga), the electron-hole balance will be changed. This impurity will only be able to contribute three valence electrons to the lattice, therefore leaving one excess hole (see figure below). Since holes will "accept" free electrons, a Group 3 impurity is also called an acceptor.

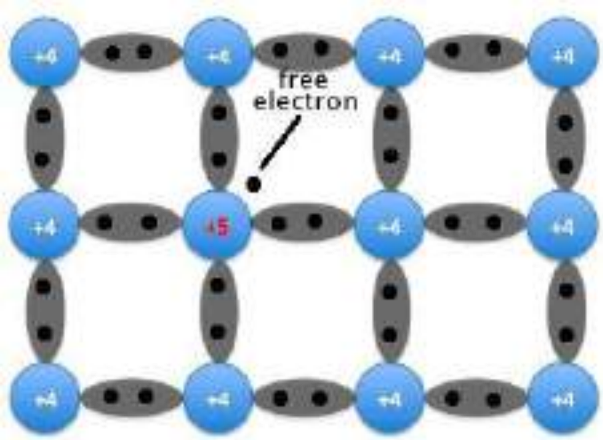


A semiconductor doped with an acceptor. An excess hole is now present.

Because an acceptor donates excess holes, which are considered to be positively charged, a semiconductor that has been doped with an acceptor is called a p-type semiconductor; "p" stands for positive. Notice that the material as a whole remains electrically neutral. In a p-type semiconductor, current is largely carried by the holes, which outnumber the free electrons. In this case, the holes are the majority carriers, while the electrons are the minority carriers.

n-type

In addition to replacing one of the lattice atoms with a Group 3 atom, we can also replace it by an atom with five valence electrons, such as the Group 5 atoms arsenic (As) or phosphorus (P). In this case, the impurity adds five valence electrons to the lattice where it can only hold four. This means that there is now one excess electron in the lattice (see figure below). Because it donates an electron, a Group 5 impurity is called a donor. Note that the material remains electrically neutral.



A semiconductor doped with a donor. A free electron is now present.

Donor impurities donate negatively charged electrons to the lattice, so a semiconductor that has been doped with a donor is called an n-type semiconductor; "n" stands for negative. Free electrons outnumber holes in an n-type material, so the electrons are the majority carriers and holes are the minority carriers.

What is P-N Junction?

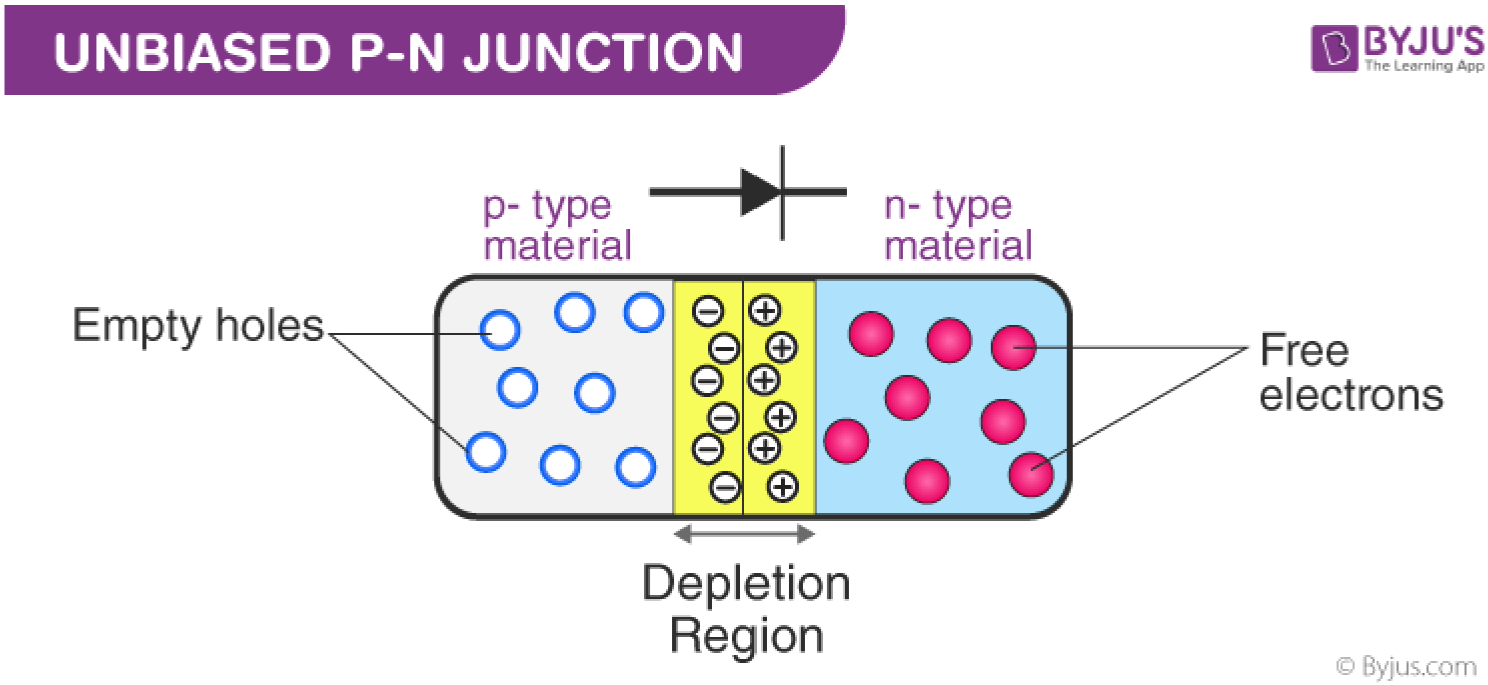
Definition: *A p-n junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.*

The p-side or the positive side of the semiconductor has an excess of holes and the n-side or the negative side has an excess of electrons. In a semiconductor, the p-n junction is created by the method of doping. The process of doping is explained in further details in the next section.

Formation of P N JunctionForward BiasReverse BiasP N Junction Formula

Formation of P-N Junction

As we know, if we use different semiconductor materials to make a p-n junction, there will be a grain boundary that would inhibit the movement of electrons from one side to the other by scattering the electrons and holes and thus we use the process of doping. We will understand the process of doping with the help of this example. Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si will get converted to n-type silicon. This sheet will now contain both p-type region and n-type region and a junction between these two regions. The processes that follow after the formation of a p-n junction are of two types – diffusion and drift. As we know, there is a difference in the concentration of holes and electrons at the two sides of a junction, the holes from the p-side diffuse to the n-side and the electrons from the n-side diffuse to the p-side. This gives rise to a diffusion current across the junction.



Also, when an electron diffuses from the n-side to the p-side, an ionized donor is left behind on the n-side, which is immobile. As the process goes on, a layer of positive charge is developed on the n-side of the junction. Similarly, when a hole goes from the p-side to the n-side, an ionized acceptor is left behind in the p-side, resulting in the formation of a layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as the depletion region. Due to this positive space charge region on either side of the junction, an electric field direction from positive charge towards the negative charge is developed. Due to this electric field, an electron on the p-side of the junction moves to the n-side of the junction. This motion is termed as the drift. Here, we see that the direction of drift current is opposite to that of the diffusion current.

Biasing conditions for the p-n Junction Diode

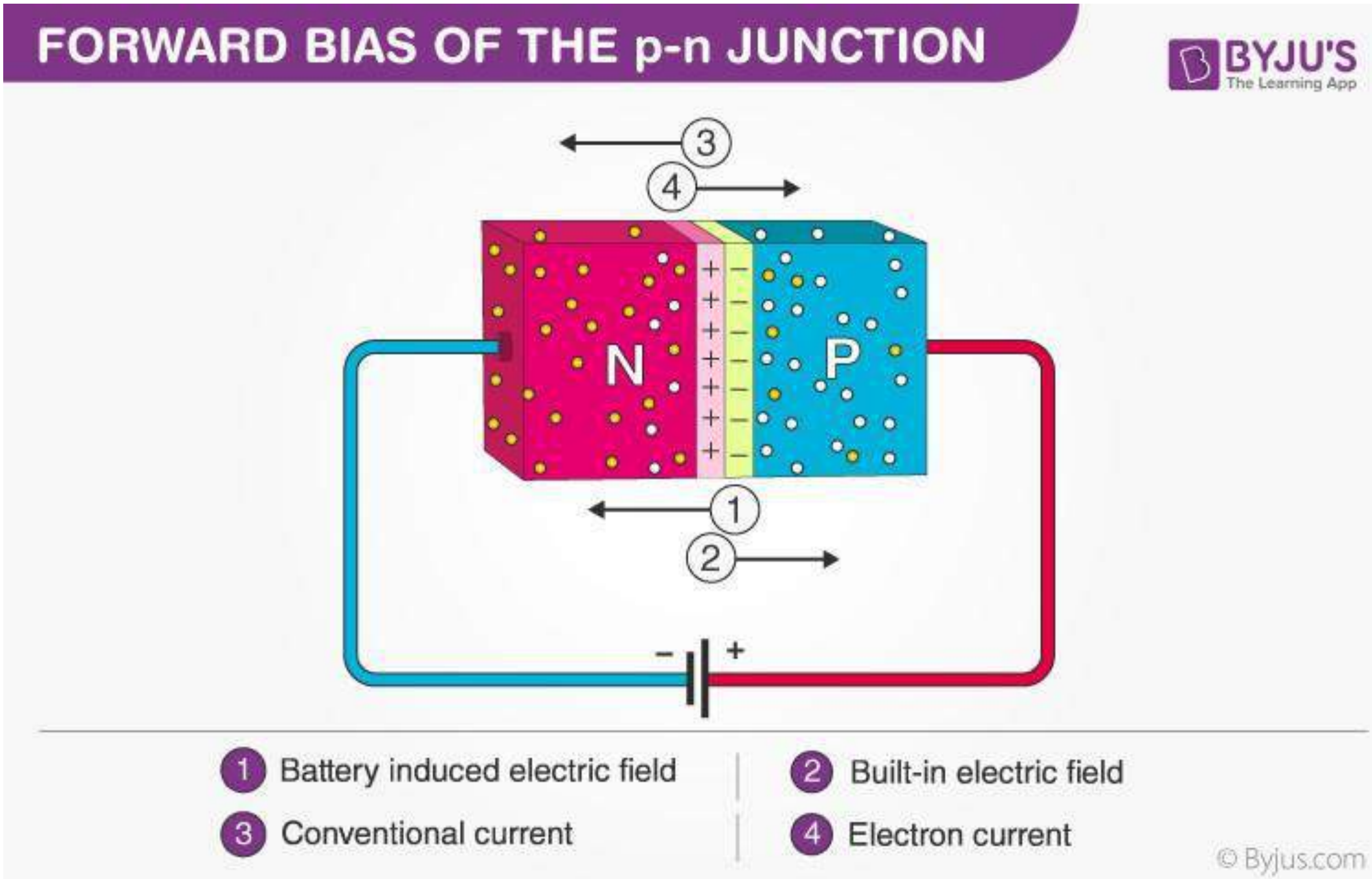
There are two operating regions in p-n junction diode:

- P-type
- N-type

There are three biasing conditions for p-n junction diode and this is based on the voltage applied:

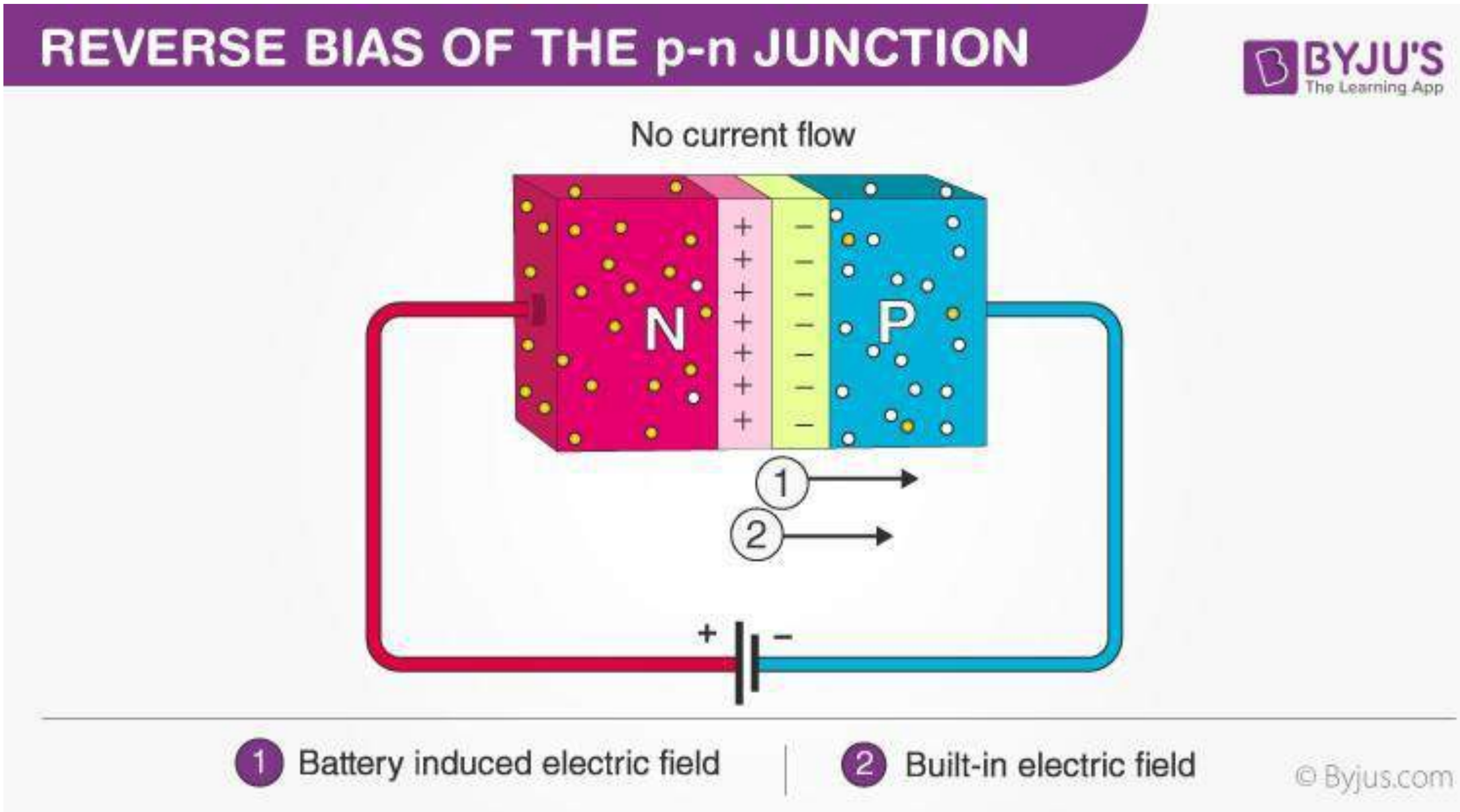
- Zero bias: There is no external voltage applied to the p-n junction diode.
- Forward bias: The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.
- Reverse bias: The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

Forward Bias



When the p-type is connected to the positive terminal of the battery and the n-type to the negative terminal then the p-n junction is said to be forward biased. When the p-n junction is forward biased, the built-in electric field at the p-n junction and the applied electric field are in opposite directions. When both the electric fields add up the resultant electric field has a magnitude lesser than the built-in electric field. This results in a less resistive and thinner depletion region. The depletion region's resistance becomes negligible when the applied voltage is large. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible and the current flows across it unimpeded.

Reverse Bias



When the p-type is connected to the negative terminal of the battery and the n-type is connected to the positive side then the p-n junction is said to be reverse biased. In this case, the built-in electric field and the applied electric field are in the same direction. When the two fields are added, the resultant electric field is in the same direction as the built-in electric field creating a more resistive, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.

What is P-N Junction?

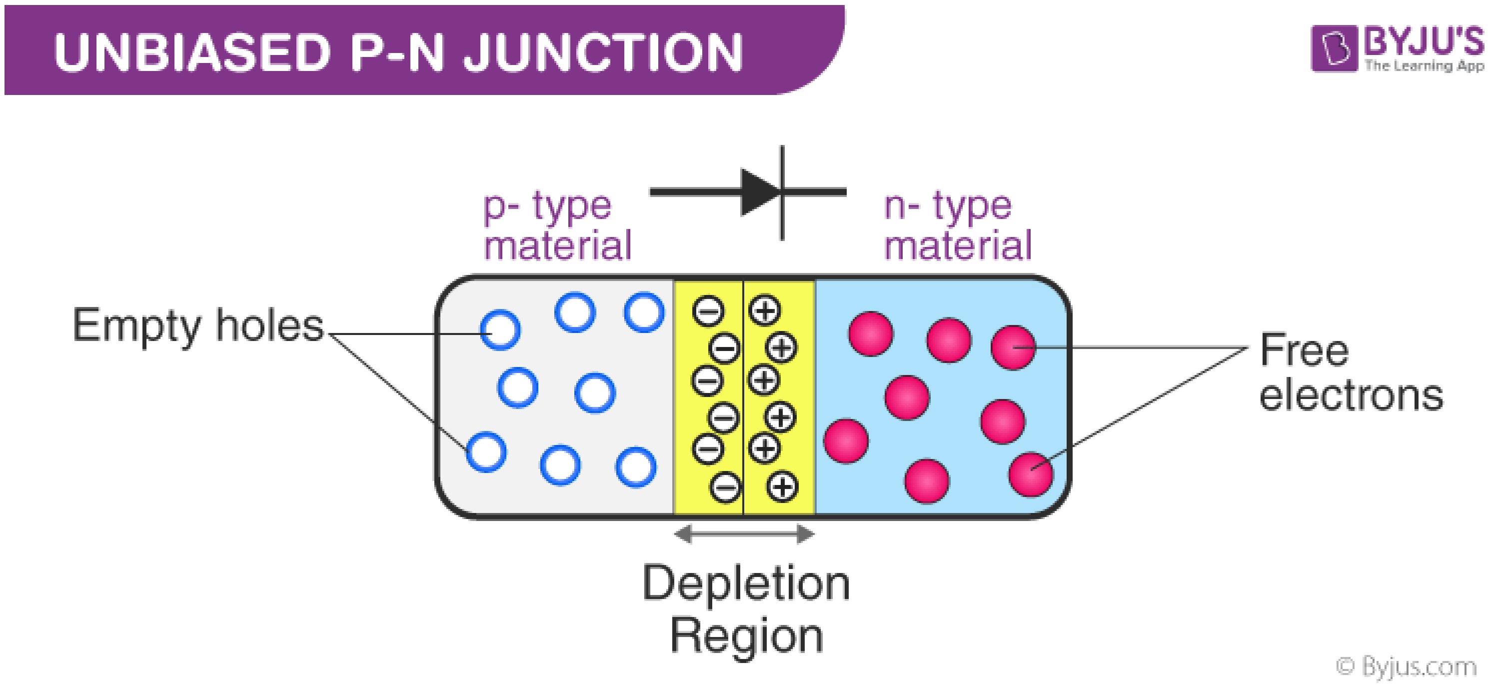
Definition: *A p-n junction is an interface or a boundary between two semiconductor material types, namely the p-type and the n-type, inside a semiconductor.*

The p-side or the positive side of the semiconductor has an excess of holes and the n-side or the negative side has an excess of electrons. In a semiconductor, the p-n junction is created by the method of doping. The process of doping is explained in further details in the next section.

Formation of P N JunctionForward BiasReverse BiasP N Junction Formula

Formation of P-N Junction

As we know, if we use different semiconductor materials to make a p-n junction, there will be a grain boundary that would inhibit the movement of electrons from one side to the other by scattering the electrons and holes and thus we use the process of doping. We will understand the process of doping with the help of this example. Let us consider a thin p-type silicon semiconductor sheet. If we add a small amount of pentavalent impurity to this, a part of the p-type Si will get converted to n-type silicon. This sheet will now contain both p-type region and n-type region and a junction between these two regions. The processes that follow after the formation of a p-n junction are of two types – diffusion and drift. As we know, there is a difference in the concentration of holes and electrons at the two sides of a junction, the holes from the p-side diffuse to the n-side and the electrons from the n-side diffuse to the p-side. This gives rise to a diffusion current across the junction.



Also, when an electron diffuses from the n-side to the p-side, an ionized donor is left behind on the n-side, which is immobile. As the process goes on, a layer of positive charge is developed on the n-side of the junction. Similarly, when a hole goes from the p-side to the n-side, an ionized acceptor is left behind in the p-side, resulting in the formation of a layer of negative charges in the p-side of the junction. This region of positive charge and negative charge on either side of the junction is termed as the depletion region. Due to this positive space charge region on either side of the junction, an electric field direction from positive charge towards the negative charge is developed. Due to this electric field, an electron on the p-side of the junction moves to the n-side of the junction. This motion is termed as the drift. Here, we see that the direction of drift current is opposite to that of the diffusion current.

Biasing conditions for the p-n Junction Diode

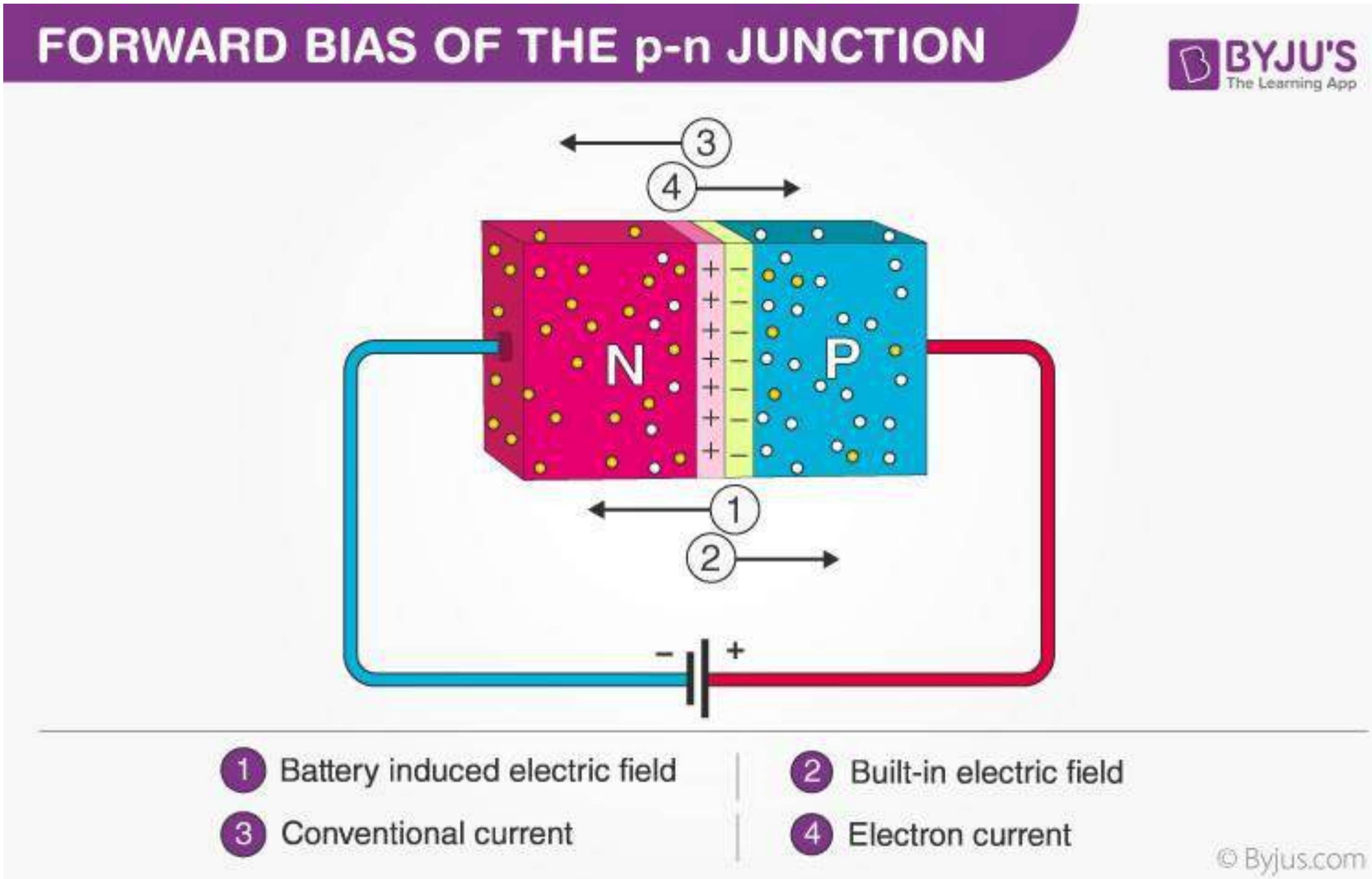
There are two operating regions in p-n junction diode:

- P-type
- N-type

There are three biasing conditions for p-n junction diode and this is based on the voltage applied:

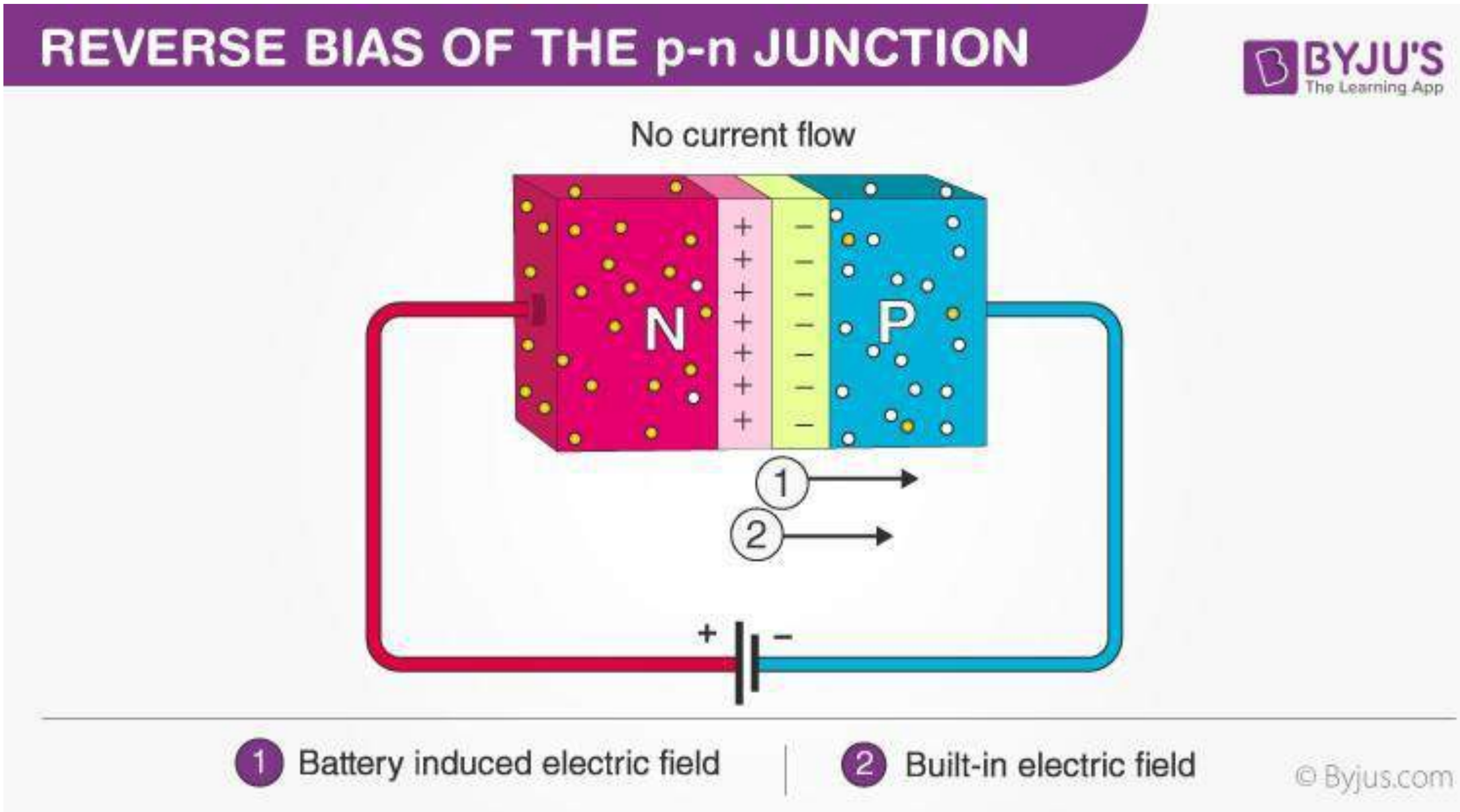
- Zero bias: There is no external voltage applied to the p-n junction diode.
- Forward bias: The positive terminal of the voltage potential is connected to the p-type while the negative terminal is connected to the n-type.
- Reverse bias: The negative terminal of the voltage potential is connected to the p-type and the positive is connected to the n-type.

Forward Bias



When the p-type is connected to the positive terminal of the battery and the n-type to the negative terminal then the p-n junction is said to be forward biased. When the p-n junction is forward biased, the built-in electric field at the p-n junction and the applied electric field are in opposite directions. When both the electric fields add up the resultant electric field has a magnitude lesser than the built-in electric field. This results in a less resistive and thinner depletion region. The depletion region's resistance becomes negligible when the applied voltage is large. In silicon, at the voltage of 0.6 V, the resistance of the depletion region becomes completely negligible and the current flows across it unimpeded.

Reverse Bias



When the p-type is connected to the negative terminal of the battery and the n-type is connected to the positive side then the p-n junction is said to be reverse biased. In this case, the built-in electric field and the applied electric field are in the same direction. When the two fields are added, the resultant electric field is in the same direction as the built-in electric field creating a more resistive, thicker depletion region. The depletion region becomes more resistive and thicker if the applied voltage becomes larger.

P-N Junction Formula

The formula used in the p-n junction depends upon the built-in potential difference created by the electric field is given as:

$$E_0=V_T\ln\left[\frac{N_D.N_A}{n_i^2}\right]$$

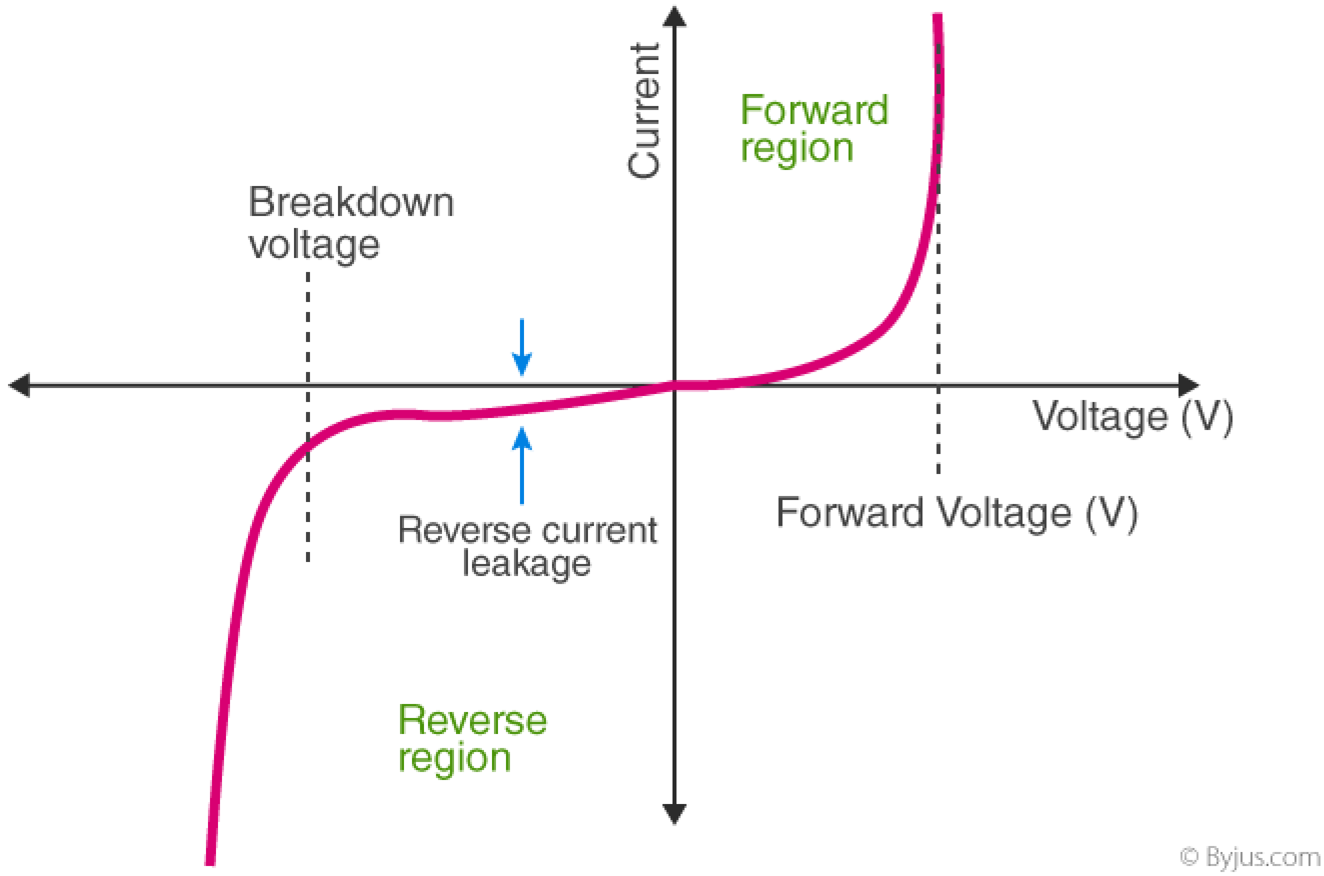
Where,

- E_0 is the zero bias junction voltage
- V_T is the thermal voltage of 26mV at room temperature
- N_D and N_A are the impurity concentrations
- n_i is the intrinsic concentration.

How does current flow in pn junction diode?

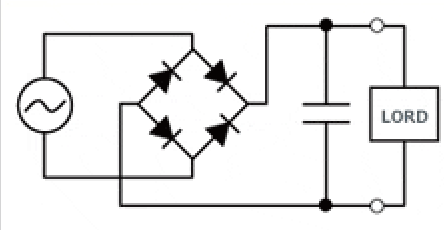
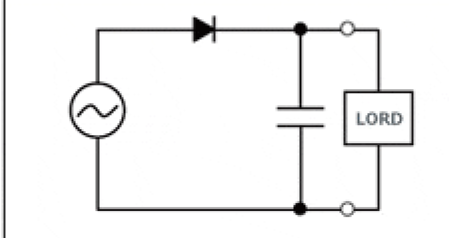
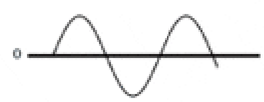
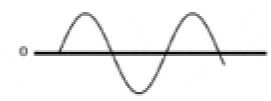
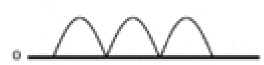
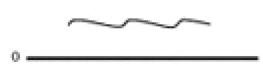
The flow of electrons from n-side towards p-side of the junction takes place when there is increase in the voltage. Similarly, flow of holes from p-side towards n-side of the junction takes place along with the increase in the voltage. This results in the concentration gradient between on both the sides of the terminals. Because of formation of concentration gradient, there will be flow of charge carriers from higher concentration region to lower concentration region. The movement of charge carriers inside the pn junction is the reason behind current flow in the circuit.

V-I Characteristics of PN Junction Diode



Full-Wave and Half-Wave Rectification

Rectification methods to convert AC (Alternating Current) to DC (Direct Current) include full-wave rectification and half-wave rectification. In both cases, rectification is performed by utilizing the characteristic that current flows only in the positive direction in a diode.

	Full-Wave Rectification	Half-Wave Rectification
Circuit Configuration		
Input Voltage Waveform		
Voltage Waveform After Rectification		
Voltage Waveform After Rectification Smoothing		

Full-wave rectification rectifies the negative component of the input voltage to a positive voltage, then converts it into DC (pulse current) utilizing a diode bridge configuration. In contrast, half-wave rectification removes just the negative voltage component using a single diode before converting to DC.
Afterward, the waveform is smoothed by charging/discharging a capacitor, resulting in a clean DC signal.
From this, it can be said that full-wave rectification is a more efficient method than half-wave rectification since the entire waveform is used.
Also, a ripple voltage that appears after smoothing will vary depending on the capacitance of this capacitor and the load.
Given the same capacitance and load, ripple voltage is smaller with full-wave rectification than haif-wave rectification. Of course it goes without saying that the smaller the ripple voltage the better the stability.

Transistor Characteristics

In physics, the graph representing the relationships between the current and the voltage of any transistor of any configuration is called Transistor Characteristics. Any two-port network which is analogous to transistor configuration circuits can be analysed using three types of characteristic curves. They are

- Input Characteristics: The curve describes the changes in the values of input current with the variation in the values of input voltage keeping the output voltage constant.
- Output Characteristics: The curve is got by plotting the output current against output voltage keeping the input current constant.
- Current Transfer Characteristics: This characteristic curve describes the variation of output current in accordance with the input current, keeping the output voltage constant.

Configuration Of Transistor

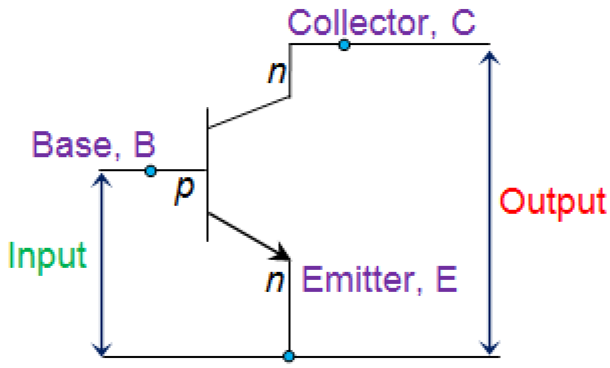
Any transistor circuit can be designed using three types of configuration. Three configurations of the transistor are based on the connection of the transistor terminal. The three types of transistor circuit configurations are:

- Common Emitter Transistor
- Common Base Transistor
- Common Collector Transistor(emitter follower).

Each of these three circuit configurations has its own characteristics curve. Based on the requirement the type will be chosen for the circuit.

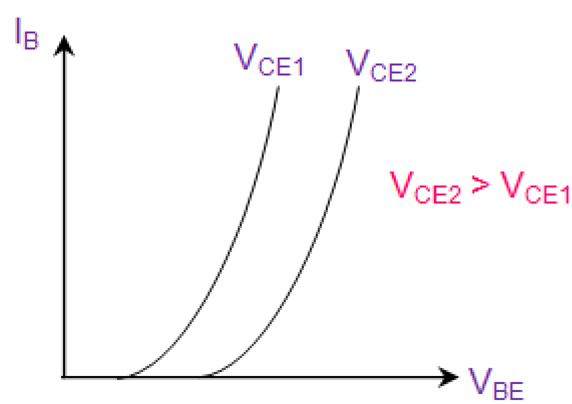
Common Emitter (CE) Configuration of Transistor

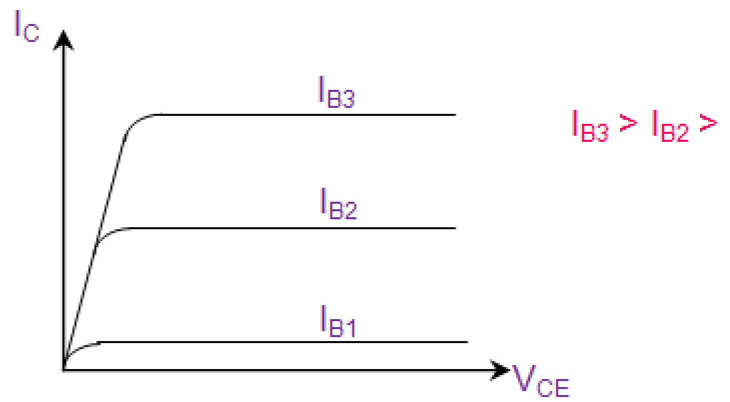
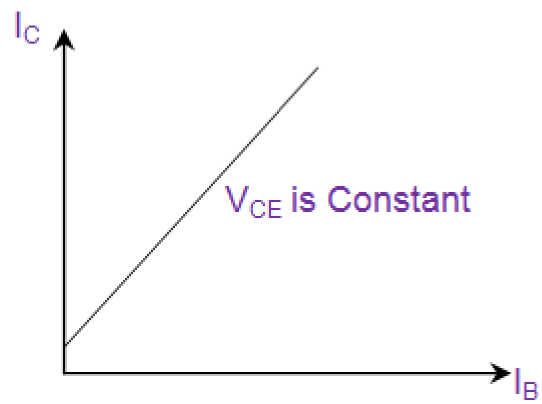
In CE Configuration, the Emitter terminal of the transistor will be connected common between the output and the input terminals.



Common Emitter (CE) Configuration of Transistor

The transistor characteristic under Common Emitter configuration is as follows:

Transistor Characteristics	**Definition**	**Formula/Expression**	**Characteristic Curve**
Input Characteristics	The variation of emitter current(I_B) with Base-Emitter voltage(V_{BE}), keeping Collector Emitter voltage(V_{CE}) constant.	$R_{in}=\Delta V_{BE}\Delta I_B \vert V_{CE}=Constant$	

Output Characteristics	The variation of collector current(I_C) with Collector-Emitter voltage(V_{CE}), keeping the base current(I_B) constant.	$R_{out}=\Delta V_{CE}\Delta I_C\|I_B=$Constant	
Current Transfer Characteristics	The variation of collector current(I_C) with the base current(I_B), keeping Collector-Emitter voltage(V_{CE}) constant. The resulting current gain has a value greater than 1.	$\alpha=\Delta I_C\Delta I_B\|V_{CB}=$Constant	

Reference pages

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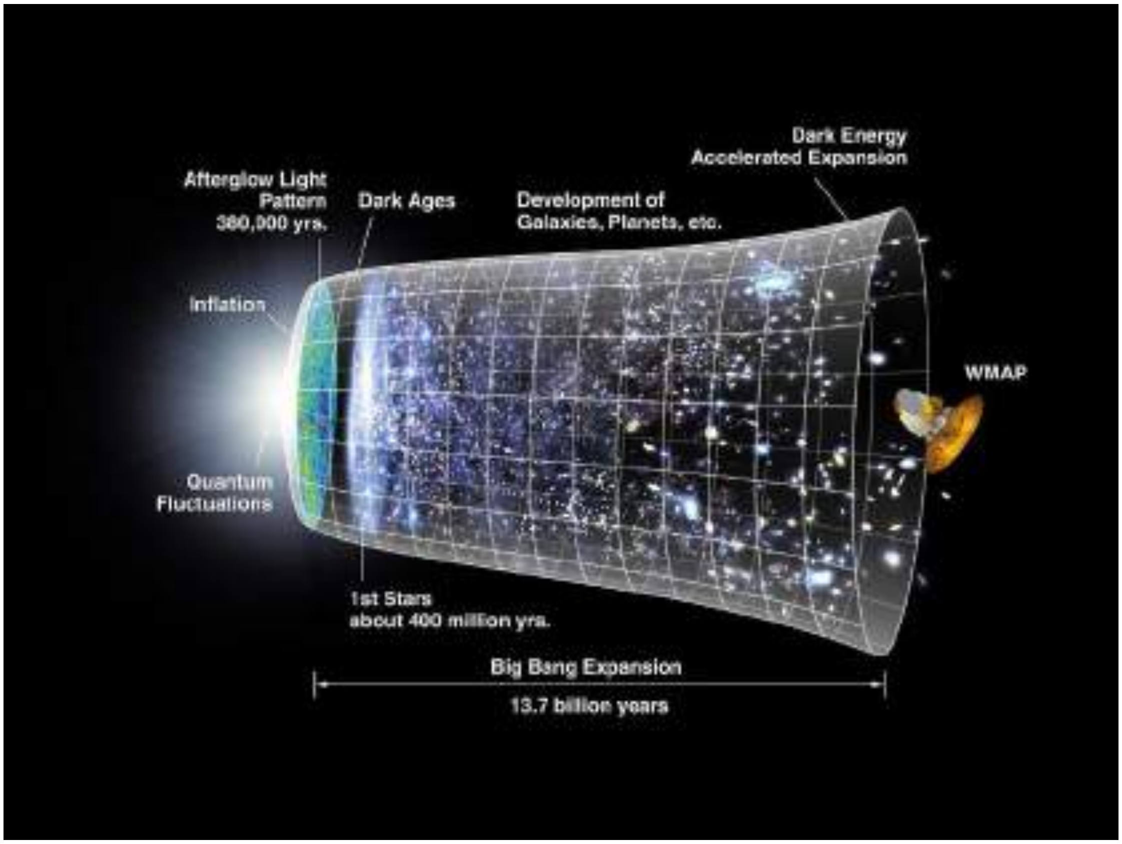
https://eng.libretexts.org/Bookshelves/Materials_Science/Supplemental_Modules_(Materials_Science)/Solar_Basics/D._P-N_Junction_Diodes/I._P-Type%2C_N-Type_Semiconductors

https://byjus.com/physics/p-n-junction/

https://www.rohm.com/electronics-basics/ac-dc/rectification#:~:text=Full%2Dwave%20rectification%20rectifies%20the,diode%20before%20converting%20to%20DC.

Unit # 18

DAWN OF MODERN PHYSICS

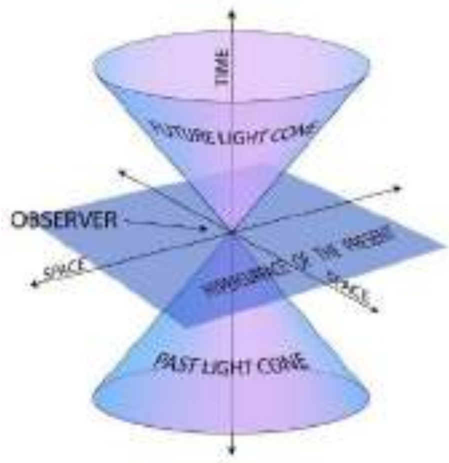


TOPICS	UNDERSTANDING	SKILLS
• Special theory of relativity • Quantum theory of radiation • Photoelectric effect • Compton's effect • Pair production and pair annihilation • Wave nature of particles • Electron microscope • Uncertainty Principle	• distinguish between inertial and non-inertial frames of reference . • describe the significance of Einstein's assumption of the constancy of the speed of light. • identify that if c is constant then space and time become relative. • explain qualitatively and quantitatively the consequence of special relativity in relation to: – the relativity of simultaneity – the equivalence between mass and energy – length contraction Conceptual linkage: This chapter is built on Planck's quantum theory Chemistry XI Resolving power, Magnifying power of microscope Physics IX – time dilation – mass increase • explain the implications of mass increase, time dilation and length contraction for space travel. • describe the concept of black body radiation.	• investigate the variation of electric current with intensity of incident light on a photocell. • determine Planck's constant using internal potential barrier of different light emitting diodes.

	• describe how energy is distributed over the wavelength range for several values of source temperature. • describe the Planck's hypothesis that radiation emitted and absorbed by the walls of a black body cavity is quantized. • elaborate the particle nature of electromagnetic radiation. • describe the phenomenon of photoelectric effect. • solve problems and analyses information using: $E = h f$ and $c = f \lambda$. • identify data sources, gather, process and present information to summarize the use of the photoelectric effect in solar cells & photocells • describe the confirmation of de Broglie's proposal by Davisson and Germen experiment in which the diffraction of electrons by the surface layers of a crystal lattice was observed. • describe the impact of de Broglie's proposal that any kind of particle has both wave and particle properties. • explain the particle model of light in terms of photons with particular energy and frequency. • describe Compton effect qualitatively. • explain the phenomena of pair production and pair annihilation. • explain how the very short wavelength of electrons, and the ability to use electrons and magnetic fields to focus them, allows electron microscope to achieve very high resolution. • describe uncertainty principle.	

Unit overview

01.Special theory of relativity



CONSEQUENCES OF SPECIAL THEORY OF RELATIVITY

We observe that in the development of special theory of relativity,frames of reference in relative motion with a constant speed **V** have been used. If the speed **V** becomes large enough to approach the velocity of light **C**, then the Galilean's transformations are found to be noticeably wrong. To correct the state of affairs it will be necessary to introduce a factor called 'Lorentz Factor' or 'Relativistic factor'.

Lorentz Factor is equal to: $\sqrt{1-\frac{v^2}{c^2}}$

This factor is in fact a measure of departure of Galilean's transformation. If $\frac{v}{c}$ is much smaller than as it is in our common situations,then $\frac{v^2}{c^2}$ is so small that the relativistic factor is essentially equal to unity. Under these conditions the classical and the relativistic physics predict nearly identical results. However when **V** approaches **c** (e.g.: V = C/5), Then the Galilean transformation will be incorrect. Based on these considerations, if we interpret the result of special theory of relativity we end up in some very interesting consequences. Without going to make actual mathematical calculation, We may summarize the important consequences of the theory of special relativity which are as under:

According to the special theory of relativity, the mass of an object in a frame of reference at rest is called its rest mass mo. if this mass is measured by an observation moving with a constant speed V relative to the object, then it will not remain constant if the speed V is comparable to C. The mass m in the moving frame will very according to the mass variation given by:

$$m = \frac{m_o}{\sqrt{1-\frac{v^2}{c^2}}}$$

Where
m = mass of object in motion
m_o = rest mass of object

This mass variation formula shows that mass changes with the velocity and not in general a constant nor the same for all observes but it is quantity that:
(a) depend upon the reference frame from which the body is being observed.
(b) is greater then or equal to the rest mass mo when the body is at rest in the frame of reference from which the body is being observed.

LENGTH CONTRACTION

In the theory of special relativity it has been found that the measurement of length of a rod in a stationary frame of reference is not the same when the rod is measured by the observer in the moving frame of reference with the velocity relative to the rod, provided the measurement is made along the direction of motion.
Hence, if L_o is the length of rod in the frame at rest, and L is the length of same rod in the moving frame, then:

$$l = l_o \sqrt{1 - \frac{v^2}{c^2}}$$

where

l_o= length of object in rest
l = length of object in motion

Since v/c is less then unity, the length L is less then L_o i.e. there is a contraction in length along the direction of motion. This is called the Lorentz-Fitzgerald contraction.
above equation tells us that an observer past whom a system is moving with a speed **v** measures object in the moving system to be shortened in length along the direction of motion by a factor:

$$\sqrt{1 - \frac{v^2}{c^2}}$$

It is important to note that only the dimension along the line of motion is changed and there is no change in the other two perpendicular directions. With the development of special theory of relativity it became apparent that there is no physical contraction of the moving objects. There is, however, an apparent contraction of body for an observer where there is a relative motion of the object and the observer. In the natural sense the observer in moving frame can not detect the contraction because in this frame it does not exist; where is in the rest frame, it does exist, but the measuring rod in the moving system has shrunk too further we must note that for moderate velocities ($v/c<<1$)of the objects the contraction in length is negligible as observed in our every day observation.

TIME DILATION

Time is regarded as an absolute quantity in classical mechanics whereas in the special theory of relativity it is considered to be a relative entity based on the measurement of time in frame of references in relative motion.
The time interval between two events taking place at the same point in space as timed with a clock at rest with respect to that point is called the proper time interval and is denoted $\Delta t_o = T_o$.Time measured with a clock in motion with respect to the events is known as relativistic time it is represented by $\Delta t = T$. Both of the time intervals T_o & **T** refer to the time elapsed between the same pair of events occurring in the two frames moving with a relative speed **v**. then, according to special relativity the two times are related by the formula:

$$T = \frac{T_o}{\sqrt{1 - \frac{v^2}{c^2}}}$$

Where
T = Time in motion
T_o = Time at rest

Above equation represents , what we call as the time dilation phenomena. According to the time dilation formula we mean that from the point of view of an observer at rest, the time of the observer in motion is dilated i.e. the clocks in moving frame run slowly and the Lorentz factor

$$\sqrt{1 - \frac{v^2}{c^2}}$$

Gives us the ratio of the rates of clocks for normal speeds, this factor is so close to unity (1.00) that we are quite unable to detect time dilation effect, but for speed comparable to the speed of light **c** the time dilation effect is quite significant.

We can now conclude that for every observer his own clock in his frame of reference run faster than do any other clocks which are moving relative to him. We may also note that every observer may consider himself to be at rest and consider all that moves as moving relative to him. This is actually an outcome of the principle of special relativity stated earlier: Every observer is equivalent to every other observer.

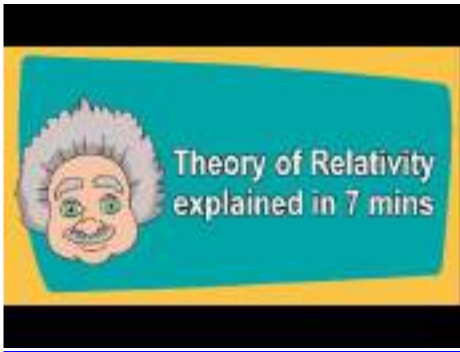
MASS ENERGY RELATION

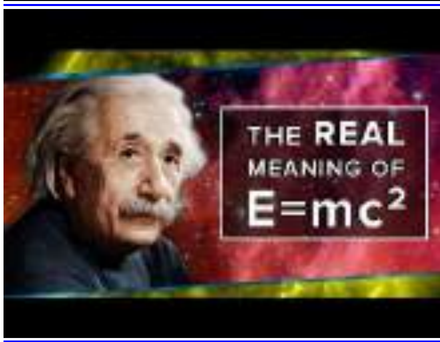
In the beginning of this section we have stated the postulates of relativity that the speed of light is a universal constant. We can not reach speeds greater than the speed of light by the relativistic addition of velocities. The equation is how to reconcile with this result of special relativity with Newton's second law, F=ma? It would be seen that any constant force, no matter how small, applied for a considerably very long time, should continuously accelerate any mass 'm' at a rate a=f/m until the speed was arbitrarily very large. Einstein, concluded that energy has inertia i.e. the more energy a body possess, the more inertia that body will display. Since, inertia is a property of matter, which is associated with mass. Thus from Einstein's argument mass is simply a property attributed to the total energy of the body and only the total energy is required, to know the total mass of the body . Thus, in special theory of relativity total energy and mass are related by the famous Einstein's equation.

$$\mathbf{E=mc^2}$$

From this relation between mass and energy it has been predicted that any process that changed the mass by a detectable amount would involve huge amounts of energy. For example, a mass change of 1.00 gram is equal to an energy change of 9×10^{13} joules.

VIDEO LINK:





02.Quantum theory of radiation

INTRODUCTION:

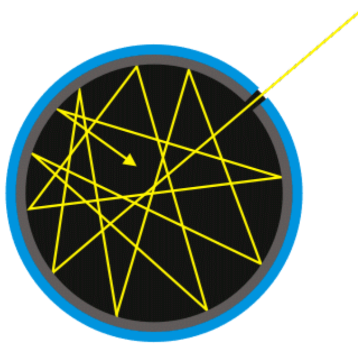
In physics, electromagnetic radiation (EM radiation or EMR) refers to the waves (or their quanta, photons) of the electromagnetic field, propagating (radiating) through space, carrying electromagnetic radiant energy. It includes radio waves, microwaves, infrared, (visible) light, ultraviolet, X-rays, and gamma rays.

Classically, electromagnetic radiation consists of electromagnetic waves, which are synchronized oscillations of electric and magnetic fields. In a vacuum, electromagnetic waves travel at the speed of light, commonly denoted *c*. In homogeneous, isotropic media, the oscillations of the two fields are perpendicular to each other and perpendicular to the direction of energy and wave propagation, forming a transverse wave. The wavefront of electromagnetic waves emitted from a point source (such as a light bulb) is a sphere. The position of an electromagnetic wave within the electromagnetic spectrum can be characterized by either its frequency of oscillation or its wavelength. Electromagnetic waves of different frequency are called by different names since they have different sources and effects on matter. In order of increasing frequency and decreasing wavelength these are: radio waves, microwaves, infrared radiation, visible light, ultraviolet radiation, X-rays and gamma rays.

Electromagnetic waves are emitted by electrically charged particles undergoing acceleration,and these waves can subsequently interact with other charged particles, exerting force on them. EM waves carry energy, momentum and angular momentum away from their source particle and can impart those quantities to matter with which they interact. Electromagnetic radiation is associated with those EM waves that are free to propagate themselves ("radiate") without the continuing influence of the moving charges that produced them, because they have achieved sufficient distance from those charges. Thus, EMR is sometimes referred to as the far field. In this language, the near field refers to EM fields near the charges and current that directly produced them, specifically electromagnetic induction and electrostatic induction phenomena.

In quantum mechanics, an alternate way of viewing EMR is that it consists of photons, uncharged elementary particles with zero rest mass which are the quanta of the electromagnetic force, responsible for all electromagnetic interactions. Quantum electrodynamics is the theory of how EMR interacts with matter on an atomic level. Quantum effects provide additional sources of EMR, such as the transition of electrons to lower energy levels in an atom and black-body radiation. The energy of an individual photon is quantized and is greater for photons of higher frequency. This relationship is given by Planck's equation $E = hf$, where E is the energy per photon, f is the frequency of the photon, and h is Planck's constant. A single gamma ray photon, for example, might carry ~100,000 times the energy of a single photon of visible light.

Blackbody Radiation:



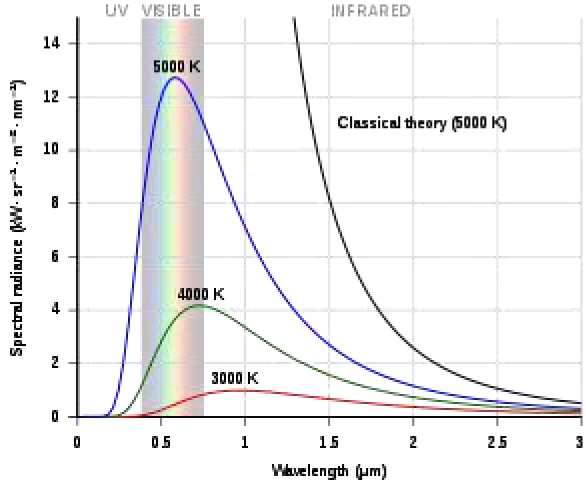
Conceptual Black Body

Black-body radiation is the thermal electromagnetic radiation within or surrounding a body in thermodynamic equilibrium with its environment, emitted by a black body (an idealized opaque, non-reflective body). It has a specific spectrum of wavelengths, inversely related to intensity that depend only on the body's temperature, which is assumed for the sake of calculations and theory to be uniform and constant

The thermal radiation spontaneously emitted by many ordinary objects can be approximated as black-body radiation. A perfectly insulated enclosure that is in thermal equilibrium internally contains black-body radiation and will emit it through a hole made in its wall, provided the hole is small enough to have a negligible effect upon the equilibrium

In a dark room, a black body at room temperature appears black because most of the energy it radiates is in the infrared spectrum and cannot be perceived by the human eye. Since the human eye cannot perceive light waves below the visible frequency, a black body at the lowest just faintly visible temperature subjectively appears grey, even though its objective physical spectrum peak is in the infrared range. The human eye perceives only black and white at low light levels as the light-sensitive retinal rods are more sensitive than cones. When the object becomes a little hotter, it appears dull red. As its temperature increases further it becomes bright red, orange, yellow, white, and ultimately blue-white.

Wien's displacement law



Wien's displacement law states that the black-body radiation curve for different temperatures will peak at different wavelengths that are inversely proportional to the temperature. The shift of that peak is a direct consequence of the Planck radiation law, which describes the spectral brightness of black-body radiation as a function of wavelength at any given temperature. However, it had been discovered by Wilhelm Wien several years before Max Planck developed that more general equation, and describes the entire shift of the spectrum of black-body radiation toward shorter wavelengths as temperature increases.

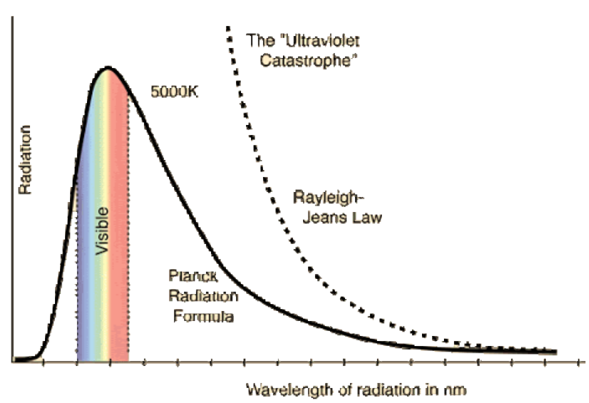
Formally, Wien's displacement law states that the spectral radiance of black-body radiation per unit wavelength, peaks at the wavelength λ_{peak} given by:

$$\lambda_{\mathrm{peak}} = \frac{b}{T}$$

Rayleigh-Jeans Law

a law expressing the energy distribution in the spectrum of a blackbody as a function of temperature. The Rayleigh-Jeans law may be written in the form

$$u_\nu = \frac{8\pi\nu^2}{c^3} kT$$

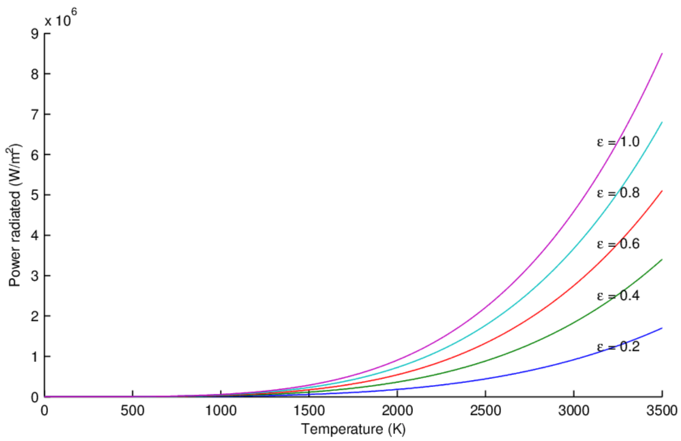


where u_ν is the radiation density corresponding to the frequency *ν*, *c* is the speed of light, *T* is the absolute temperature, and *k* is the Boltzmann constant.

The Rayleigh-Jeans law was derived in 1900 by Lord Rayleigh from classical concepts of the uniform distribution of energy with respect to degrees of freedom. In work conducted between 1905 and 1909, J. Jeans applied the methods of classical statistical mechanics to standing waves in a cavity and arrived at the same equation as Rayleigh.

The Rayleigh-Jeans law of radiation is in good agreement with experiment only for small v—that is, for long wavelengths. According to the law, as v increases, the radiant energy should increase without bound. In the far ultraviolet and in still shorter-wavelength regions of the spectrum, the density of radiant energy should reach extremely large values, a situation called the ultraviolet catastrophe. This prediction, however, is inconsistent with experiment. A blackbody energy distribution valid for the entire spectrum can be obtained only on the basis of quantum concepts (*see* PLANCK'S RADIATION LAW). The Rayleigh-Jeans law is a special case of Planck's law for small v and can be used instead of Planck's law when radiation at sufficiently long wavelengths is being considered and when high accuracy of calculation is not required.

Stefan-Boltzmann law:



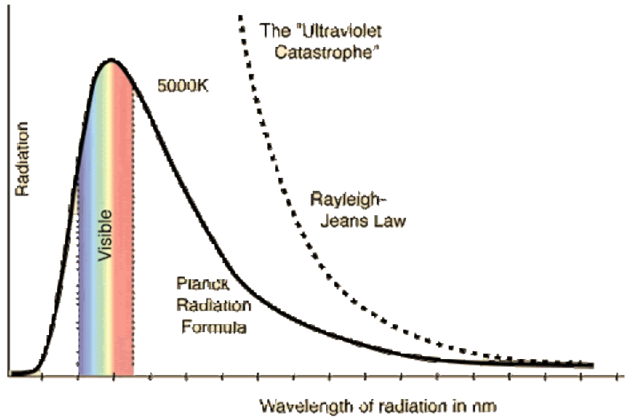
statement that the total radiant heat power emitted from a surface is proportional to the fourth power of its absolute temperature. Formulated in 1879 by Austrian physicist Josef Stefan as a result of his experimental studies, the same law was derived in 1884 by Austrian physicist Ludwig Boltzmann from thermodynamic considerations: if E is the radiant heat energy emitted from a unit area in one second (that is, the power from a unit area) and T is the absolute temperature (in kelvins),

then

$$E = \sigma T^4$$

the Greek letter sigma (σ) representing the constant of proportionality, called the Stefan-Boltzmann constant. This constant has the value $5.670374419 \times 10^{-8}$ watt per metre^2 per K^4. The law applies only to blackbodies, theoretical surfaces that absorb all incident heat radiation.

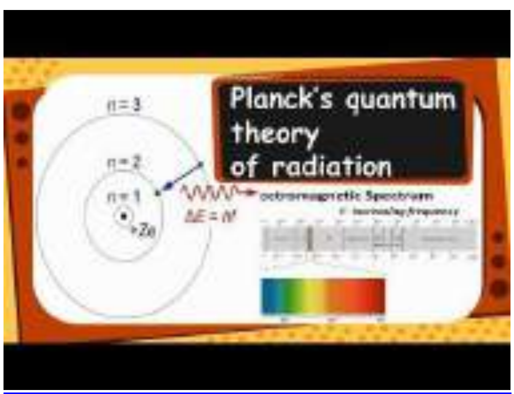
Planck's radiation law

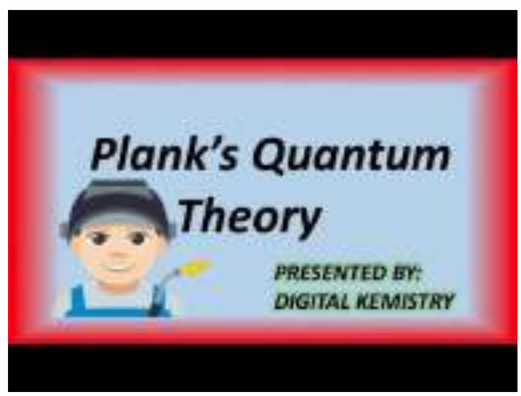


A mathematical relationship formulated in 1900 by German physicist Max Planck to explain the spectral-energy distribution of radiation emitted by a blackbody (a hypothetical body that completely absorbs all radiant energy falling upon it, reaches some equilibrium temperature, and then reemits that energy as quickly as it absorbs it). Planck assumed that the sources of radiation are atoms in a state of oscillation and that the vibrational energy of each oscillator may have any of a series of discrete values but never any value between. Planck further assumed that when an oscillator changes from a state of energy E_1 to a state of lower energy E_2, the discrete amount of energy $E_1 - E_2$, or quantum of radiation, is equal to the product of the frequency of the radiation, symbolized by the Greek letter ν and a constant h, now called Planck's constant, that he determined from blackbody radiation data; i.e.,

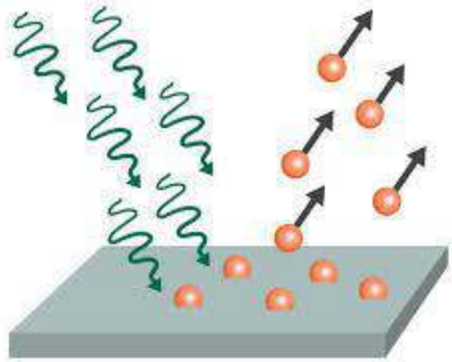
$$E_1 - E_2 = h\nu$$

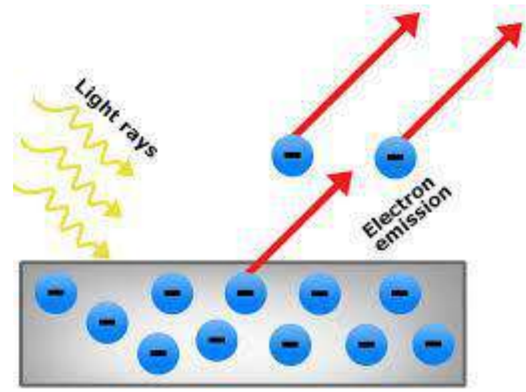
Video link:

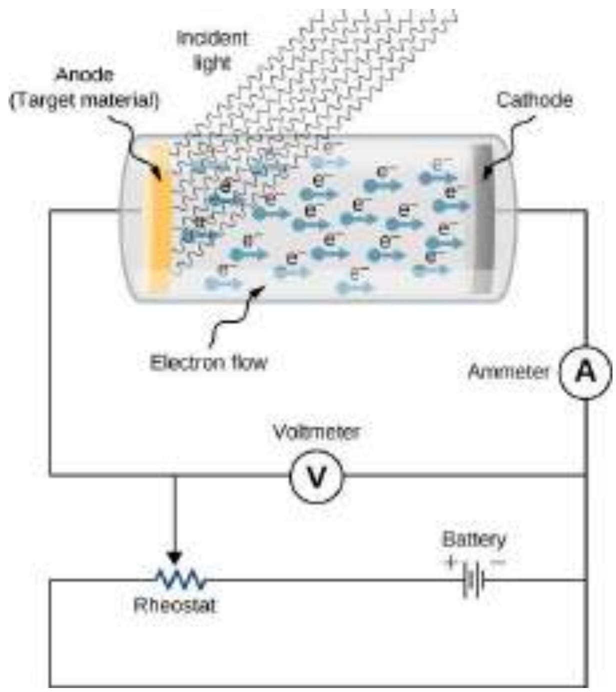




03.Photoelectric effect:







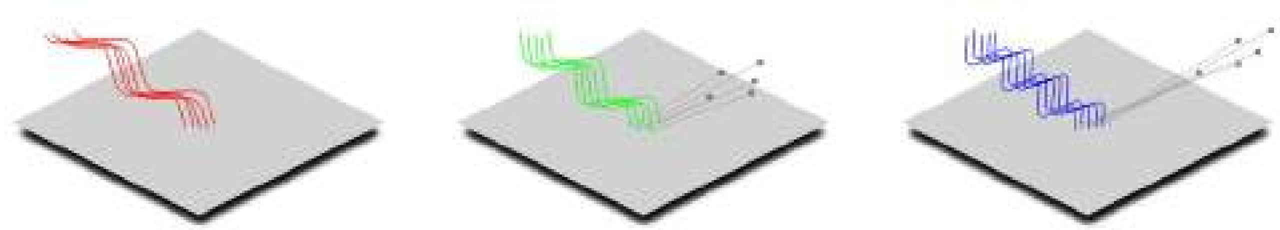
Under the right circumstances light can be used to push electrons, freeing them from the surface of a solid. This process is called the photoelectric effect (*or* photoelectric emission *or* photoemission), a material that can exhibit this phenomena is said to be photo emissive, and the ejected electrons are called photoelectrons*;* but there is nothing that would distinguish them from other electrons. All electrons are identical to one another in mass, charge, spin, and magnetic moment.

Knocking electrons free from the photo emissive plate would give it a slight positive charge. Since the second plate was connected to the first by the wiring of the circuit, it too would become positive, which would then attract the photoelectrons floating freely through the vacuum where they would land and return back to the plate from which they started. Keep in mind that this experiment doesn't create electrons out of light, it just uses the energy in light to push electrons that are already there around the circuit. The photoelectric current generated by this means was quite small, but could be measured with the micro ammeter (a sensitive galvanometer with a maximum deflection of only a few micro amps). It also serves as a measure of the rate at which photoelectrons are leaving the surface of the photo emissive material.

Note how the power supply is wired into the circuit — with its negative end connected to the plate that isn't illuminated. This sets up a potential difference that tries to push the photoelectrons back into the photo emissive surface. When the power supply is set to a low voltage it traps the least energetic electrons, reducing the current through the micro ammeter. Increasing the voltage drives increasingly more energetic electrons back until finally none of them are able to leave the metal surface and the micro ammeter reads zero. The potential at which this occurs is called the stopping potential. It is a measure of the maximum kinetic energy of the electrons emitted as a result of the photoelectric effect.

What Lenard found was that the intensity of the incident light had no effect on the maximum kinetic energy of the photoelectrons. Those ejected from exposure to a very bright light had the same energy as those ejected from exposure to a very dim light *of the same frequency*. In keeping with the law of conservation of energy, however, more electrons were ejected by a bright source than a dim source.

Later experiments by others, most notably the American physicist Robert Millikan in 1914, found that light with frequencies below a certain cutoff value, called the threshold frequency, would not eject photoelectrons from the metal surface no matter how bright the source was. These result were completely unexpected. Given that it is possible to move electrons with light and given that the energy in a beam of light is related to its intensity, classical physics would predict that a more intense beam of light would eject electrons with greater energy than a less intense beam no matter what the frequency. This was not the case, however.



Red light does not eject photoelectrons (even if it is very bright).

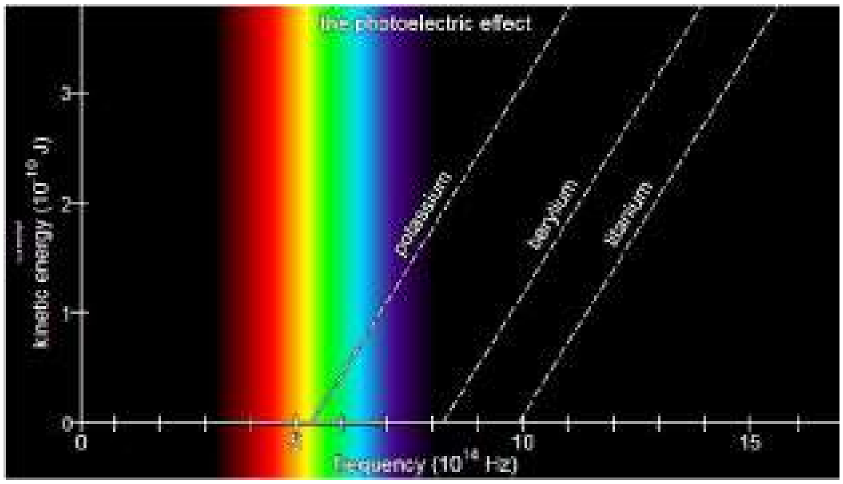
Green light does eject photoelectrons (even if it is very dim).

Blue light ejects photoelectrons with more energy than green light (even if it is very dim).

Actually, maybe these results aren't all that typical. Most elements have threshold frequencies that are ultraviolet and only a few dip down low enough to be green or yellow like the example shown above. The materials with the lowest threshold frequencies are all semiconductors. Some have threshold frequencies in the infrared region of the spectrum.

New idea

The two factors affecting maximum kinetic energy of photoelectrons are the frequency of the incident radiation and the material on the surface. As shown in the graph below, electron energy increases with frequency in a simple linear manner above the threshold. All three curves have the same slope (equal to Planck's constant) which shows that the energy-frequency relation is constant for all materials. Below the threshold frequency photoemission does not occur. Each curve has a different intercept on the energy axis, which shows that threshold frequency is a function of the material.



Equations

Einstein and Millikan described the photoelectric effect using a formula (in contemporary notation) that relates the maximum kinetic energy (K_{max}) of the photoelectrons to the frequency of the absorbed photons (f) and the threshold frequency (f_0) of the photo emissive surface.

$$K_{max} = h(f - f_0)$$

or if you prefer, to the energy of the absorbed photons (E) and the *work function* (φ) of the surface

$$K_{max} = E - \varphi$$

where the first term is the energy of the absorbed photons (E) with frequency (f) or wavelength (λ)

$$E = hf = \frac{hc}{\lambda}$$

and the second term is the work function (φ) of the surface with threshold frequency (f_0) or threshold wavelength (λ_0)

$$\varphi = hf_0 = \frac{hc}{\lambda_0}$$

The maximum kinetic energy (K_{max}) of the photoelectrons (with charge e) can be determined from the stopping potential (V_0).

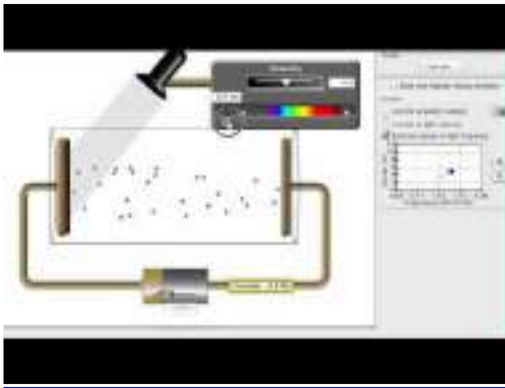
$$V_0 = \frac{W}{q} = \frac{K_{max}}{e}$$

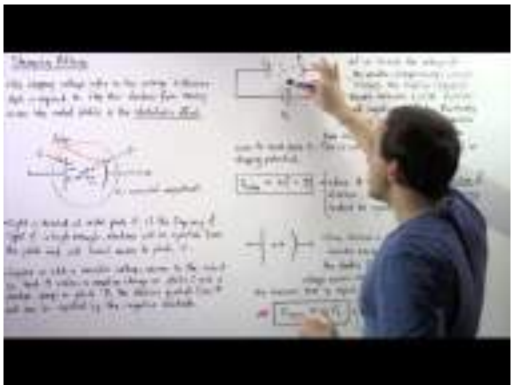
Thus…

$$K_{max} = eV_0$$

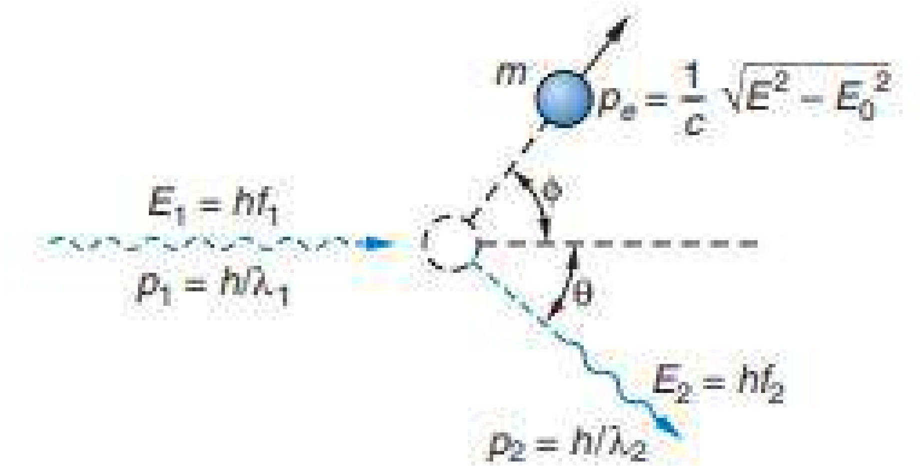
When charge (e) is given in coulombs, the energy will be calculated in joules. When charge (e) is given in elementary charges, the energy will be calculated in *electron volts*. This results in a lot of constants. Use the one that's most appropriate for your problem.

Video Link:

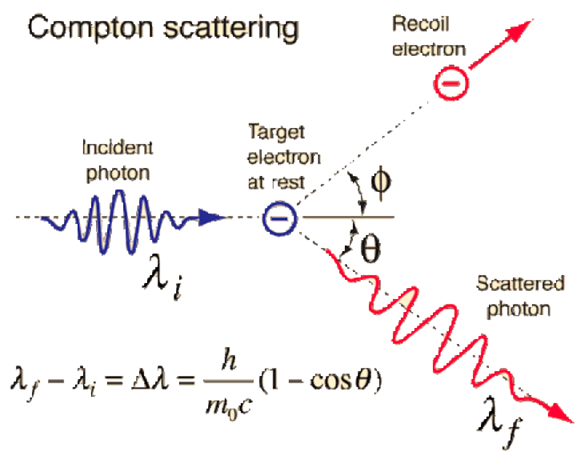




04.Compton’s effect



The scattering of x rays can be treated as a collision of a photon of initial momentum h/1 and a free electron. Using conservation of momentum and energy, the momentum of the scattered photon h/2 can be related to the initial momentum, the electron mass, and the scattering angle. The resulting Compton equation for the change in the wavelength of the x ray is Equation 3-25.



Let λ_1 and λ_2 be the wavelengths of the incident and scattered x rays, respectively, as shown in Figure 3-18. The corresponding momenta are

$$p_1 = \frac{E_1}{c} = \frac{hf_1}{c} = \frac{h}{\lambda_1}$$

and

$$p_2 = \frac{E_2}{c} = \frac{hf_2}{c} = \frac{h}{\lambda_2}$$

using $f\lambda = c$. Since Compton used the K_α line of molybdenum ($\lambda = 0.0711$ nm; see Figure 3-15*b*), the energy of the incident x ray (17.4 keV) is much greater than the binding energy of the valence electrons in the carbon-scattering block (about 11 eV); therefore, the carbon electrons can be considered to be free.

Conservation of momentum gives

$$\mathbf{p}_1 = \mathbf{p}_2 + \mathbf{p}_e$$

or

$$\begin{aligned} p_e^2 &= p_1^2 + p_2^2 - 2\mathbf{p}_1 \cdot \mathbf{p}_2 \\ &= p_1^2 + p_2^2 - 2p_1 p_2 \cos\theta \qquad \textbf{3-26} \end{aligned}$$

where $\boldsymbol{p}_e$ is the momentum of the electron after the collision and θ is the scattering angle of the photon, measured as shown in Figure 3-18. The energy of the electron before the collision is simply its rest energy $E_0 = mc^2$ (see Chapter 2). After the collision, the energy of the electron is $(E_0^2 + p_e^2c^2)^{1/2}$.

Conservation of energy gives

$$p_1 c + E_0 = p_2 c + (E_0^2 + p_e^2 c^2)^{1/2}$$

Transposing the term $p_2 c$ and squaring, we obtain

$$E_0^2 + c^2(p_1 - p_2)^2 + 2cE_0(p_1 - p_2) = E_0^2 + p_e^2 c^2$$

or

$$p_e^2 = p_1^2 + p_2^2 - 2p_1 p_2 + \frac{2E_0(p_1 - p_2)}{c} \qquad \textbf{3-27}$$

Eliminating p_e^2 between Equations 3-26 and 3-27, we obtain

$$\frac{E_0(p_1 - p_2)}{c} = p_1 p_2 (1 - \cos\theta)$$

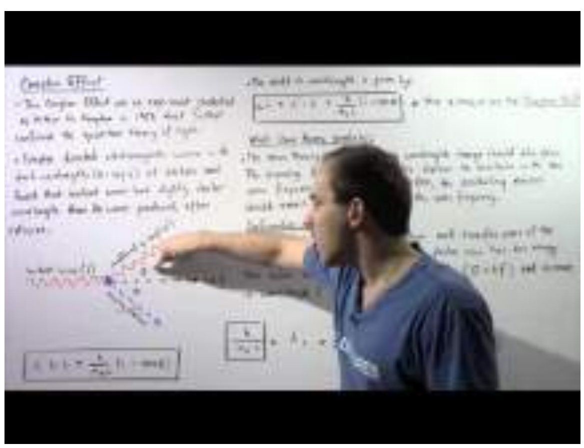
Multiplying each term by $hc/p_1 p_2 E_0$ and using $\lambda = h/p$, we obtain *Compton's equation*:

$$\lambda_2 - \lambda_1 = \frac{hc}{E_0}(1 - \cos\theta) = \frac{hc}{mc^2}(1 - \cos\theta)$$

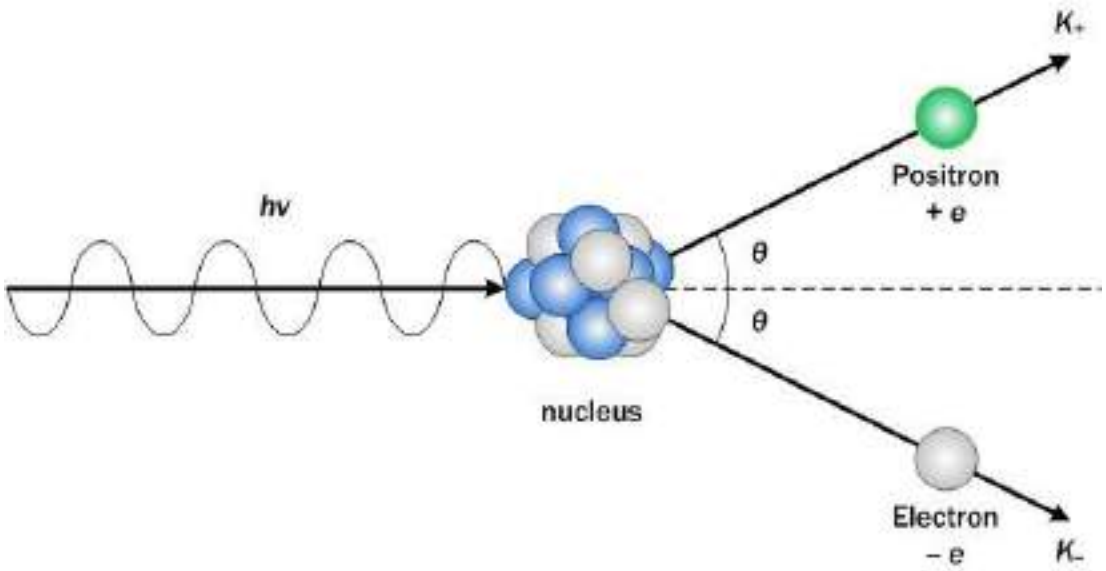
or

$$\lambda_2 - \lambda_1 = \frac{h}{mc}(1 - \cos\theta) \qquad \textbf{3-25}$$

Video Link:

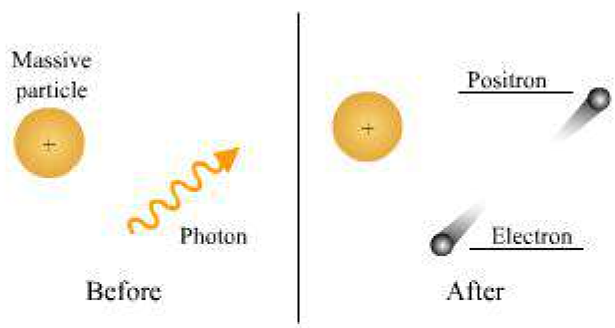


05.Pair production



Third principle mechanism of ionization

The third process of ionization is known as **pair-production**. In this process, the initial photon energy is very high, normally occurring at energies of 1.02 Mev and above. This particular process does not involve orbital electrons, rather the interaction occurs near the nucleus of the atom instead.



$$E_{\substack{rest\\mass}} = m_0 c^2$$

$$E_{rest} = (9.1x10^{-31})(9x10^{16})\ \frac{eV}{1.6 \times 10^{-19} J}$$

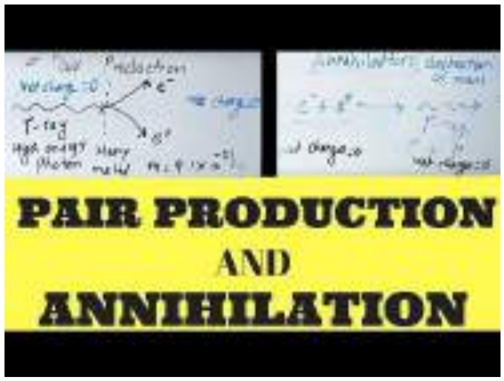
$$E_{rest} = 0.511 MeV$$

$$For\ Two\ Electrons = 2x0.511 MeV$$

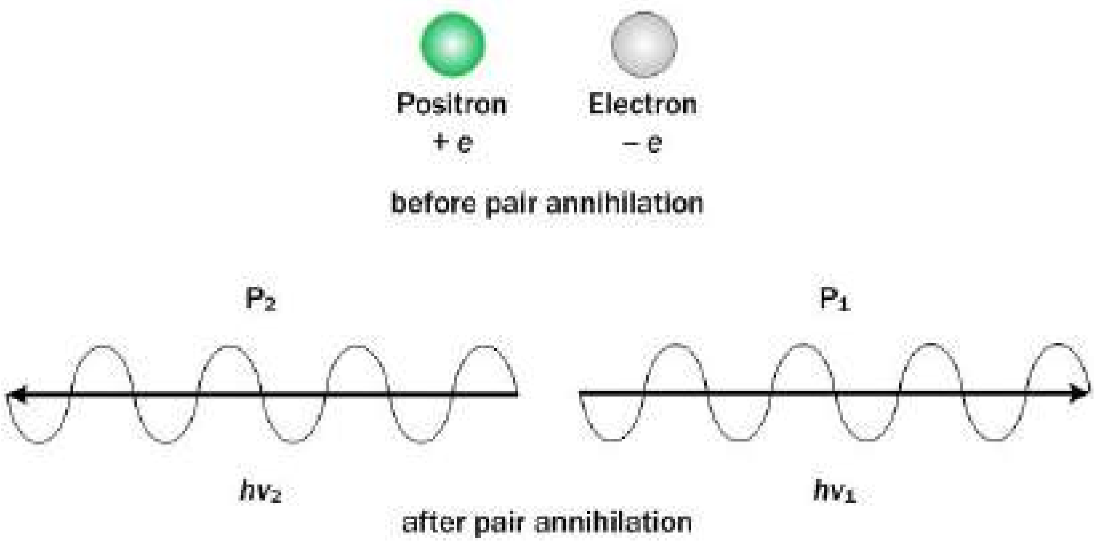
$$= 1.02 MeV$$

As the photon energy approaches the nucleus of the atom, it is changed into an electron -positron pair. The electron and positron move in different paths away from each other. A **positron** is nuclear in origin, possessing a positive charge, and mass equal to that of an electron. Technically a positron is the sister particle to the electron. Being positively charged, the positron immediately joins with an electron. The result of this process is annihilation of the positron, and the emission of two new photons, each with equal energy, but one half that of the original photons. These two new photons continue to go through ionization, eventually producing the Compton effect, and finally diminishing to the Photoelectric effect and total absorption.

Video Link:



Pair annihilation



Pair Annihilation means the reverse process of pair production. In the pair annihilation, the electron and positron in the stationary state combine with each other and annihilate. Surely, the particles are disappeared and radiation energy will occur instead of two particles. For the momentum conservation, the most frequent process in pair annihilation is making two photons that have exactly opposite direction and the same amount of momentum. (Sometimes it produces three photons in the pair annihilation process.)

Figure 2 is shown the annihilation of pair electron and positron which is making two photons. In the case of Figure 2, the energy balance can be represented as:

$K_- + K_+ + 2m_0c^2 = 2\,h\nu$ ---------eq.2

K_- and K_+ represent the kinetic energy of the electron and positron before the collision. Also, $2m_0c^2$ means the rest mass energy of both particles. From the equation 2, if the initial kinetic energy was zero, then,

$h\nu = m_0c^2 = 0.511$ MeV ---------eq.3

Therefore, in the equation 3, photons produced by pair annihilation have 0.511 MeV energy, and it correspond to 0.024Å of the wavelength in γ-ray. However, if the initial kinetic energy is not the same with zero, photon's energy is larger than 0.511 MeV, and its wavelength might be shorter than 0.024Å.
The positron is produced by the process of pair production. Generally, this positively-charged particle loses their energy by colliding with other particles in the path within matter, and finally combines with electron. We call those, "combined things", "positroium". The positronium collapse within about 10-10 second and produce two photons(pair annihilation).

06.Wave nature of particles

In experiments like photoelectric effect and Compton effect, radiation behaves like particles. de Broglie, a French physicist asked whether in some situations, the reverse could be true, i.e., would objects which are generally regarded as particles (e.g. electrons) behave like waves ? In 1924 de Broglie postulated that we can associate a wave with every material object. In analogy with photons, he proposed that the wavelength associated with such a matter wave is related to the particle momentum 'P' through the relationship

$$\lambda = \frac{h}{p}$$

Calculate the wavelength associated with a cricket ball of mass 0.2 kg moving with a speed of 30 m/s

Solution :

$$p = mv = 0.2 \times 30 = 6 \ \text{kg m/s}$$

$$\lambda = \frac{h}{p} = \frac{6.63 \times 10^{-34}}{6} = 1.1 \times 10^{-34} \ \text{m}$$

Exercise 1

Neutrons produced in a reactor are used for chain reaction after they are ``thermalized", i.e., their kinetic energies are reduced to that of the energy of air molecules at room temperature. Taking the room temperature as 300 K, estimate the de Broglie wavelength of such thermal neutrons. (mass of neutron = 1.67×10^{-27} kg.)

(Ans. 0.145 nm)

Exercise 2

Calculate de Broglie wavelength of a proton moving with a velocity of 10^4 m/s.

(Ans. 4×10^{-11} m/s)

07.Electron microscope

- An electron microscope is a microscope that uses a beam of accelerated electrons as a source of illumination.
- It is a special type of microscope having a high resolution of images, able to magnify objects in nano metres, which are formed by controlled use of electrons in vacuum captured on a phosphorescent screen.
- Ernst Ruska (1906-1988), a German engineer and academic professor, built the first Electron Microscope in 1931, and the same principles behind his prototype still govern modern EMs.

Working Principle of Electron microscope

Electron microscopes use signals arising from the interaction of an electron beam with the sample to obtain information about structure, morphology, and composition.

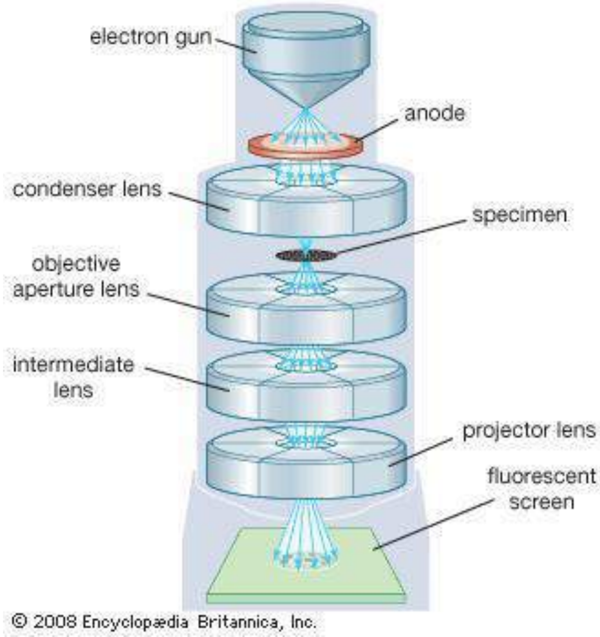
1. The electron gun generates electrons.
2. Two sets of condenser lenses focus the electron beam on the specimen and then into a thin tight beam.
3. To move electrons down the column, an accelerating voltage (mostly between 100 kV-1000 kV) is applied between tungsten filament and anode.
4. The specimen to be examined is made extremely thin, at least 200 times thinner than those used in the optical microscope. Ultra-thin sections of 20-100 nm are cut which is already placed on the specimen holder.
5. The electronic beam passes through the specimen and electrons are scattered depending upon the thickness or refractive index of different parts of the specimen.
6. The denser regions in the specimen scatter more electrons and therefore appear darker in the image since fewer electrons strike that area of the screen. In contrast, transparent regions are brighter.

7. The electron beam coming out of the specimen passes to the objective lens, which has high power and forms the intermediate magnified image.
8. The ocular lenses then produce the final further magnified image

Types of Electron microscope

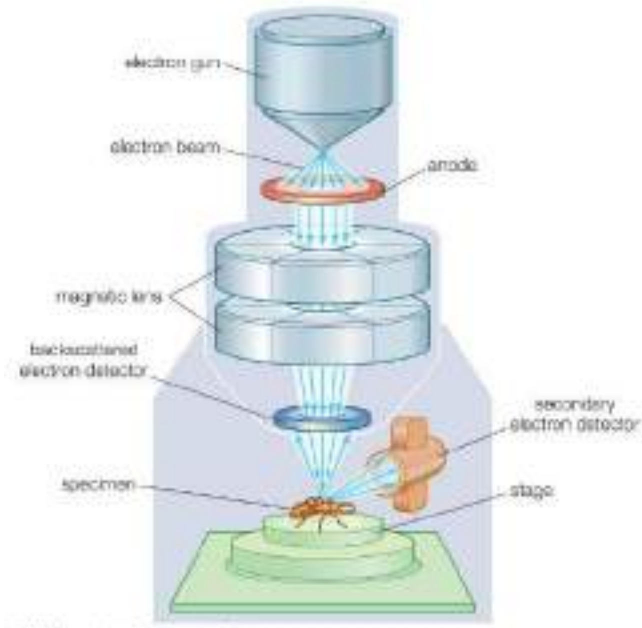
There are two types of electron microscopes, with different operating styles:

01.The transmission electron microscope (TEM)



- The transmission electron microscope is used to view thin specimens through which electrons can pass generating a projection image.
- The TEM is analogous in many ways to the conventional (compound) light microscope.
- TEM is used, among other things, to image the interior of cells (in thin sections), the structure of protein molecules (contrasted by metal shadowing), the organization of molecules in viruses and cytoskeletal filaments (prepared by the negative staining technique), and the arrangement of protein molecules in cell membranes (by freeze-fracture).

02.The scanning electron microscope (SEM)



- Conventional scanning electron microscopy depends on the emission of secondary electrons from the surface of a specimen.
- Because of its great depth of focus, a scanning electron microscope is the EM analog of a stereo light microscope.
- It provides detailed images of the surfaces of cells and whole organisms that are not possible by TEM. It can also be used for particle counting and size determination, and for process control.
- It is termed a scanning electron microscope because the image is formed by scanning a focused electron beam onto the surface of the specimen in a raster pattern.

Parts of Electron microscope

EM is in the form of a tall vacuum column which is vertically mounted. It has the following components:

1. **Electron gun**

- The electron gun is a heated tungsten filament, which generates electrons.

2. **Electromagnetic lenses**

- **Condenser lens** focuses the electron beam on the specimen. A second condenser lens forms the electrons into a thin tight beam.
- The electron beam coming out of the specimen passes down the second of magnetic coils called the **objective lens**, which has high power and forms the intermediate magnified image.
- The third set of magnetic lenses called **projector (ocular) lenses** produce the final further magnified image.
- Each of these lenses acts as an image magnifier all the while maintaining an incredible level of detail and resolution.

3. **Specimen Holder**

- The specimen holder is an extremely thin film of carbon or collodion held by a metal grid.

4. **Image viewing and Recording System.**
- The final image is projected on a fluorescent screen.
- Below the fluorescent screen is a camera for recording the image.

Applications

- Electron microscopes are used to investigate the ultrastructure of a wide range of biological and inorganic specimens including microorganisms, cells, large molecules, biopsy samples, metals, and crystals.
- Industrially, electron microscopes are often used for quality control and failure analysis.
- Modern electron microscopes produce electron micrographs using specialized digital cameras and frame grabbers to capture the images.
- Science of microbiology owes its development to the electron microscope. Study of microorganisms like bacteria, virus and other pathogens have made the treatment of diseases very effective.

Advantages

- Very high magnification
- Incredibly high resolution
- Material rarely distorted by preparation
- It is possible to investigate a greater depth of field
- Diverse applications

Limitations

- The live specimen cannot be observed.
- As the penetration power of the electron beam is very low, the object should be ultra-thin. For this, the specimen is dried and cut into ultra-thin sections before observation.
- As the EM works in a vacuum, the specimen should be completely dry.
- Expensive to build and maintain
- Requiring researcher training
- Image artifacts resulting from specimen preparation.
- This type of microscope is a large, cumbersome extremely sensitive to vibration and external magnetic fields.

Video Link:

08.Uncertainty Principle

The Uncertainty Principle

The position and momentum of a particle cannot be simultaneously measured with arbitrarily high precision. There is a minimum for the product of the uncertainties of these two measurements. There is likewise a minimum for the product of the uncertainties of the energy and time.

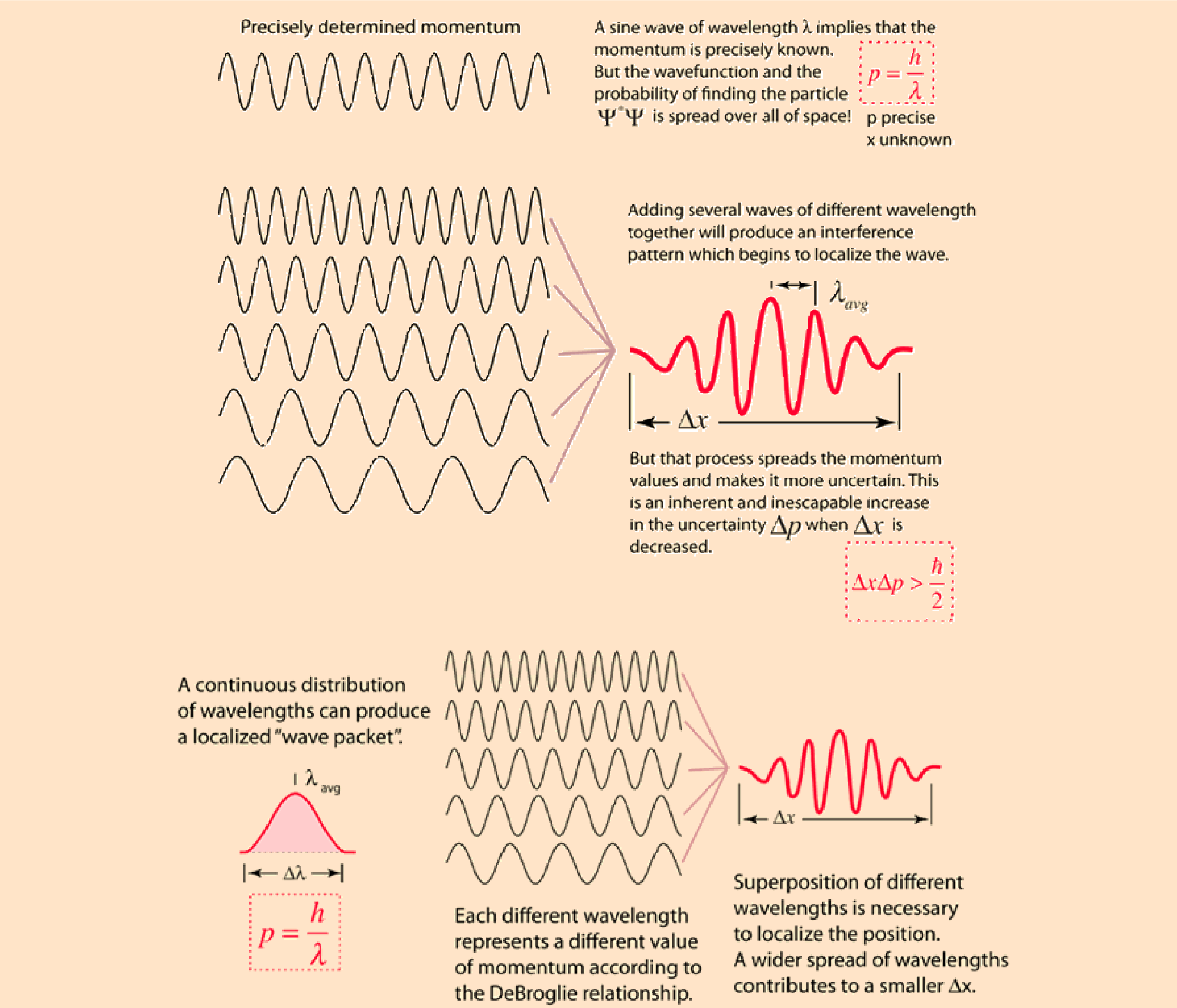
$$\Delta x \Delta p > \frac{\hbar}{2}$$

$$\Delta E \Delta t > \frac{\hbar}{2}$$

This is not a statement about the inaccuracy of measurement instruments, nor a reflection on the quality of experimental methods; it arises from the wave properties inherent in the quantum mechanical description of nature. Even with perfect instruments and technique, the uncertainty is inherent in the nature of things.

Uncertainty Principle

Important steps on the way to understanding the uncertainty principle are wave-particle duality and the DeBroglie hypothesis. As you proceed downward in size to atomic dimensions, it is no longer valid to consider a particle like a hard sphere, because the smaller the dimension, the more wave-like it becomes. It no longer makes sense to say that you have precisely determined both the position and momentum of such a particle. When you say that the electron acts as a wave, then the wave is the quantum mechanical wavefunction and it is therefore related to the probability of finding the electron at any point in space. A perfect sinewave for the electron wave spreads that probability throughout all of space, and the "position" of the electron is completely uncertain.



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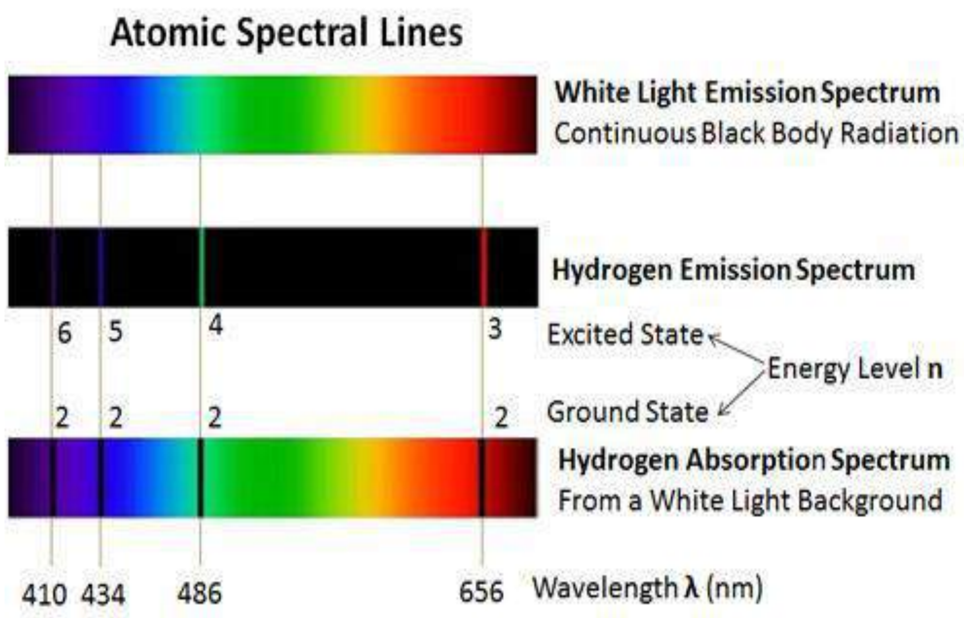
Unit 19

Atomic Spectra



Topics	Understandings	Skills
• Atomic spectra • Emission of spectral lines • Ionization and excitation potentials • Inner shell transitions and characteristic X-rays • Laser	The students will: • Describe and explain the origin of different types of optical spectra. • Show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g. atomic hydrogen) and deduce how this leads to spectral lines. • Explain how the uniqueness of the spectra of elements can be used to identify an element. • Analyse the significance of the hydrogen spectrum in the development of Bohr's model of the atom. • Explain hydrogen atom in terms of energy levels on the basis of Bohr Model. • Determine the ionization energy and various excitation energies of an atom using an energy level diagram. • Solve problems and analyse information using. • $1/\lambda = R_H\,[1/p_2 - 1/n_2]$. • Understand that inner shell transitions in heavy elements result into emission of characteristic X-rays. • Explain the terms spontaneous emission, stimulated emission, meta stable states, population inversion and laser action. • Describe the structure and purpose of the main components of a He-Ne gas laser.	•Observe the line spectrum of mercury with diffraction grating and spectrometer to determine the wavelength of several different lines, and hence draw a conclusion about the width of visible spectrum. • Examine the optical spectra by spectrometer and diffraction grating using different sources such as discharge tube (hydrogen, helium or neon) or of flames.

Unit overview

Atomic spectra

When atoms are excited they emit light of certain wavelengths which correspond to different colors. The emitted light can be observed as a series of colored lines with dark spaces in between; this series of colored lines is called a **line** or **atomic spectra**. Each element produces a unique set of spectral lines. Since no two elements emit the same spectral lines, elements can be identified by their line spectrum.

Electromagnetic Radiation and the Wave Particle Duality

Energy can travel through a vacuum or matter as electromagnetic radiation. Electromagnetic radiation is a transverse wave with magnetic and electric components that oscillate perpendicular to each other. The **electromagnetic spectrum** is the range of all possible wavelengths and frequencies of electromagnetic radiation including visible light.

According to the wave particle duality concept, although electromagnetic radiation is often considered to be a wave, it also behaves like a particle. In 1900, while studying black body radiation, Max Planck discovered that energy was limited to certain values and was not continuous as assumed in classical physics. This means that when energy increases, it does so by tiny jumps called quanta (quantum in the singular). In other words, a quantum of energy is to the total energy of a system as an atom is to the total mass of a system. In 1905, Albert Einstein proposed that energy was bundled into packets, which became known as photons. The discovery of photons explained why energy increased in small jumps. If energy was bundled into tiny packets, each additional packet would contribute a tiny amount of energy causing the total amount of energy to jump by a tiny amount, rather than increase smoothly as assumed in classical physics.

List of Variables Discussed in this Article

- λ is the wavelength of light (Greek letter Lambda)
- v is the frequency of light (Greek letter Nu)
- n is the quantum number of a energy state
- E is the energy of that state

Table 1: Important Constants

Constant	Meaning	Value
c	speed of light	2.99792458×10^{8} ms^{-1}
h	Planck's constant	6.62607×10^{-34} Js
eV	electron volt	1.60218×10^{-19} J
R_H	Rydberg constant for H	2.179×10^{-18} J

Units to Know

Wavelength, or the distance from one peak to the other of a wave, is most often measured in meters, but can be measured using other SI units of length where practical. The number of waves that pass per second is the frequency of the wave. The SI unit for frequency is the Hertz (abbreviated Hz). 1 Hz is equal to $1s^{-1}$. The speed of light is constant. In a vacuum the speed of light is 2.99792458×10^{8} ms^{-1}. The relationship between wavelength (λ), frequency (ν), and the speed of light (c) is:

$v=c\lambda(1)$

The energy of electromagnetic radiation of a particular frequency is measured in Joules and is given by the equation:

$E=hv(2)$

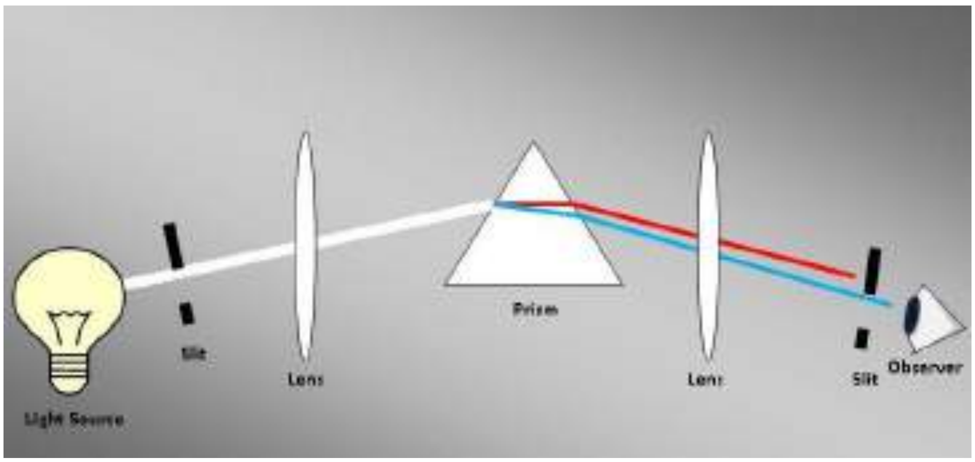
with

- H as Planck's constant ($6.62606876 \times 10^{-34}$ Js)

The electron volt is another unit of energy that is commonly used. The electron volt (eV) is defined as the kinetic energy gained by an electron when it is accelerated by a potential electrical difference of 1 volt. It is equal to 1.60218×10^{-19} J.

Spectroscope

A spectrum is a range of frequencies or wavelengths. By the process of refraction, a prism can split white light into it's component wavelengths. However this method is rather crude, so a **spectroscope** is used to analyze the light passing through the prism more accurately. The diagram to the right shows a simple prism spectroscope (click to enlarge). The smaller the difference between distinguishable wavelengths, the higher the resolution of the spectroscope. The observer (shown as an eye in the diagram) sees the radiation passing through the slit as a spectral line. To obtain accurate measurements of the radiation, and electronic device often takes the place of the observer, the device is then called a spectrophotometer. In more modern Spectrophotometers, a diffraction grating is used instead of a prism to disperse the light.

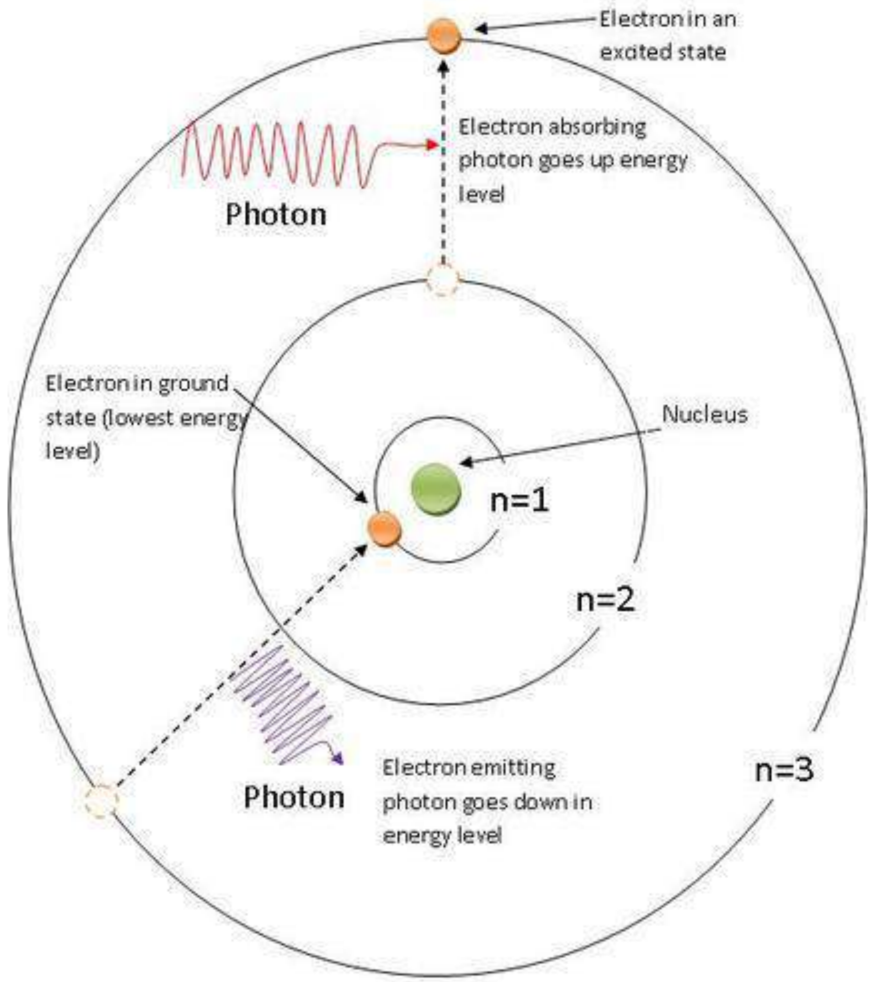


How Atoms React when Excited by Light

Electrons can only exist in certain areas around the nucleus called shells. Each shell corresponds to a specific energy level which is designated by a quantum number n. Since electrons cannot exist between energy levels, the quantum number n is always an integer value (n=1,2,3,4…). The electron with the lowest energy level (n=1) is the closest to the nucleus. An electron occupying its lowest energy level is said to be in the ground state. The energy of an electron in a certain energy level can be found by the equation:

$$E_n = -\frac{R_H}{n^2} \quad (3)$$

Where R_H is a constant equal to 2.179×10^{-18} J and n is equal to the energy level of the electron.



When light is shone on an atom, its electrons absorb photons which cause them to gain energy and jump to higher energy levels. The higher the energy of the photon absorbed, the higher the energy level the electron jumps to. Similarly, an electron can go down energy levels by emitting a photon. The simplified version of this principal is illustrated in the figure to the left based on the Bohr model of the Hydrogen atom. The energy of the photon emitted or gained by an electron can be calculated from this formula:

Ephoton=*RH*(1*n*2*i*–1*n*2*f*)(4)

Where n_i is the initial energy level of the electron and n_f is the final energy level of the electron. The frequency of the photon emitted when an electron descends energy levels can be found using the formula:

nuphoton=*Ei*−*Efh*(5)

with

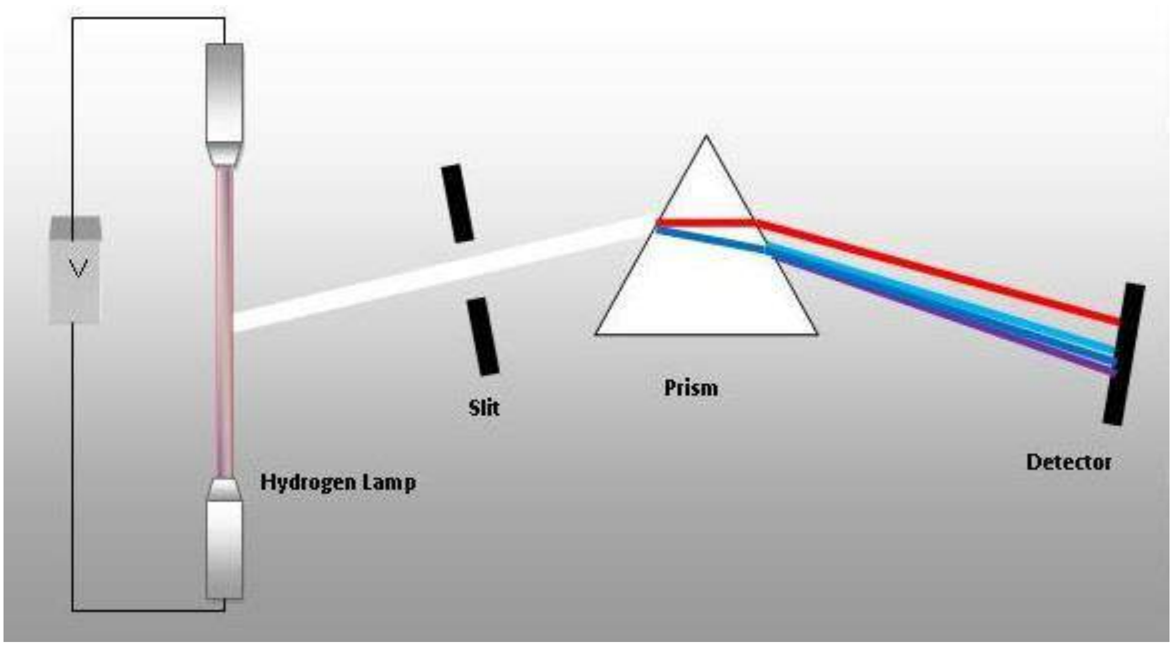
Ei is the initial energy of the electron and

Ef is the final energy of the electron.

Since an electron can only exist at certain energy levels, they can only emit photons of certain frequencies. These specific frequencies of light are then observed as spectral lines. Similarly, a photon has to be of the exact wavelength the electron needs to jump energy levels in order to be absorbed, explaining the dark bands of an absorption spectra.

Emission Lines

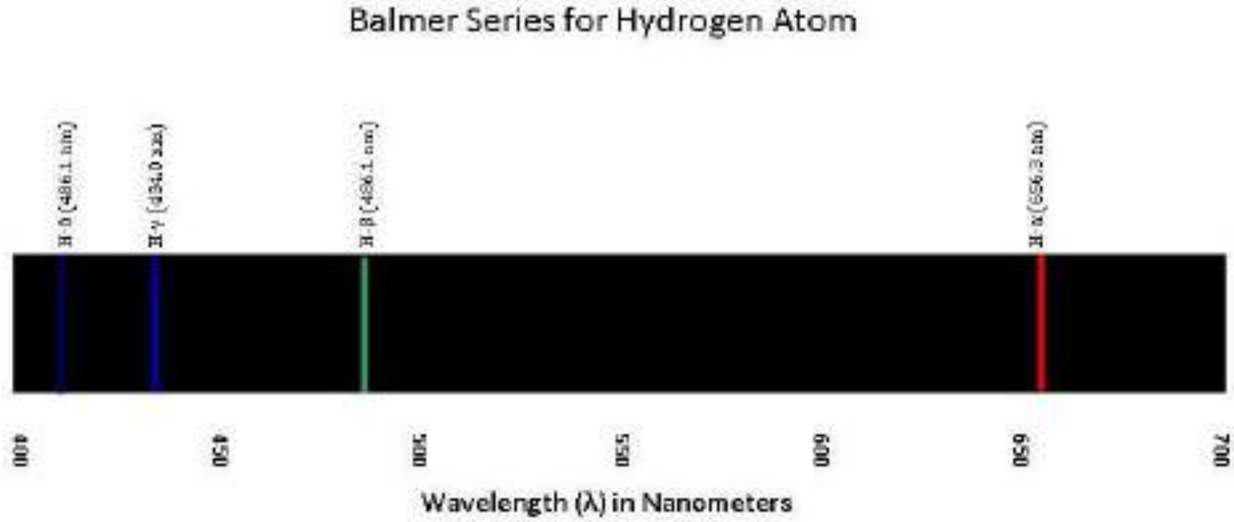
As discussed above, when an electron falls from one energy level in an atom to a lower energy level, it emits a photon of a particular wavelength and energy. When many electrons emit the same wavelength of photons it will result in a spike in the spectrum at this particular wavelength, resulting in the banding pattern seen in atomic emission spectra. The graphic to the right is a simplified picture of a **spectrograph**, in this case being used to photograph the spectral lines of Hydrogen.



In this spectrograph, the Hydrogen atoms inside the lamp are being excited by an electric current. The light from the lamp then passes through a prism, which diffracts it into its different frequencies. Since the frequencies of light correspond to certain energy levels (n) it is therefore possible to predict the frequencies of the spectral lines of Hydrogen using an equation discovered by Johann Balmer.

$v=3.2881x1015s-1(122-1n2)(6)$

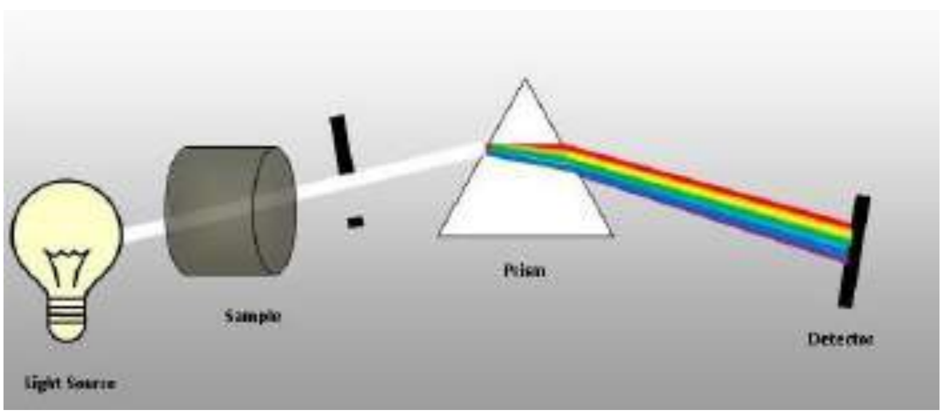
Where n must be a number greater than 2. This is because Balmer’s formula only applies to visible light and some longer wavelengths of ultraviolet.



The frequencies in this region of Hydrogen's atomic spectra are called the Balmer series. The Balmer series for Hydrogen is pictured to the left. There are several other series in the Hydrogen atom which correspond to different parts of the electromagnetic spectrum. The Lyman series, for example, extends into the ultraviolet, and therefore can be used to calculate the energy of to n=1.

Absorption Lines

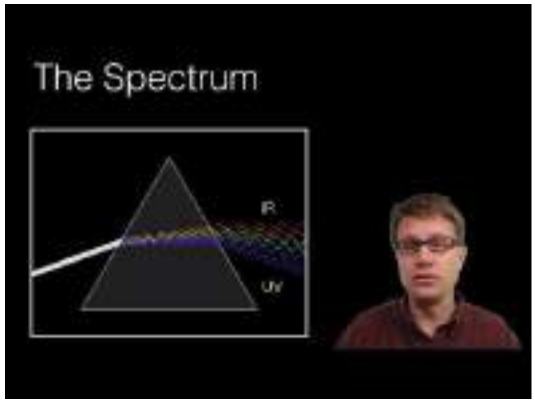
When an electron jumps from a low energy level to a higher level, the electron will absorb a photon of a particular wavelength. This will show up as a drop in the number of photons of this wavelength and as a black band in this part of the spectrum. The figure to the right illustrates a mechanism to detect an absorption spectrum. A white light is shone through a sample. The atoms in the sample absorb some of the light, exciting their electrons. Since the electrons only absorb light of certain frequencies, the absorption spectrum will show up as a series of black bands on an otherwise continuous spectrum.

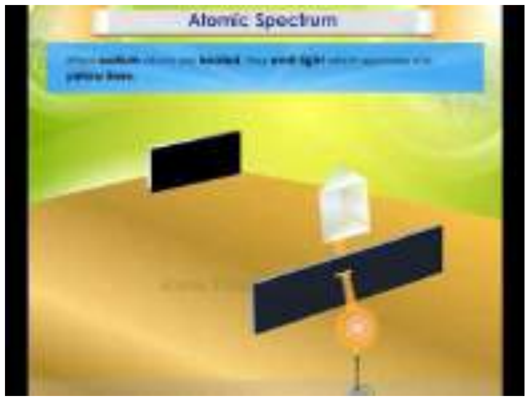


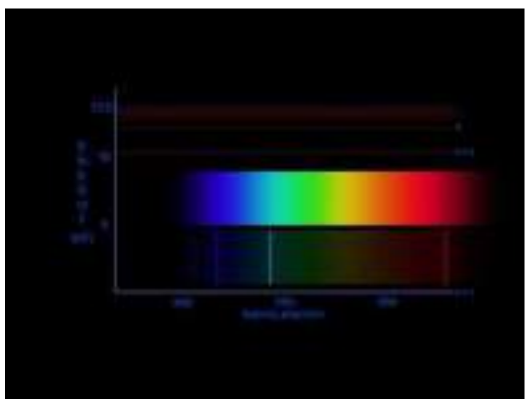
Applications of Atomic Spectral Analysis

Atomic spectroscopy has many useful applications. Since the emission spectrum is different for every element, it acts as an atomic fingerprint by which elements can be identified. Some elements were discovered by the analysis of their atomic spectrum. Helium, for example, was discovered while scientists were analyzing the absorption spectrum of the sun. Emission spectra is especially useful to astronomers who use emission and absorption spectra to determine the make up of far away stars and other celestial bodies

Videos







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Assessment

1. Using the Balmer equation, find the frequency of the radiation corresponding to n=3.
2. What is the frequency of the spectral line produced when an electron moves from n=5 to n=2 in a Hydrogen atom?
3. What value of n does the line at 656.3 nm in the Balmer series correspond to?
4. A photon with a wavelength of 397nm is emitted from an electron in energy level 7 of a Hydrogen atom. What is the new energy level of the electron?
5. Find the frequency in Hertz of radiation with an energy of 2.179×10^{-18} J per photon.

6. What frequency of light would be needed to make an electron in a Hydrogen atom jump from n=1 to n=3 ?
7. A spectral line is measured to have a wavelength of 1000nm. Is this within the Balmer series?

Solutions

1.)Using the Balmer equation, find the frequency of the radiation corresponding to n=3.

The Balmer Equation is: $\nu = 3.2881 \times 10^{15} s^{-1} (1/2^2 - 1/n^2)$

We simply plug in the given value for n: $\nu = 3.2881 \times 10^{15} s^{-1} (1/2^2 - 1/3^2)$

The answer is $\nu = 4.5668\ s^{-1}$

2.) What is the frequency of the spectral line produced when an electron moves from n=5 to n=2 in a Hydrogen atom?

We use equation number 4: $E_{photon} = R_H (1/n_i^2 - 1/n_f^2)$

We simply plug in the given values for n and the Rhydberg constant for Hydrogen:

$E_{photon} = 2.179 \times 10^{-18}\ J\ (1/5^2 - 1/2^2)$

$E_{photon} = 4.5759 \times 10^{-19}\ J$

Next, we rearrange equation 2 to solve for frequency (v):

v=E/h

Then plug in the values for E and h:

$v = (4.5759 \times 10^{-19}\ J)/(6.62607 \times 10^{-34}\ Js)$

$v = 6.905 \times 10^{14} s^{-1}$

3.) What value of n does the line at 656.3 nm in the Balmer series correspond to?

We then substitute equation 1 into equation 2 to get this equation:

$E = hc/\lambda$

We convert the wavelength of the photon to meters, and then plug it into the equation

$E = (6.62607 \times 10^{-34}\ Js)(\ 2.99792458 \times 10^{8}\ ms^{1})/(6.563 \times 10^{-7} m)$

$E = 3.20267344 \times 10^{-19} J$

We then use this value to find the frequency (v).

$v = (3.20267344 \times 10^{-19} J)\ /(6.62607 \times 10^{-34}\ Js)$

$v = 4.567917995 \times 10^{14}$

We then use equation 6 to find the energy level:

$4.567917995 \times 10^{14} = 3.2881 \times 10^{15} s^{-1} (1/2^2 - 1/n^2)$

n= 3

4.) A photon with a wavelength of 397nm is emitted from an electron in energy level 7 of a Hydrogen atom. What is the new energy level of the electron?

We use equation number 3 ($E_n = -R_H/n^2$)to find the number of joules when n=7:

$E_7 = (2.179 \times 10^{-18} J)/7^2$

$E_7 = -4.4469388 \times 10^{-20} J$

We then substitute equation 1 into equation 2 to get this equation:

$E=hc/\lambda$

We convert the wavelength of the photon to meters, and then plug it into the equation

$E_{photon} = (6.62607 \times 10^{-34} Js)(2.99792458 \times 10^8 ms^{-1})/(3.97 \times 10^{-7} m)$

$E_{photon} = 5.00358898 \times 10^{-19} J$

We then subtract the energy of the photon emitted from the energy level the electron was originally in; this will give us the energy of the new energy level:

$E_{n\ final} = E_{n\ initial} - E_{photon}$

Plug the values previously calculated into the equation:

$E_{n\ final} = (-4.4469388 \times 10^{-20} J) – (5.00358898 \times 10^{-19} J)$

$E_{n\ final} = -5.4482829 \times 10^{-19} J$

To figure out the energy level (n), we can plug our $E_{n\ final}$ into equation number 3:

$E_n = -R_H/n^2$

$-5.4482829 \times 10^{-19} J = (-2.179 \times 10^{-18} J)/n^2$

We solve for n, and get:

n=2

5.) Find the frequency in Hertz of radiation with an energy of 2.179×10^{-18} J per photon.

We rearrange equation 2:

v=E/h

Plug in the values:

$v=(2.179 \times 10^{-18}\ J)/(6.62607 \times 10^{-34}\ Js)$

$v= 3.289 \times 10^{15}\ s^{-1}$

6.) What frequency of light would be needed to make an electron in a Hydrogen atom jump from n=1 to n=3 ?

Using equation3($E_n = -R_H/n^2$), we calculate the energy when n=1 and when n=3.

$E_1 = -2.179 x 10^{-18} J$

$E_3 = -2.42 x 10^{-19} J$

We next use equation5 to find the frequency of the photon that must be absorbed.

$\nu_{photon} = (E_i - E_f)/h$

$\nu_{photon} = [(-2.179 x 10^{-18} J) – (-2.42 x 10^{-19} J)] / (6.62607 \times 10^{-34}\ Js)$

$\nu_{photon} = 2.923301 \times 10^{15} s^{-1}$

7.)A spectral line is measured to have a wavelength of 1000nm. Is this within the Balmer series?

No, the Balmer series does not extend into the infrared.

Excitation and Ionization potentials

Excitation

By definition, if an electron is accelerated by 1 volt of potential difference. it acquires 1 eV of energy. So if the electron is accelerated through a p.d. of 10.2 volts, it acquires 10.2 eV energy. If such an extra electron collides with a ground state hydrogen atom, the hydrogen atom may be excited to the first excited energy state. Hence, the 10,2 volt of potential difference is the first excitation potential for a hydrogen atom. Second excitation potential for the hydrogen atom is given by (E:, in eV — E, in eV) volt and so on.
Thus, the excitation potential of an energy of an atom is the potential. which is required for an electron to jump from the ground state to any one of its excited states.

Ionization potential

The potential difference through which the extra electron is to be in acceleration in order for it to cause the ionization of an atom is called the ionization potential of the atom. For example, for the hydrogen atom, the ionization energy is 13.6 eV. By definition of 1 eV, an electron acquires 13.6 eV energy when it is accelerated through a potential difference of 13.6 volts.
Thus. ionization potential is the minimum potential to be applied in order to remove the electron completely from its ground state to infinity.

Emission Spectra

When the excited atoms make transitions from the excited state to the lower lying energy levels. then the emission spectra is obtained. Emission spectra are classified into continuous, line and a band spectrum visible from hot solid is an example of the continuous spectrum. A continuous spectrum is produced by incandescent solids, liquids, and compressed gasses. Line spectra are discontinuous lines produced by excited atoms and ions as they fall back to the lower energy level.

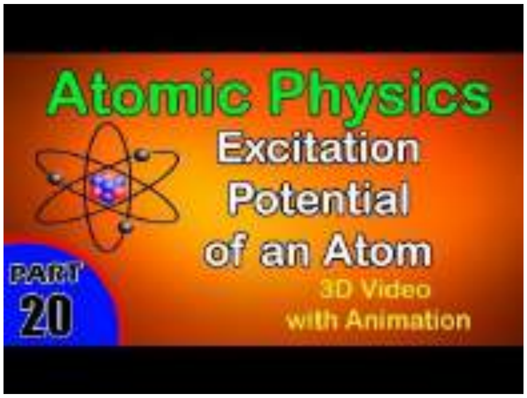
Absorption spectra

Absorption spectra are obtained when electrons are taken from lower energy states to the higher energy states. Various absorption series are Lyman, Balmer. Paschen. Bradcet, and Pfund.

Limitations of Bohrs Theory of Hydrogen Atom

- Elliptical orbits are possible for the electron orbits, but Bohrs theory does not tell us why only elliptical orbits are possible.
- Bohrs theory does not explain the spectra of only simple atoms like hydrogen but fails to explain the spectra of multi-electron atoms.
- The fine structure of certain spectral lines of hydrogen could not be explained by Bohrs theory.
- It does not explain the relative intensities of spectral lines.
- This theory does not account for the wave nature of electrons.

Video



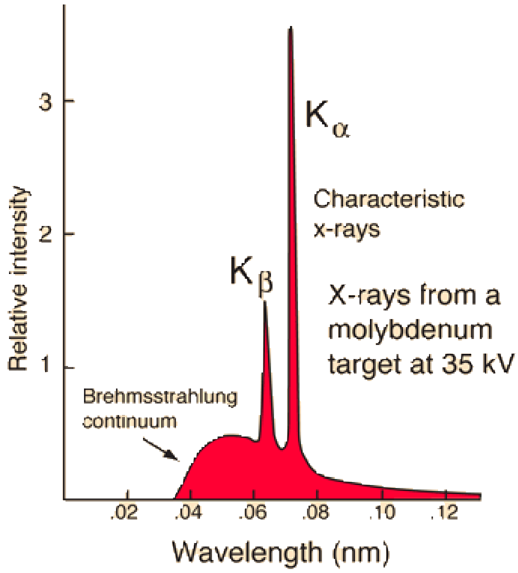
Refrence

https://www.kullabs.com/classes/subjects/units/lessons/notes/note-detail/3024

Inner shell transitions

Inner shell transitions in medium to very heavy atoms are treated within a relativistic framework. The many-body part of the calculation includes full relaxation, correlation and the admixture of, sometimes degenerate, states with two vacancies and one excited particle. The Breit interaction is treated on equal footing with the Coulomb part of the electron-electron interaction through the whole calculation and the retardation beyond the Breit interaction is included in lowest order. The effect of the finite nuclear size is substantial and special care has been taken to use a correct nuclear mean square radius even for deformed nuclei. Hydrogenic radiative corrections (with finite nucleus effects) as well as screening contributions are included. Comparison with experiments over a wide range of elements show agreement within combined theoretical and experimental uncertainties.

Characteristic X-Rays



Characteristic x-rays are emitted from heavy elements when their electrons make transitions between the lower atomic energy levels. The characteristic x-ray emission which is shown as two sharp peaks in the illustration at left occur when vacancies are produced in the n=1 or K-shell of the atom and electrons drop down from above to fill the gap. The x-rays produced by transitions from the n=2 to n=1 levels are called K-alpha x-rays, and those for the n=3→1 transition are called K-beta x-rays.

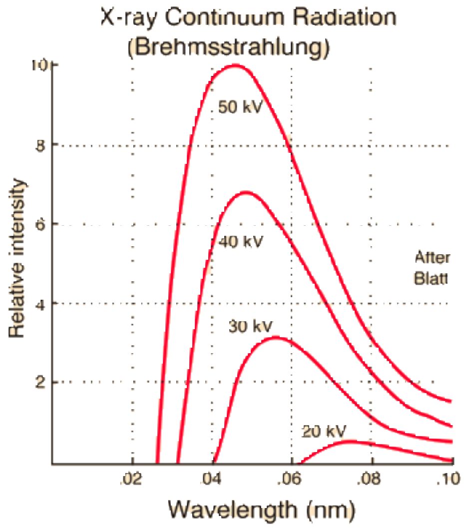
Transitions to the n=2 or L-shell are designated as L x-rays (n=3→2 is L-alpha, n=4→2 is L-beta, etc.). The continuous distribution of x-rays which forms the base for the two sharp peaks at left is called "bremsstrahlung" radiation.

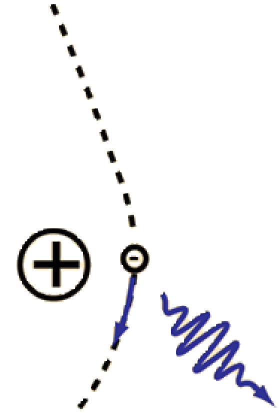
X-ray production typically involves bombarding a metal target in an x-ray tube with high speed electrons which have been accelerated by tens to hundreds of kilovolts of potential. The bombarding electrons can eject electrons from the inner shells of the atoms of the metal target. Those vacancies will be quickly filled by electrons dropping down from higher levels, emitting x-rays with sharply defined frequencies associated with the difference between the atomic energy levels of the target atoms.

The frequencies of the characteristic x-rays can be predicted from the Bohr model. Moseley measured the frequencies of the characteristic x-rays from a large fraction of the elements of the periodic table and produced a plot of them which is now called a "Moseley plot".

Characteristic x-rays are used for the investigation of crystal structure by x-ray diffraction. Crystal lattice dimensions may be determined with the use of Bragg's law in a Bragg spectrometer.

Bremsstrahlung X-Rays





"Bremsstrahlung" means "braking radiation" and is retained from the original German to describe the radiation which is emitted when electrons are decelerated or "braked" when they are fired at a metal target. Accelerated charges give off electromagnetic radiation, and when the energy of the bombarding electrons is high enough, that radiation is in the x-ray region of the electromagnetic spectrum. It is characterized by a continuous distribution of radiation which becomes more intense and shifts toward higher frequencies when the energy of the bombarding electrons is increased. The curves above are from the 1918 data of Ulrey, who bombarded tungsten targets with electrons of four different energies.

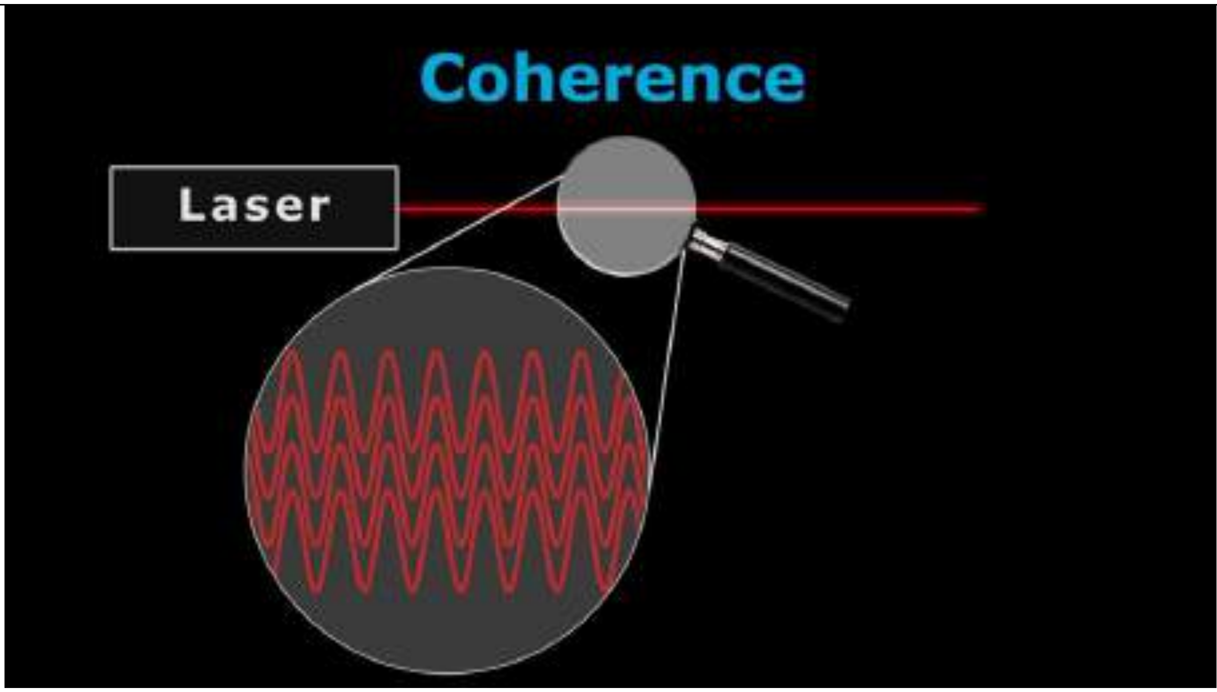
The bombarding electrons can also eject electrons from the inner shells of the atoms of the metal target, and the quick filling of those vacancies by electrons dropping down from higher levels gives rise to sharply defined characteristic x-rays.

Video

Refrence

http://hyperphysics.phy-astr.gsu.edu/hbase/quantum/xrayc.html

Laser

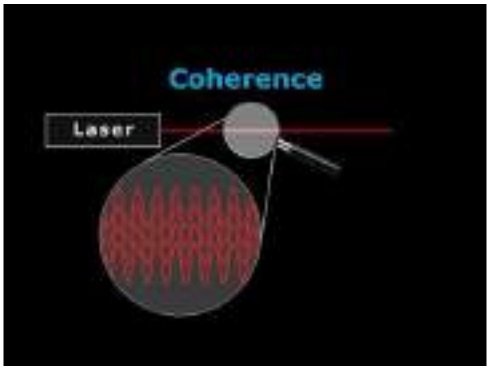


A laser is a device that emits light through a process of optical amplification based on the stimulated emission of electromagnetic radiation. The term "laser" originated as an acronym for "light amplification by stimulated emission of radiation".[1][2][3] The first laser was built in 1960 by Theodore H. Maiman at Hughes Research Laboratories, based on theoretical work by Charles Hard Townes and Arthur Leonard Schawlow.

A laser differs from other sources of light in that it emits light which is *coherent*. Spatial coherence allows a laser to be focused to a tight spot, enabling applications such as laser cutting and lithography. Spatial coherence also allows a laser beam to stay narrow over great distances (collimation), enabling applications such as laser pointers and lidar. Lasers can also have high temporal coherence, which allows them to emit light with a very narrow spectrum, i.e., they can emit a single color of light. Alternatively, temporal coherence can be used to produce pulses of light with a broad spectrum but durations as short as a femtosecond ("ultrashort pulses").

Lasers are used in optical disk drives, laser printers, barcode scanners, DNA sequencing instruments, fiber-optic, semiconducting chip manufacturing (photolithography), and free-space optical communication, laser surgery and skin treatments, cutting and welding materials, military and law enforcement devices for marking targets and measuring range and speed, and in laser lighting displays for entertainment. They have been used for car headlamps on luxury cars, by using a blue laser and a phosphor to produce highly directional white light

Video



Refrence

https://en.wikipedia.org/wiki/Laser

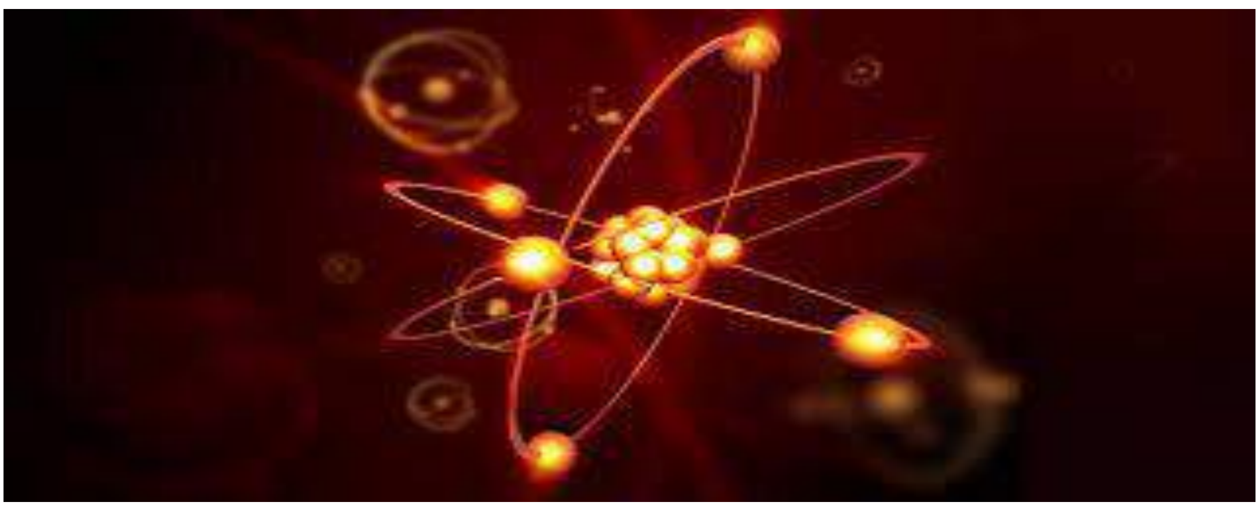
Learning Outcomes

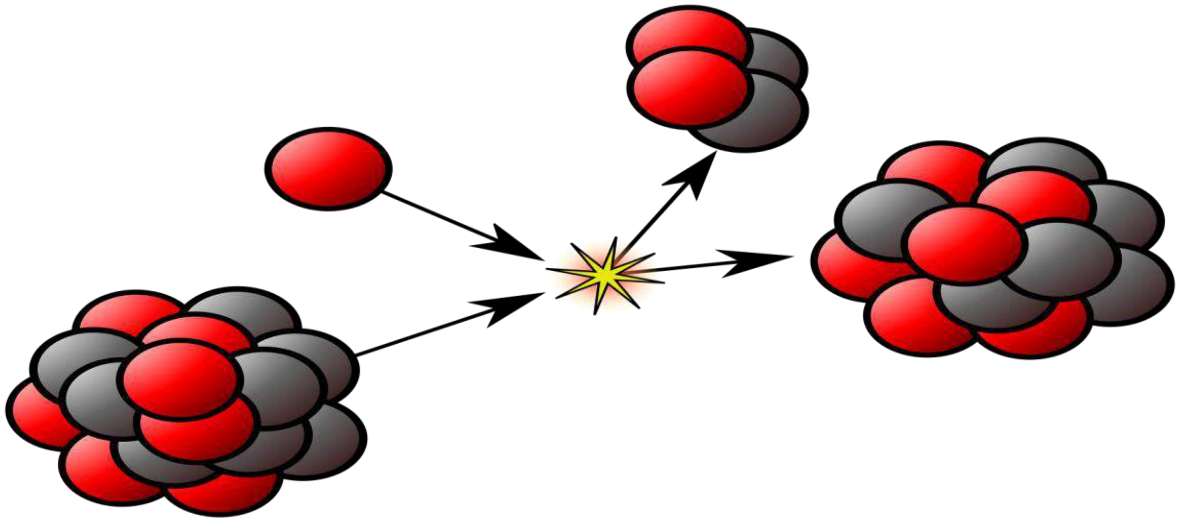
The students will:

- Describe and explain the origin of different types of optical spectra.
- Show an understanding of the existence of discrete electron energy levels in isolated atoms (e.g.atomic hydrogen) and deduce how this leads to spectral lines.
- Explain how the uniqueness of the spectra of elements can be used to identify an element.
- Analyse the significance of the hydrogen spectrum in the development of Bohr's model of the atom.
- Explain hydrogen atom in terms of energy levels on the basis of Bohr Model.
- Determine the ionization energy and various excitation energies of an atom using an energy level diagram.
- Solve problems and analyse information using.
- $1/\lambda = R_H [1/p_2 - 1/n_2]$.
- Understand that inner shell transitions in heavy elements result into emission of characteristic X- rays.
- Explain the terms spontaneous emission, stimulated emission, meta stable states, population inversion and laser action.
- Describe the structure and purpose of the main components of a He-Ne gas laser

Unit 20

Nuclear Physics





Topics	Understandings	Skills
• Composition of atomic nuclei • Isotopes • Mass spectrograph • Mass defect and binding energy • Radioactivity (properties of α, β and γ rays) • Energy from nuclear decay • Half life and rate of decay • Interaction of radiation with matter • Radiation detectors (GM counter and solid state detector) • Nuclear reactions • Nuclear fission (fission chain reaction) • Nuclear reactors (types of nuclear reactor) • Nuclear fusion (nuclear reaction in the Sun) • Radiation exposure • Biological and medical uses of radiations (radiation therapy, diagnosis of diseases,tracers techniques) • Basic forces of nature • Elementary particles and particle classification (hadrons, leptons and quarks)	The students will: • Describe a simple model for the atom to include protons, neutrons and electrons. • Determine the number of protons, neutrons and nucleons it contains for the specification of a nucleus in the form A. • Explain that an element can exist in various isotopic forms each with a different number of neutrons. • Explain the use of mass spectrograph to demonstrate the existence of isotopes and to measure their relative abundance. • Define the terms unified mass scale, mass defect and calculate binding • Illustrate graphically the variation of binding energy per nucleon with the mass number. • Explain the relevance of binding energy per nucleon to nuclear fusion and to nuclear fission. • Identify that some nuclei are unstable, give out radiation to get rid of excess energy and are said to be radioactive. • Describe that an element may change into another element when radioactivity occurs. • Identify the spontaneous and random nature of nuclear decay. • Describe the term half life and solve problems using the equation $\lambda=0.693/T_{1/2}$. • Determine the release of energy from different nuclear reactions. • Explain that atomic number and mass number conserve in nuclear reactions. • Describe energy and mass conservation in simple reactions and in radioactive decay. • Describe the phenomena of nuclear fission and fusion. • Describe the fission chain reaction. • Describe the function of various components of a nuclear reactor. • Describe the interaction of nuclear radiation with matter. • Describe the use of Geiger Muller counter and solid state detectors to detect the radiations. • Describe the basic forces of nature. • Describe the key features and components of the standard model of matter including hadrons, leptons and	The students will: • Simulate the radioactive decay of nuclei using a set of at least 100 dice and measure the simulated half life of the nuclei. • Draw the characteristics curve of a Geiger Muller tube. • Determine the amount of background radiation in your surroundings and identify their possible sources. • Set up a G.M. point tube and show the detection of Alpha particles with the help of CRO and determine the count rate using a scalar unit.

	quarks.	

Science, Technology and Society Connections

The students will:

- Explain the basic principle of nuclear reactor.
- Describe and discuss the function of the principle components of a water moderated power reactor (core, fuel, rods, moderator, control rods, heat exchange, safety rods and shielding).
- Explain why the uranium fuel needs to be enriched.
- Compare the amount of energy released in a fission reaction with the (given) energy released in a chemical reaction.
- Describe how the conditions in the interiors of the Sun and other stars allow nuclear fusion to take place and hence, how nuclear fusion is their main energy conversion process.
- Show an awareness about nuclear radiation exposure and biological effects of radiation.
- Describe the term dosimetry.
- Describe the use of radiations for medical diagnosis and therapy.
- Explain the importance of limiting exposure to ionizing radiation.
- Describe the examples of the use of radioactive tracers in medical diagnosis, agriculture and industry.

Unit overview

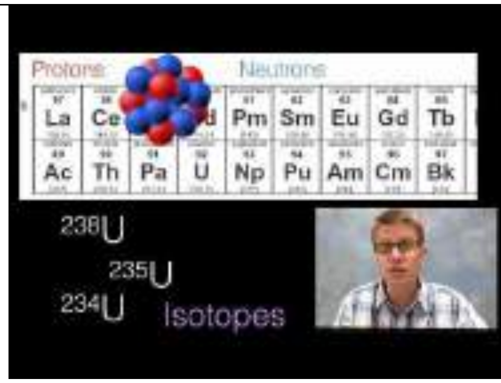
Composition of atomic nuclei

The **nucleus** is the center of an atom. It is made up of nucleons called (protons and neutrons) and is surrounded by the electron cloud. The size (diameter) of the nucleus is between 1.6 fm (10^{-15} m) (for a proton in light hydrogen) to about 15 fm (for the heaviest atoms, such as uranium). These sizes are much smaller than the size of the atom itself by a factor of about 23,000 (uranium) to about 145,000 (hydrogen). Although it is only a very small part of the atom, the nucleus has most of the mass. Almost all of the mass in an atom is made up from the protons and neutrons in the nucleus with a very small contribution from the orbiting electrons.

Neutrons have no charge and protons are positively charged. Because the nucleus is only made up of protons and neutrons it is positively charged. Things that have the same charge repel each other: this repulsion is part of what is called electromagnetic force. Unless there was something else holding the nucleus together it could not exist because the protons would push away from each other. The nucleus is actually held together by another force known as the strong nuclear force.

The word *nucleus* is from 1704, meaning “kernel of a nut”. In 1844, Michael Faraday used nucleus to describe the “central point of an atom”. The modern atomic meaning was proposed by Ernest Rutherford in 1912. The use of the word *nucleus* in atomic theory, however, did not happen immediately. In 1916, for example, Gilbert N. Lewis wrote in his famous article *The Atom and the Molecule* that "the atom is composed of the *kernel* and an outer atom or *shell*"

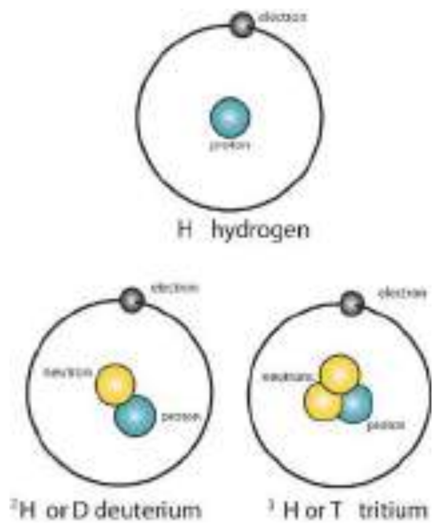
Videos



Reference pages

https://simple.wikipedia.org/wiki/Atomic_nucleus

Isotopes



Atoms that have the same atomic number (number of protons), but different mass numbers (number of protons and neutrons) are called isotopes. There are naturally occurring isotopes and isotopes that are artificially produced. Isotopes are separated through mass spectrometry; MS traces show the relative abundance of isotopes vs. mass number (mass : charge ratio).

Introduction

As mentioned before, isotopes are atoms that have the same atomic number, but different mass numbers. Isotopes are denoted the same way as nuclides, but they are often symbolized only with the mass numbers because isotopes of the same element have the the same atomic number. Carbon, for example, has two naturally occurring isotopes, 126*C*

and 136*C*. Because both of these isotopes have 6 protons, they are often written as 12*C* and 13*C*. 12*C* has 6 neutrons, and 13*C*

has 7 neutrons.

Of all the elements on the periodic table, only 21 are pure elements. Pure, or monotopic, elements are those elements with only one naturally occurring nuclide. The following lists the 21 pure elements

1. $^{27}_{13}Al$
2. $^{75}_{33}As$
3. $^{9}_{4}Be$
4. $^{209}_{83}Bi$
5. $^{133}_{55}Cs$
6. $^{59}_{27}Co$
7. $^{19}_{9}F$
8. $^{197}_{79}Au$
9. $^{165}_{67}Ho$
10. $^{127}_{53}I$
11. $^{55}_{25}Mn$
12. $^{93}_{41}Nb$
13. $^{31}_{15}P$
14. $^{141}_{59}Pr$
15. $^{103}_{45}Rh$
16. $^{45}_{21}Sc$
17. $^{23}_{11}Na$
18. $^{159}_{65}Tb$
19. $^{232}_{90}Th$
20. $^{169}_{69}Tm$
21. $^{89}_{39}Y$

Isotopes of the other elements either occur naturally or are artificially produced.

Natural and Artificial Isotopes

Most elements have naturally occurring isotopes. Percent natural abundances indicate which isotopes of any given element are predominant (occur in greater abundance) and which only occur in trace amounts. Mercury, for example, has seven naturally occurring isotopes: 196*Hg*

, 198*Hg*, 199*Hg*, 200*Hg*, 201*Hg*, 202*Hg*, 204*Hg*; these have the percent natural abundances of 0.146%, 10.02%, 16.84%, 23.13%, 13.22%, 29.80%, and 6.85%, respectively. It is clear that 202*Hg* occurs with greatest abundance, and 200*Hg*

is the next most abundant, but the other isotopes only occur in small traces.

Note: The sum of the percent natural abundances of all the isotopes of any given element must total 100%.

There are 20 elements with only artificially produced isotopes. The majority of these are heavier elements; the lightest elements with artificial isotopes are 43*Tc* and 61*Pm*. The other elements that only have artificial isotopes are those with atomic numbers of 84-88 and 89-103, otherwise known as the actinoids, but excluding 90*Th* and 92*U*

Some naturally occurring and artificially produced isotopes are radioactive. The nucleus of a radioactive isotope is unstable; radioactive isotopes spontaneously decay, emitting alpha, beta, and gamma rays until they reach a stability, usually in the state of a different element. Bismuth (20983*Bi*

) has the highest atomic and mass number of all the stable nuclides. All nuclides with atomic number and mass number greater than 83 and 209, respectively, are radioactive. However, there are some lighter nuclides that are radioactive. For example, hydrogen has two naturally occurring stable isotopes, 1*H* and 2*H* (deuterium), and a third naturally occurring radioactive isotope, 3*H*

(tritium).

Radioisotope Dating

The presence of certain radioisotopes in an object can be used to determine its age. Carbon dating is based on the fact that living plants absorb stable 12*C*

, 13*C* and radioactive 14*C* from the atmosphere, and animals absorb them from the plants. An organism no longer absorbs carbon after it dies, its age can be determined by measuring the ratio of 13*C* to 14*C*

in the sample and extrapolating based on its decay rate.

Art forgeries are often detected by similar means. 137*Cs*

and 90*Sr*

do not occur naturally and are only present in the atmosphere today because of nuclear weapons. Any object created before July 1945, then, would have neither of these elements, so finding them through mass spectrometry or other means would indicate that it was created later.

Isotopic Masses, Percent Natural Abundance, and Weighted-Average Atomic Mass

Because most elements occur as isotopes and different isotopes have different masses, the atomic mass of an element is the average of the isotopic masses, weighted according to their naturally occurring abundances; this is the mass of each element recorded on the periodic table, also known as the relative atomic mass (A_r). Treating isotopic masses in weighted averages gives greater importance to the isotope with greatest percent natural abundance. Below is a general equation to calculate the atomic mass of an element based on percent natural abundance and isotopic masses:

$$\text{atomic mass of an element} = \left({}^{*}\text{fractional abundance of isotope 1} \times \text{mass of isotope 1}\right) + \left(\text{fractional abundance of isotope 2} \times \text{mass of isotope 2}\right) + \ldots$$

* fractional abundance is the percent abundance divided by 100%

Bromine has two naturally occurring isotopes: bromine-79 has a mass of 78.9183 u and an abundance of 50.69%, and bromine-81 has a mass of 80.92 u and an abundance of 49.31%. The equation above can be used to solve for the relative atomic mass of bromine:

$$\text{atomic mass of Br} = (0.5069 \times 78.9183\ \text{u}) + (0.4931 \times 80.92\ \text{u}) = 79.91\ \text{u}$$

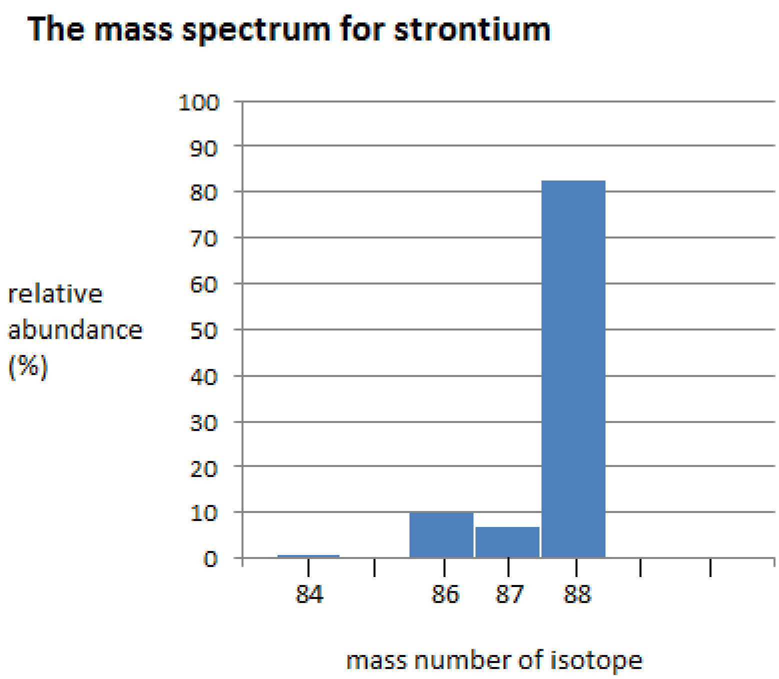
This is the relative atomic number of bromine that is listed on the periodic table.

Comparing their isotopic masses of any given element to the relative atomic mass of the element reveals that the A_r is very close to the isotope that occurs most frequently. Thus, the isotope whose isotopic mass is closest to the atomic mass of the element is the isotope that occurs in the greatest abundance.

Mass Spectrometry

Mass spectrometry is a technique that can be used to distinguish between isotopes of a given element. A mass spectrometer separates each isotope by mass number. Each isotope is characterized by a peak (of given intensity) according to its relative abundance. The most intense peak corresponds to the isotope that occurs in the largest relative natural abundance, and vice versa. Refer to Mass Spectrometry: Isotope Effects.

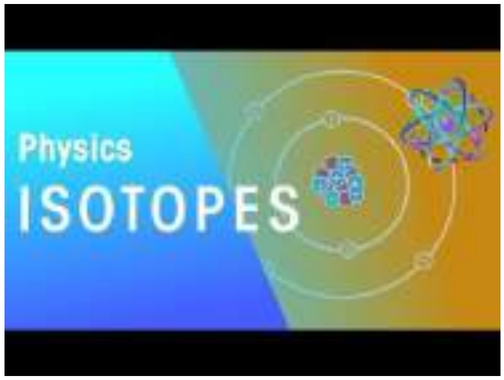
Example



The mass spectrum of strontium has four different peaks, varying in intensity. The four peaks indicate that there are four isotopes of strontium. The four isotopes of strontium have isotopic mass numbers of 84, 86, 87, and 88, and relative abundances of 0.56%, 9.86%, 7.00%, and 82.58%, respectively. The intensity of the peak corresponds to the abundance. 84*Sr*

has the smallest peak, which corresponds to its relative abundance of 0.56%, whereas 88*Sr* has the largest peak, which corresponds to its relative abundance of 82.58%. This indicates that 88*Sr* is the isotope that occurs in highest amounts.

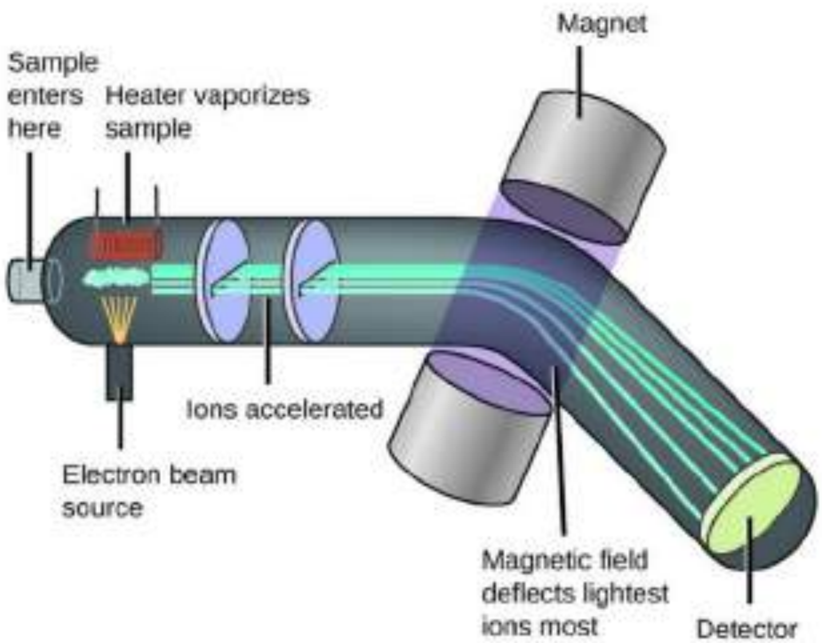
Video



Reference

https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Atomic_Theory/Isotopes

Mass spectrograph



Mass spectrograph, device used to separate electrically charged particles according to their masses; a form of the instrument known as a mass spectrometer is often used to measure the masses of isotopes of elements. J. J. Thomson and F. W. Aston showed (c.1900) that magnetic and electric fields can be used to deflect streams of charged particles traveling in a vacuum, and that the degree of bending depends on the masses and electric charges of the particles. In the mass spectrograph the particles, in the form of ions, pass through deflecting fields (produced by carefully designed magnetic pole pieces and electrodes) and are detected by photographic plates. The beam of ions first passes through a velocity selector, consisting of a combination of electric and magnetic fields that eliminates all particles except those of a given velocity. The remaining ion beam then enters an evacuated chamber where a magnetic field bends it into a semicircular path ending at the photographic plate. The radius of this path depends upon the mass of the particles (all other factors, such as velocity and charge, being equal). Thus, if in the original stream isotopes of various masses are present, the position of the blackened spots on the plate makes possible a calculation of the isotope masses. The mass spectrograph is widely used in chemical analysis and in the detection of impurities.

How a mass spectrometer works

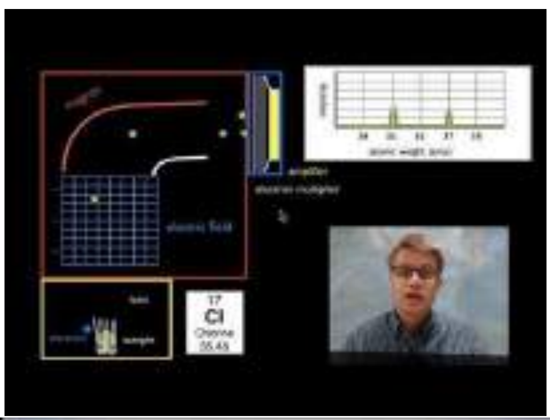
If something is moving and you subject it to a sideways force, instead of moving in a straight line, it will move in a curve - deflected out of its original path by the sideways force.

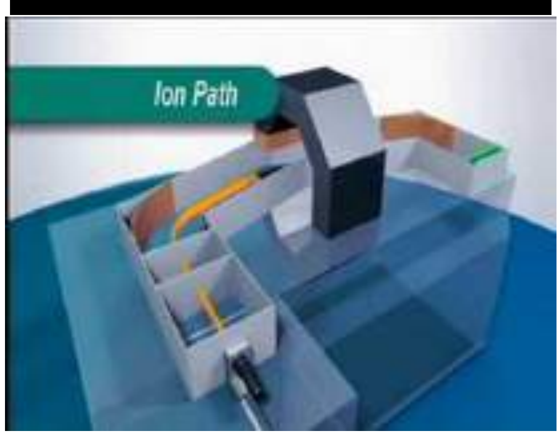
Suppose you had a cannonball travelling past you and you wanted to deflect it as it went by you. All you've got is a jet of water from a hose-pipe that you can squirt at it. Frankly, its not going to make a lot of difference! Because the cannonball is so heavy, it will hardly be deflected at all from its original course.

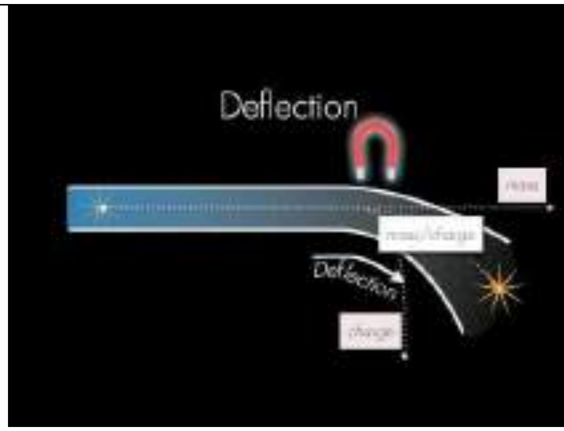
But suppose instead, you tried to deflect a table tennis ball travelling at the same speed as the cannonball using the same jet of water. Because this ball is so light, you will get a huge deflection.

The amount of deflection you will get for a given sideways force depends on the mass of the ball. If you knew the speed of the ball and the size of the force, you could calculate the mass of the ball if you knew what sort of curved path it was deflected through. The less the deflection, the heavier the ball

Video







Reference

https://www.infoplease.com/encyclopedia/science/physics/concepts/mass-spectrograph

https://www.chemguide.co.uk/analysis/masspec/howitworks.html

Mass defect and binding energy

Binding Energy

Nuclear binding energy is the energy required to split a nucleus of an atom into its component parts: protons and neutrons, or, collectively, the nucleons. The binding energy of nuclei is always a positive number, since all nuclei require net energy to separate them into individual protons and neutrons.

Mass Defect

Nuclear binding energy accounts for a noticeable difference between the actual mass of an atom's nucleus and its expected mass based on the sum of the masses of its non-bound components.

Recall that energy (E) and mass (m) are related by the equation:

[latex]E=mc^2[/latex]

Here, *c* is the speed of light. In the case of nuclei, the binding energy is so great that it accounts for a significant amount of mass.

The actual mass is always less than the sum of the individual masses of the constituent protons and neutrons because energy is removed when when the nucleus is formed. This energy has mass, which is removed from the total mass of the original particles. This mass, known as the mass defect, is missing in the resulting nucleus and represents the energy released when the nucleus is formed.

Mass defect (M_d) can be calculated as the difference between observed atomic mass (m_o) and that expected from the combined masses of its protons (m_p, each proton having a mass of 1.00728 amu) and neutrons (m_n, 1.00867 amu):

[latex]M_d=(m_n+m_p)-m_o[/latex]

Nuclear Binding Energy

Once mass defect is known, nuclear binding energy can be calculated by converting that mass to energy by using $E=mc^2$. Mass must be in units of kg.

Once this energy, which is a quantity of joules for one nucleus, is known, it can be scaled into per-nucleon and per-mole quantities. To convert to joules/mole, simply multiply by Avogadro's number. To convert to joules per nucleon, simply divide by the number of nucleons.

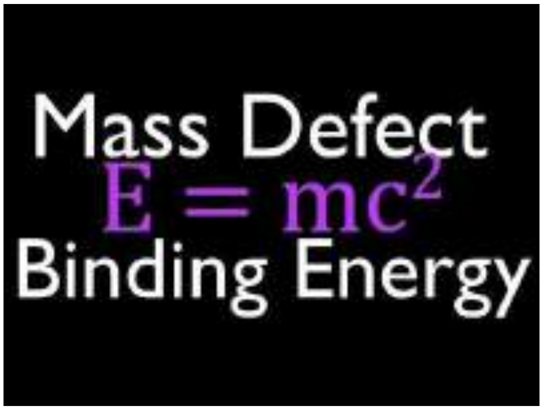
Nuclear binding energy can also apply to situations when the nucleus splits into fragments composed of more than one nucleon; in these cases, the binding energies for the fragments, as compared to the whole, may be either positive or negative, depending on where the parent nucleus and the daughter fragments fall on the nuclear binding energy curve. If new binding energy is available when light nuclei fuse, or when heavy nuclei split, either of these processes result in the release of the binding energy. This energy—available as nuclear energy—can be used to produce nuclear power or build nuclear weapons. When a large nucleus splits into pieces, excess energy is emitted as photons, or gamma rays, and as kinetic energy, as a number of different particles are ejected.

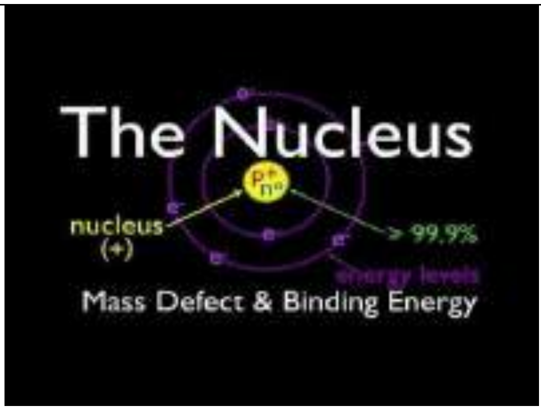
Nuclear binding energy is also used to determine whether fission or fusion will be a favorable process. For elements lighter than iron-56, fusion will release energy because the nuclear binding energy increases with increasing mass. Elements heavier than iron-56 will generally release energy upon fission, as the lighter elements produced contain greater nuclear binding energy. As such, there is a peak at iron-56 on the nuclear binding energy curve.

Nuclear binding energy curve . This graph shows the nuclear binding energy (in MeV) per nucleon as a function of the number of nucleons in the nucleus. Notice that iron-56 has the most binding energy per nucleon, making it the most stable nucleus.

The rationale for this peak in binding energy is the interplay between the coulombic repulsion of the protons in the nucleus, because like charges repel each other, and the strong nuclear force, or strong force. The strong force is what holds protons and neutrons together at short distances. As the size of the nucleus increases, the strong nuclear force is only felt between nucleons that are close together, while the coulombic repulsion continues to be felt throughout the nucleus; this leads to instability and hence the radioactivity and fissile nature of the heavier elements.

Video

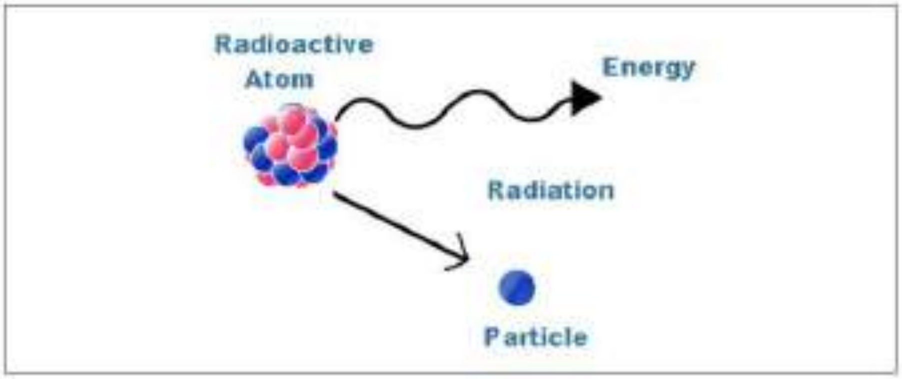




Reference

https://courses.lumenlearning.com/introchem/chapter/nuclear-binding-energy-and-mass-defect/

Radioactivity (properties of α, β and γ rays)



During radioactivity, particles like alpha, beta & gamma rays are emitted by an atom, due to unstable atom trying to gain stability. Hence, the atoms eventually decay by emitting a particle that transforms when they are unstable and transforms the nucleus into a lower energy state. This process of decaying continues till the nucleus attains a stable stage.

There exist three major types of radiations emitted by the radioactive particles namely:

- Alpha
- Beta

- Gama

These radiations are released from the nucleus of an atom. Their behavior differs from one another, though all the three causes some ionization and carry some penetration power. Let's discuss the properties of beta, alpha and gamma one by one.

Alpha Rays

Alpha rays are the positively charged particles. Alpha-particle is highly active and energetic helium atom that contains two neutrons and protons. These particles have the minimum penetration power and highest ionization power. They can cause serious damage if get into the body due to their high ionization power. They are capable of ionizing numerous atoms by a short distance. It is due to the fact that the radioactive substances that release alpha particles are required to be handled after wearing rubber gloves.

Beta Rays

Beta particles are extremely energetic electrons that are liberated from the inner nucleus. They bear negligible mass and carry the negative charge. A neutron in the nucleus splits into a proton and an electron on the emission of a beta particle. Hence, it is the electron that is emitted by the nucleus at a rapid pace. Beta particles have a higher penetration power when compared to alpha particles and can travel through the skin with ease. Beta particles can be dangerous and any contact with the body must be avoided, though their ionization power is low.

Gamma Rays

The waves arising from the high-frequency end of the electromagnetic spectrum that has no mass are known as gamma rays. They hold the highest power of penetration. They are the most penetrating but least ionizing and very difficult to resist them from entering the body. The Gamma rays carry a large amount of energy and can also travel via thick concrete and thin lead.

The below table describes the characteristics of beta, alpha and gamma radiations and compares the masses and charges of the three rays.

Property	α\alphaα ray	β\betaβ ray	γ\gammaγ ray
Nature	Positive charged particles, 2He 4 nucleus	Negatively charged particles (electrons).	Uncharged ?~0.01a, electromagneti radiation
Charge	+2e	–e	0
Mass	6.6466 × 10–27 kg	9.109 × 10–31 kg	0
Range	~10 cm in air, can be stopped by 1mm of Aluminium	Upto a few m in air, can be stopped by a thin layer of Aluminium	Several m in air, can be stopped by a layer of Lead
Natural Sources	By natural radioisotopes e.g.92U236	By radioisotopes e.g.29Co68	Excited nuclei formed as a result of decay

Video

Reference

https://byjus.com/jee/properties-of-alpha-beta-gamma-rays/

Energy from nuclear decay

The decay energy is the energy released by a radioactive decay. Radioactive decay is the process in which an unstable atomic nucleus loses energy by emitting ionizing particles and radiation. This decay, or loss of energy, results in an atom of one type, called the parent nuclide transforming to an atom of a different type, called the daughter nuclide.

Video

Reference

https://en.wikipedia.org/wiki/Decay_energy

Half life and rate of decay

Describing reaction rates is based on the time required for the concentration of a reactant to decrease to one-half its initial value. This period of time is called the half-life of the reaction, written as $t_{1/2}$. Thus the half-life of a reaction is the time required for the reactant concentration to decrease from $[A]_0$ to $[A]_{0/2}$. If two reactions have the same order, the faster reaction will have a shorter half-life, and the slower reaction will have a longer half-life.

The half-life of a first-order reaction under a given set of reaction conditions is a constant. This is not true for zeroth- and second-order reactions. The half-life of a first-order reaction is independent of the concentration of the reactants. This becomes evident when we rearrange the integrated rate law for a first-order reaction (Equation 14.21) to produce the following equation:

$$\ln\frac{[A]_0}{[A]}=kt \quad (1)$$

Substituting $[A]_{0/2}$ for $[A]$ and $t_{1/2}$ for t (to indicate a half-life) into Equation 1

gives

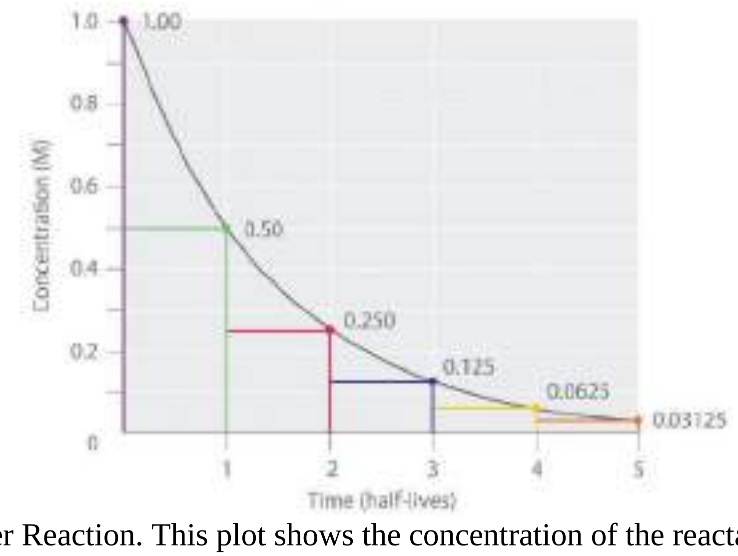
$$\ln\frac{[A]_0}{[A]_0/2}=\ln 2=kt_{1/2} \quad (2)$$

Substituting $\ln 2 \approx 0.693$

into the equation results in the expression for the half-life of a first-order reaction:

$t_{1/2}=\frac{0.693}{k} \quad (3)$

Thus, for a first-order reaction, each successive half-life is the same length of time, as shown in Figure 1
, and is *independent* of [A].



The Half-Life of a First-Order Reaction. This plot shows the concentration of the reactant in a first-order reaction as a function of time and identifies a series of half-lives, intervals in which the reactant concentration decreases by a factor of 2. In a first-order reaction, every half-life is the same length of time.

If we know the rate constant for a first-order reaction, then we can use half-lives to predict how much time is needed for the reaction to reach a certain percent completion.

Number of Half-Lives	Percentage of Reactant Remaining
1	$\frac{100\%}{2}=50\%$

12(100%)=50%

2 50%2=25%

12(12)(100%)=25%

3 25%2=12.5%

12(12)(12)(100%)=12.5%

n 100%2*n*

(12)*n*(100%)=(12)*n*%

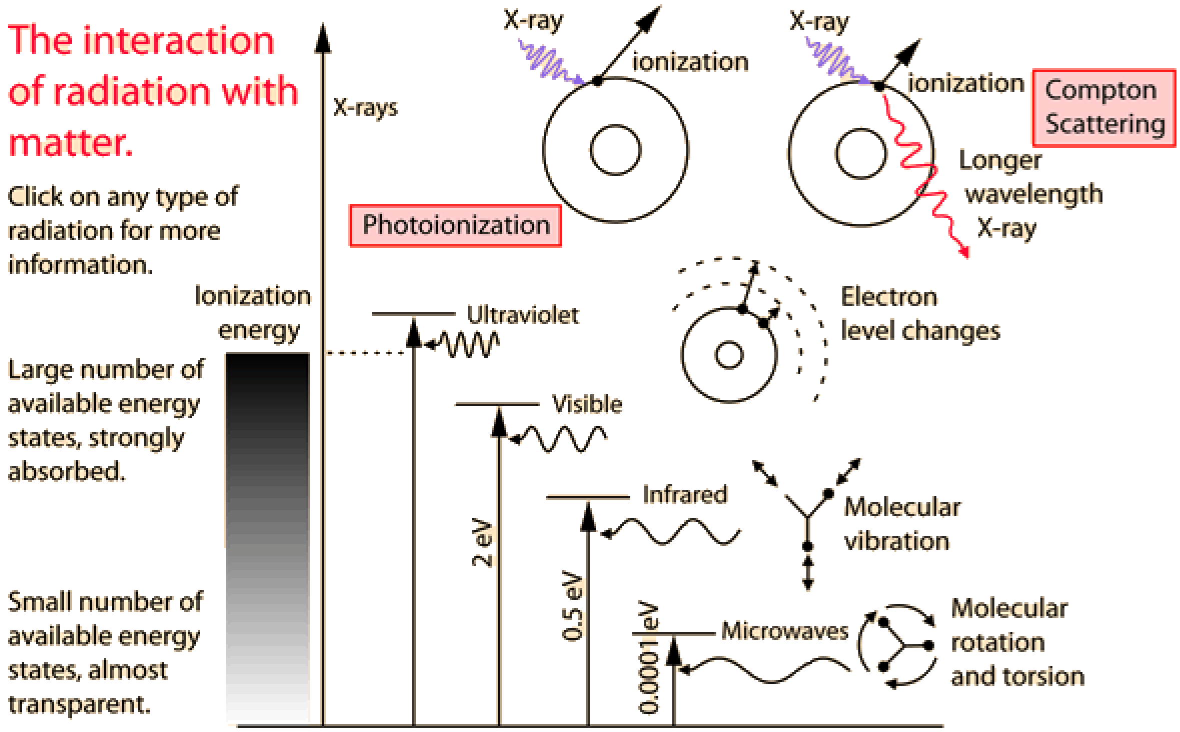
As you can see from this table, the amount of reactant left after *n* half-lives of a first-order reaction is $(1/2)^n$ times the initial concentration.

Video

Reference

https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Nuclear_Chemistry/Nuclear_Kinetics/Half-Lives_and_Radioactive_Decay_Kinetics

Interaction of radiation with matter



You may click on any of the types of radiation for more detail about its particular type of interaction with matter. The different parts of the electromagnetic spectrum have very different effects upon interaction with matter. Starting with low frequency radio waves, the human body is quite transparent. (You can listen to your portable radio inside your home since the waves pass freely through the walls of your house and even through the person beside you!) As you move upward through microwaves and infrared to visible light, you absorb more and more strongly. In the lower ultraviolet range, all the uv from the sun is absorbed in a thin outer layer of your skin. As you move further up into the x-ray region of the spectrum, you become transparent again, because most of the mechanisms for absorption are gone. You then absorb only a small fraction of the radiation, but that absorption involves the more violent ionization events. Each portion of the electromagnetic spectrum has quantum energies appropriate for the excitation of certain types of physical processes. The energy levels for all physical processes at the atomic and molecular levels are quantized, and if there are no available quantized energy levels with spacings which match the quantum energy of the incident radiation, then the material will be transparent to that radiation, and it will pass through. If electromagnetic energy is absorbed, but cannot eject electrons from the atoms of the material, then it is classified as non-ionizing radiation, and will typically just heat the material.

Video

Reference

http://hyperphysics.phy-astr.gsu.edu/hbase/mod3.html

Radiation detectors (GM counter and solid state detector)

For those who work with or around radiation, one of the most important factors is an awareness of the levels of radiation around them. This is primarily accomplished through the use of radiation detectors of varying types. A basic understanding of the different types of detectors out there and how they work can go a long way both to finding the best detector for the required task and also for maximizing the benefits of operating that detector.

A NOTE: "GEIGER COUNTERS"

Many people, thinking of radiation detection, tend to group them all together under the term "Geiger counters," a misconception heartily encouraged by popular TV shows and movies. While one of the most common types of radiation detector is in fact called a "Geiger Mueller (G-M) tube," the catchall phrase "Geiger Counter" isn't always the most appropriate. It applies to a very specific type of detector, and generally to a specific application of that detector. Radiation detection devices are typically categorized by either the type of detector element employed, or by the application involved. People will refer to instruments as an Ion Chamber, or a Survey Meter, or a Contamination Meter, or a Frisker Probe. Popular culture has so thoroughly subverted the proper usage of "Geiger Counter" that using the phrase doesn't generally provide enough information about the device in question.

FIRST RADIATION DETECTORS

Since the early days of radiation testing by Roentgen and Becquerel, scientists have sought ways to measure and observe the radiation given off by the materials they worked with. One of the earliest means of capturing any sort of data from radioactivity was a photographic plate. A photographic plate would be placed in the path/vicinity of a radioactive beam or material. When the plate was developed, it would have spots or be fogged from the exposure to the radiation. Henri Becquerel used a method similar to this to demonstrate the existence of radiation in 1896.

Another common early detector was the electroscope. These used a pair of gold leaves that would become charged by the ionization caused by radiation and repel each other. This provided a means of measuring radiation with a better level of sensitivity than was reliably possible using photographic plates. Depending on the arrangement of the device, they could be configured to measure alpha or beta particles, and were a valuable tool for early experiments involving radioactivity.

An interesting early device, borne out of a desire to measure the actual individual particles or rays being emitted by a radioactive substance, as opposed to a more gross measurement of a radioactive field, was the spinthariscope. Developed by William Crookes, who had also invented the Crookes Tube used by Wilhelm Roentgen to discover X-Rays, it used a zinc sulfide screen at the end of a tube, with a lens at the other end, with a small amount of a radioactive substance near the zinc sulfide screen. The zinc sulfide would react with the alpha particles emitted, and each interaction would result in a tiny flash of light. This was one of the first means of counting a rate of decay, albeit a very tedious one, as it meant scientists had to work in shifts watching and literally counting the flashes of light. The spinthariscope wasn't very practical as a long term solution for radiation detection, though it did undergo a revival later in the 20th century as an educational tool. This tendency of certain materials to give off light when exposed to radiation would also prove valuable in future radiation detection technologies.

These early devices, and many others, such as cloud chambers, were valuable in developing an understanding of the basic principles of radiation and conducting important experiments that set the stage for later developments. This included development of new types of radiation detectors, many of which are still in use today, such as G-M Tubes, Ion Chambers, and Scintillators.

WHERE/WHEN YOU'D NEED RADIATION DETECTORS

An important part of knowing what type of detector to use is to have an idea of how and where it will be used. Different applications and settings call for different types of detectors, as each detector type has various ways it can be specialized to fit a role. The applications for radiation detection instruments can be broadly categorized into a few different core tasks: measurement, protection, and search.

Radiation measurement tasks are for situations where there is a known presence of radioactive materials which need to be monitored. The goal with this type of detection is awareness. Awareness of the strength of an established radioactive field, the boundaries of a radioactive area, or simply of the spread of radioactive contamination. These are settings where the presence of radiation is expected, or at least considered likely. The requirements for detectors involved in these settings are unique, often with relatively higher measurement ranges or with modifications needed to specifically look for one type of radiation.

Radiation protection is similar to radiation measurement applications in the sense that it is usually in a setting where radiation is expected to be found. However, the goals are different. With radiation measurement settings, the goal is to monitor the radioactivity itself, to be aware of fluctuations, boundaries, etc. With radiation protection, the goal is monitoring people. Radiation dosimetry is the most common example of this, with radiation badges being worn by medical personnel, nuclear industry workers, and many other occupationally exposed workers all over the world. The importance of this is that it provides protection from the most harmful effects of radiation exposure through awareness, in that a wearer can keep informed of how much radiation they've been exposed to, and how that corresponds to potential health effects, and alter their behavior or position or schedule accordingly.

Radiation search differs from the other two basic categories of radiation detection applications in that it is predicated both on the fact that radiation is not expected in the area, and the desire to keep things that way. Primarily the goal of radiation security personnel, first responders, or groups such as customs & border inspectors, radiation search has a different set of requirements to mirror the significantly different circumstances in which it takes place. Detectors need to be highly sensitive, with the concern being more about smaller, concealed radioactive sources or materials.

Spectroscopy is often very helpful as well, since it is typically a small subset of radioactive isotopes that are of concern, and being able to filter those out that are present due to legitimate reasons such as medical treatment or just an accumulation of a naturally occurring radioactive substance is important.

These three categories, and the varying tasks that fit inside them, help determine what the best type of instrument or detector is best suited for the task.

TYPES

When talking about radiation detection instruments, there are three types of detectors that are most commonly used, depending on the specific needs of the device. These are: Gas-Filled Detectors, Scintillators, and Solid State detectors. Each has various strengths and weaknesses that recommend them to their own specific roles.

GAS FILLED

The first type of radiation detector, gas-filled detectors, are amongst the most commonly used. There are several types of gas-filled detector, and while they have various differences in how they work, they all are based on similar principles. When the gas in the detector comes in contact with radiation, it reacts, with the gas becoming ionized and the resulting electronic charge being measured by a meter.

The different types of gas-filled detectors are: ionization chambers, proportional counters, and Geiger-Mueller (G-M) tubes. The major differentiating factor between these different types is the applied voltage across the detector, which determines the type of response that the detector will register from an ionization event.

ION CHAMBER

At the lower end of the voltage scale for gas-filled detectors are Ionization Chambers, or Ion Chambers. They operate at a low voltage, meaning that the detector only registers a measurement from the “primary” ions (in actuality pair of ions created: a positively charged ion and a free election) caused by an interaction with a radioactive photon in the reaction chamber. Thus the measurement that the detector records is directly proportional to the number of ion pairs created. This is particularly useful as a measure of absorbed dose over time. They are also valuable for the measurement of high-energy gamma rays, as they don’t have any of the issues with dead time that other detector types can have.

However, ion chambers are unable to discriminate between different types of radiation, meaning they cannot be used for spectroscopy. They can also tend towards being more expensive than other solution. Despite this, they are valuable detectors for survey meters. They are also widely used in laboratories to establish reference standards for calibrations.

PROPORTIONAL

The next step up on the voltage scale for gas-filled detectors is the proportional (or gas-proportional) counter. They are generally devised so that for much of the area inside the chamber, they perform similarly to an ion chamber, in that interactions with radiation create ion pairs. However, they have a strong enough voltage that the ions "drift" towards the detector anode. As the ions approach the detector anode, the voltage increases, until they reach a point where a "gas amplification" effect occurs.

Gas amplification means that the original ions created by the reaction with a photon of radiation causes further ionization reactions, which multiply the strength of the output pulse measured across the detector. The resulting pulse is proportional to the number of original ion pairs formed, which correlates to the energy of the radioactive field that it is interacting with.

The makes proportional counters very useful for some spectroscopy applications, since they react differently to different energies, and thus are able to tell the difference between different types of radiation that they come into contact with. They are also highly sensitive, which coupled with their effectiveness at alpha and beta detection and discrimination, makes this type of detector very valuable as a contamination screening detector.

GM TUBE

The last major class of gas-filled detectors is the Geiger-Mueller tube, the origin of the name "Geiger Counter." Operating at a much higher voltage than other detector types, they differ from other detector types in that each ionization reaction, regardless of whether it is a single particle interaction or a stronger field, causes a gas-amplification effect across the entire length of the detector anode. Thus they can only really function as simple counting devices, used to measure count rates or, with the correct algorithms applied, dose rates.

After each pulse, a G-M has to be "reset" to its original state. This is accomplished by quenching. This can be accomplished electronically by temporarily lowering the anode voltage on the detector after each pulse, which allows the ions to recombine back to their inert state. This can also be accomplished chemically with a quenching gas such as halogen which absorbs the additional photons created by an ionization avalanche without becoming ionized itself.

Due to the extensive reaction G-M tubes experience with each pulse of radiation, they can experience something called "dead time" at higher exposure rates, meaning that there is a lag between the pulse cascade and when the gas is able to revert to its original state and be ready to detect another pulse. This can be accommodated for with calibration, or with algorithms in the detection instruments themselves to "calculate" what the additional pulses would be based on the existing measurement data.

SCINTILLATORS

The second major type of detectors utilized in radiation detection instruments are Scintillation Detectors. Scintillation is the act of giving off light, and for radiation detection it is the ability of some material to scintillate when exposed to radiation that makes them useful as detectors. Each photon of radiation that interacts with the scintillator material will result in a distinct flash of light, meaning that in addition to being highly sensitive, scintillation detectors are able to capture specific spectroscopic profiles for the measured radioactive materials.

Scintillation detectors work through the connection of a scintillator material with a photomultiplier (PM) tube. The PM tube uses a photocathode material to convert each pulse of light into an electron, and then amplifies that signal significantly in order to generate a voltage pulse that can then be read and interpreted. The number of these pulses that are measured over time indicated the strength of the radioactive source being measured, whereas the information on the specific energy of the radiation, as indicated by the number of photons of light being captured in each pulse, gives information on the type of radioactive material present.

Due to their high sensitivity and their potential ability to "identify" radioactive sources, scintillation detectors are particularly useful for radiation security applications. These can take many forms, from handheld devices used to screen containers for hidden or shielded radioactive material, to monitors set up to screen large areas or populations, able to differentiate between natural or medical sources of radiation and sources of more immediate concern, such as Special Nuclear Material (SNM).

SOLID STATE

The last major detector technology used in radiation detection instruments are solid state detectors. Generally using a semiconductor material such as silicon, they operate much like an ion chamber, simply at a much smaller scale, and at a much lower voltage. Semiconductors are materials that have a high resistance to electronic current, but not as high a resistance as an insulator. They are composed of a lattice of atoms that contain "charge carriers," these being either electrons available to attach to another atom, or electron "holes," or atoms with an empty place where an electron would/could be.

Silicon solid state detectors are composed of two layers of silicon semiconductor material, one "n-type," which means it contains a greater number of electrons compared to holes, and one "p-type," meaning it has a greater number of holes than electrons. Electrons from the n-type migrate across the junction between the two layers to fill the holes in the p-type, creating what's called a depletion zone.

This depletion zone acts like the detection area of an ion chamber. Radiation interacting with the atoms inside the depletion zone causes them to re-ionize, and create an electronic pulse which can be measured. The small scale of the detector and of the depletion zone itself means that the ion pairs can be collected quickly, meaning that the instruments utilizing this type of detector can have a particularly quick response time. This, when coupled with their small size, makes this type of solid state detector very useful for electronic dosimetry applications. They are also able to withstand a much higher amount of radiation over their lifetime than other detectors types such as G-M Tubes, meaning that they are also useful for instruments operating in areas with particularly strong radiation fields

Video

Reference

https://www.mirion.com/learning-center/radiation-detector-types/introduction-to-radiation-detectors

Nuclear reactions

Nuclear reactions are processes in which one or more nuclides are produced from the collisions between two atomic nuclei or one atomic nucleus and a subatomic particle. The nuclides produced from nuclear reactions are different from the reacting nuclei (commonly referred to as the parent nuclei).

Two notable types of nuclear reactions are **nuclear fission reactions** and **nuclear fusion reactions**. The former involves the absorption of neutrons (or other relatively light particles) by a heavy nucleus, which causes it to split into two (or more) lighter nuclei. Nuclear fusion reactions are the processes in which two relatively light nuclei combine (via a collision) to afford a single, heavier nucleus.

Processes that are not Considered to be Nuclear Reactions

The term 'nuclear reaction' is generally used to refer to the externally induced changes brought on to atomic nuclei. Therefore, the following processes cannot be classified as nuclear reactions:

- Nuclear scattering processes – processes that involve the collision and subsequent separation of atomic nuclei without any notable changes in the nuclear composition. In these processes, only momentum and energy are transferred.
- Nuclear Decay – a process through which an unstable nucleus emits radiation in order to lose energy.
- Spontaneous fission reactions – nuclear fission reactions that do not require a neutron to proceed and are, therefore, not induced.

These processes are quite similar to nuclear reactions (but are spontaneous rather than induced).

Why do Nuclear Reactions Release Tremendous Amounts of Energy?

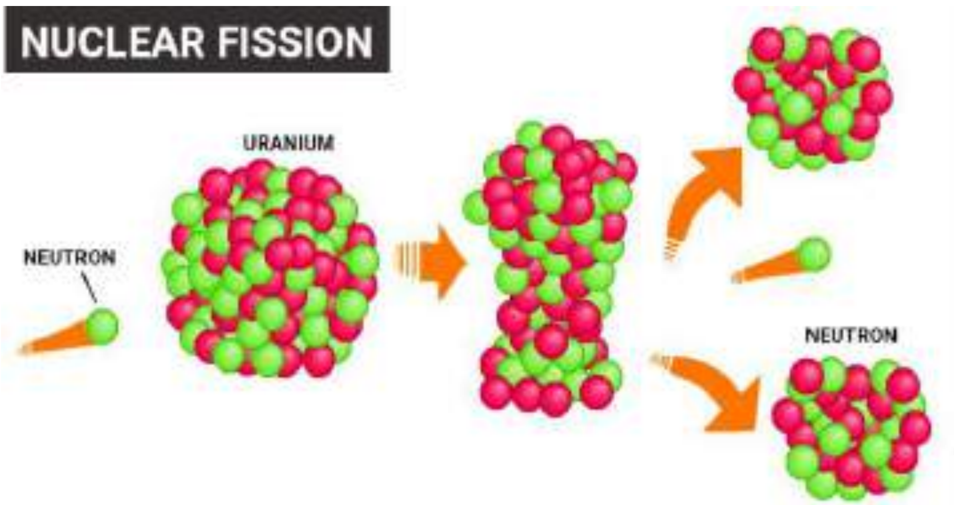
The mass of an atomic nucleus is always less than the sum of the individual masses of each subatomic particle that constitutes it (protons and neutrons). This difference in mass is attributed to nuclear binding energy (often referred to as a mass defect). Nuclear binding energy can be defined as the energy required to hold all the protons and neutrons within the nucleus.

During a nuclear reaction (such as a fission or fusion reaction), the mass accounted for by the nuclear binding energy is released in accordance with the equation $e = mc^2$ (energy = mass times the square of the speed of light).

To simplify, the products formed in nuclear fission and nuclear fusion always have a lower mass than the reactants. This 'missing' mass is converted into energy. A single gram of matter can release approximately 90,00,00,00,000 kilojoules of energy.

Nuclear Fission

Nuclear fission refers to the splitting of an atomic nucleus into two or more lighter nuclei. This process can occur through a nuclear reaction or through radioactive decay. Nuclear fission reactions often release a large amount of energy, which is accompanied by the emission of neutrons and gamma rays (photons holding huge amounts of energy, enough to knock electrons out of atoms).



Nuclear fission was first discovered by the German chemists Otto Hahn and Fritz Strassmann in the year 1938. The energy produced from fission reactions is converted into electricity in nuclear power plants. This is done by using the heat produced from the nuclear reaction to convert water into steam. The steam is used to rotate turbines in order to generate electricity.

Examples

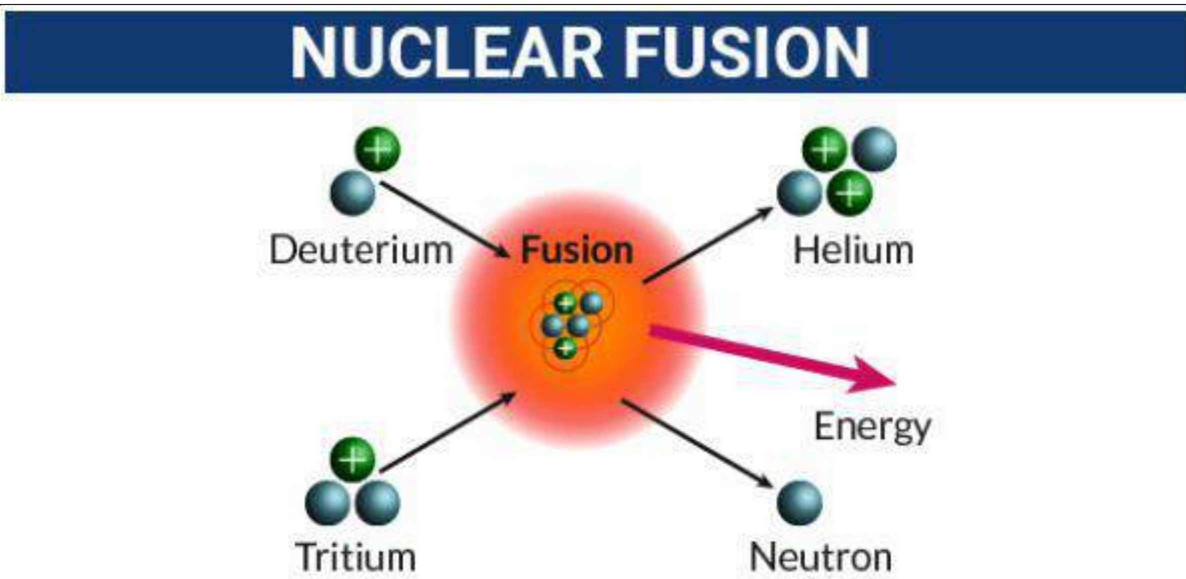
An important example of nuclear fission is the splitting of the uranium-235 nucleus when it is bombarded with neutrons. Various products can be formed from this nuclear reaction, as described in the equations below.

- $^{235}U + {}^{1}n \rightarrow {}^{141}Ba + {}^{92}Kr + 3\,{}^{1}n$
- $^{235}U + {}^{1}n \rightarrow {}^{144}Xe + {}^{90}Sr + 2\,{}^{1}n$
- $^{235}U + {}^{1}n \rightarrow {}^{146}La + {}^{87}Br + 3\,{}^{1}n$
- $^{235}U + {}^{1}n \rightarrow {}^{137}Te + {}^{97}Zr + 2\,{}^{1}n$
- $^{235}U + {}^{1}n \rightarrow {}^{137}Cs + {}^{96}Rb + 3\,{}^{1}n$

Another important example of nuclear fission is the splitting of the plutonium-239 nucleus.

Nuclear Fusion

In nuclear fusion reactions, at least two atomic nuclei combine/fuse into a single nucleus. Subatomic particles such as neutrons or protons are also formed as products in these nuclear reactions.



An illustration of the nuclear fusion reaction between deuterium (^2H) and tritium (^3H) that yields helium (^4He) and a neutron (^1n) is provided above. Such fusion reactions occur at the core of the sun and other stars. The fusion of deuterium and tritium nuclei is accompanied by a loss of approximately 0.0188 amu of mass (which is completely converted into energy). Approximately $1.69*10^9$ kilojoules of energy are generated for every mole of helium formed.

Other Important Types of Nuclear Reactions

Alpha Decay

Nuclei with mass numbers greater than 200 tend to undergo alpha decay – a process in which a ^4He nucleus, commonly referred to as an alpha particle ($^4{}_2\alpha$) is liberated from the parent nucleus.

The general equation for alpha decay is: $\mathbf{^{A}{}_{Z}X \rightarrow {}^{(A-4)}{}_{(Z-2)}X' + {}^{4}{}_{2}\alpha}$

Where A is the mass number and Z is the atomic number. An example of alpha decay is provided below.

$\mathbf{^{226}Ra \rightarrow {}^{222}Rn + {}^{4}{}_{2}\alpha}$

Here, the radium-226 nucleus decays into a radon-222 nucleus, liberating an alpha particle in the process.

Beta Decay

Beta decay occurs when a neutron is converted into a proton, which is accompanied by the emission of a beta particle (high-energy electron). An example of this type of nuclear reaction is the beta decay of carbon-14 that affords nitrogen-14:

$\mathbf{^{14}{}_{6}C \rightarrow {}^{14}{}_{7}N + {}^{0}{}_{-1}\beta}$

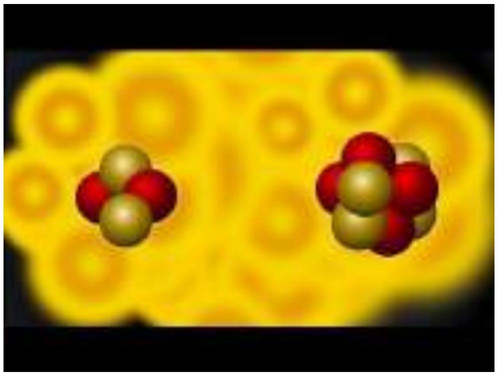
Gamma Emission

Gamma emission occurs when an excited nucleus (often produced from the radioactive decay of another nucleus) returns to its ground state, which is accompanied by the emission of a high energy photon.

An example of gamma emission is the de-excitation of the excited thallium-234 nucleus (which is produced from the alpha decay of uranium-238). The equation for this nuclear reaction is:

$^{234}Th^{*} \rightarrow {}^{234}Th + \gamma$

Video



Reference

https://byjus.com/chemistry/nuclear-reaction/

Radiation exposure

Radiation is energy in the form of particles or waves. Radiation is emitted naturally in sunlight and is also made by man for use in X-rays, cancer treatment, and for nuclear facilities and weapons.

Long-term exposure to small amounts of radiation can lead to gene mutations and increase the risk of cancer, while exposure to a large amount over a brief period can lead to radiation sickness. Some examples of the symptoms seen in radiation sickness include nausea, skin burns, hair loss and reduced organ function. In severe cases, exposure to a large amount of radiation can even cause death.

In terms of radiation in relation to health, two forms of radiation can be considered: non-ionising radiation (low energy radiation) and ionising radiation (high energy radiation).

As the more powerful form of radiation, ionising radiation is more likely to damage tissue than non-ionising radiation. The main source of exposure to ionising radiation is the radiation used during medical exams such as X-ray or computed tomography scans. However, the amounts of radiation used are so small that the risk of any damaging effects is minimal. Even when radiotherapy is used to treat cancer, the amount of ionising radiation used is so carefully controlled that the risk of problems associated with exposure is tiny.

Examples of non-ionising radiation include visible light, microwaves, ultraviolet (UV) radiation, infrared radiation, radio waves, radar waves, mobile phone signals and wireless internet connections.

The main source of non-ionising radiation that has been proven damaging to health is UV-radiation. High levels of UV-radiation can cause sunburn and increase the risk of skin cancer developing.

Some researchers have suggested that the use of telecommunications devices such as mobile phones may be damaging, but no risk associated with the use of these devices has yet been identified in any scientific studies.

Video

Reference

https://www.news-medical.net/health/What-is-Radiation-Exposure.aspx

Biological and medical uses of radiations (radiation therapy, diagnosis of diseases,tracers techniques)

Applications of radioactivity

In medicine

Radioisotopes have found extensive use in diagnosis and therapy, and this has given rise to a rapidly growing field called nuclear medicine. These radioactive isotopes have proven particularly effective as tracers in certain diagnostic procedures. As radioisotopes are identical chemically with stable isotopes of the same element, they can take the place of the latter in physiological processes. Moreover, because of their radioactivity, they can be readily traced even in minute quantities with such detection devices as gamma-ray spectrometers and proportional counters. Though many radioisotopes are used as tracers, iodine-131, phosphorus-32, and technetium-99*m* are among the most important. Physicians employ iodine-131 to determine cardiac output, plasma volume, and fat metabolism and particularly to measure the activity of the thyroid gland where this isotope accumulates. Phosphorus-32 is useful in the identification of malignant tumours because cancerous cells tend to accumulate phosphates more than normal cells do. Technetium-99*m*, used with radiographic scanning devices, is valuable for studying the anatomic structure of organs.

Such radioisotopes as cobalt-60 and cesium-137 are widely used to treat cancer. They can be administered selectively to malignant tumours and so minimize damage to adjacent healthy tissue.

In industry

Foremost among industrial applications is power generation based on the release of the fission energy of uranium (*see* nuclear fission; nuclear reactor: Nuclear fission reactors). Other applications include the use of radioisotopes to measure (and control) the thickness or density of metal and plastic sheets, to stimulate the cross-linking of polymers, to induce mutations in plants in order to develop hardier species, and to preserve certain kinds of foods by killing microorganisms that cause spoilage. In tracer applications radioactive isotopes are employed, for example, to measure the effectiveness of motor oils on the wearability of alloys for piston rings and cylinder walls in automobile engines. For additional information about industrial uses, *see* radiation: Applications in science and industry.

In science

Research in the Earth sciences has benefited greatly from the use of radiometric-dating techniques, which are based on the principle that a particular radioisotope (radioactive parent) in geologic material decays at a constant known rate to daughter isotopes. Using such techniques, investigators have been able to determine the ages of various rocks and rock formations and thereby quantify the geologic time scale (*see* geochronology: Absolute dating). A special application of this type of radioactivity age method, carbon-14 dating, has proved especially useful to physical anthropologists and archaeologists. It has helped them to better determine the chronological sequence of past events by enabling them to date more accurately fossils and artifacts from 500 to 50,000 years old.

Radioisotopic tracers are employed in environmental studies, as, for instance, those of water pollution in rivers and lakes and of air pollution by smokestack effluents. They also have been used to measure deep-water currents in oceans and snow-water content in watersheds. Researchers in the biological sciences, too, have made use of radioactive tracers to study complex processes. For example, thousands of plant metabolic studies have been conducted on amino acids and compounds of sulfur, phosphorus, and nitrogen.

Outside of nuclear power and nuclear weaponry, there remains a wide array of ways in which radioactive material and the radiation it gives off remain useful in the daily lives of people all over the world.

SMOKE DETECTORS

An Americium-241 source from a smoke detector

Some smoke detectors also use radioactive elements as part of their detection mechanism, usually americium-241, which use the ionizing radiation of the alpha particles to cause and then measure changes in the ionization of the air immediately around the detector. A change due to smoke in the air will cause the alarm to sound.

MEDICINE


X-Rays are one of the most common uses of radiation in medicine, providing valuable information to doctors and other medical professionals on patient injuries or maladies

Hospitals use radiation in a wide range of ways. X-Ray, CT, and PET machines use X-ray (X-ray and CT) and Gamma radiation (PET) to produce detailed images of the human body, which provide valuable diagnostic information for doctors and their patients. Radionuclides are also used to directly treat illnesses, such as radioactive iodine, which is taken up almost exclusively by the thyroid, to treat cancer or hyperthyroidism. Radioactive tracers and dyes are also used to be able to accurately map a specific area or system, such as in a cardiac stress test, which may use a radioactive isotope like Technetium-99 to identify areas of the heart and surrounding arteries with diminished blood flow.

RADIOGRAPHY

Essentially high-powered versions of the types of X-Ray machines used in medicine, industrial radiography cameras use X-rays or even gamma sources (such as Iridium-192, Cobalt-60, or Cesium-137) to examine hard to reach or hard to see places. This is frequently used to examine welds for defects or irregularities, or examining other materials to locate structural anomalies or internal components.

An industrial radiography camera being used to inspect a weld for defects

Industrial radiography is also very useful for secure, non-invasive scanning at security checkpoints, such as airports, where x-ray baggage scanners are in routine use. Larger versions of the same machines are often used to examine shipping containers all over the world.

FOOD SAFETY

The Radura is the international symbol denoting that a food product has been irradiated

Food irradiation is the process of using radioactive sources to sterilize foodstuffs. The radiation works by killing bacteria and viruses, or eliminating their ability to reproduce by severely damaging their DNA or RNA. Since neutron radiation is not used, the remaining food doesn’t become radioactive itself, leaving it safe to eat. This method is also used to sterilize food packaging, medical devices, and manufacturing parts.

Video

Reference

https://www.britannica.com/science/radioactivity/Applications-of-radioactivity

https://www.mirion.com/learning-center/radiation-safety-basics/uses-of-radiation

Basic forces of nature

Fundamental interaction, in physics, any of the four basic forces gravitational, electromagnetic, strong, and weak that govern how objects or particles interact and how certain particles decay. All the known forces of nature can be traced to these fundamental interactions. The fundamental interactions are characterized on the basis of the following four criteria: the types of particles that experience the force, the relative strength of the force, the range over which the force is effective, and the nature of the particles that mediate the force.

Read More on This Topic
subatomic particle: The basic forces and their messenger particles
The previous section of this article presented an overview of the basic issues in particle physics, including the four fundamental interactions...

Gravitation and electromagnetism were recognized long before the discovery of the strong and weak forces because their effects on ordinary objects are readily observed. The gravitational force, described systematically by Isaac Newton in the 17th century, acts between all objects having mass; it causes apples to fall from trees and determines the orbits of the planets around the Sun. The electromagnetic force, given scientific definition by James Clerk Maxwell in the 19th century, is responsible for the repulsion of like and the attraction of unlike electric charges; it also explains the chemical behaviour of matter and the properties of light. The strong and weak forces were discovered by physicists in the 20th century when they finally probed into the core of the atom. The strong force acts between quarks, the constituents of all subatomic particles, including protons and neutrons. The residual effects of the strong force bind the protons and neutrons of the atomic nucleus together in spite of the intense repulsion of the positively charged protons for each other.

The weak force manifests itself in certain forms of radioactive decay and in the nuclear reactions that fuel the Sun and other stars. Electrons are among the elementary subatomic particles that experience the weak force but not the strong force.

The four forces are often described according to their relative strengths. The strong force is regarded as the most powerful force in nature. It is followed in descending order by the electromagnetic, weak, and gravitational forces. Despite its strength, the strong force does not manifest itself in the macroscopic universe because of its extremely limited range. It is confined to an operating distance of about 10^{-15} metre—about the diameter of a proton. When two particles that are sensitive to the strong force pass within this distance, the probability that they will interact is high. The range of the weak force is even shorter. Particles affected by this force must pass within 10^{-17} metre of one another to interact, and the probability that they will do so is low even at that distance unless the particles have high energies. By contrast, the gravitational and electromagnetic forces operate at an infinite range. That is to say, gravity acts between all objects of the universe, no matter how far apart they are, and an electromagnetic wave, such as the light from a distant star, travels undiminished through space until it encounters some particle capable of absorbing it.

For years physicists have sought to show that the four basic forces are simply different manifestations of the same fundamental force. The most successful attempt at such a unification is the electroweak theory, proposed during the late 1960s by Steven Weinberg, Abdus Salam, and Sheldon Lee Glashow. This theory, which incorporates quantum electrodynamics (the quantum field theory of electromagnetism), treats the electromagnetic and weak forces as two aspects of a more-basic electroweak force that is transmitted by four carrier particles, the so-called gauge bosons. One of these carrier particles is the photon of electromagnetism, while the other three—the electrically charged W^+ and W^- particles and the neutral Z^0 particle—are associated with the weak force. Unlike the photon, these weak gauge bosons are massive, and it is the mass of these carrier particles that severely limits the effective range of the weak force.

In the 1970s investigators formulated a theory for the strong force that is similar in structure to quantum electrodynamics. According to this theory, known as quantum chromodynamics, the strong force is transmitted between quarks by gauge bosons called gluons. Like photons, gluons are massless and travel at the speed of light. But they differ from photons in one important respect: they carry what is called “colour” charge, a property analogous to electric charge. Gluons are able to interact together because of colour charge, which at the same time limits their effective range.

Investigators are seeking to devise comprehensive theories that will unify all four basic forces of nature. So far, however, gravity remains beyond attempts at such unified field theories.

The current physical description of the fundamental interactions is embodied within the Standard Model of particle physics, which outlines the properties of all the fundamental particles and their forces. Graphical representations of the effect of fundamental interactions on the behaviour of elementary subatomic particles are incorporated in Feynman diagrams.

Video

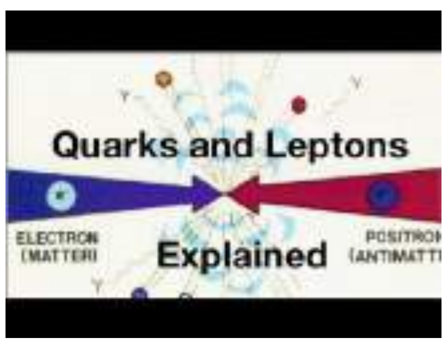
Reference

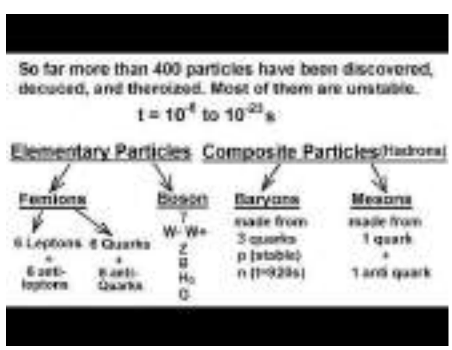
https://www.britannica.com/science/fundamental-interaction

Elementary particles and particle classification (hadrons, leptons and quarks)

Elementary Particles in Physics S. Gasiorowicz and P. Langacker Elementary-particle physics deals with the fundamental constituents of matter and their interactions. In the past several decades an enormous amount of experimental information has been accumulated, and many patterns and systematic features have been observed. Highly successful mathematical theories of the electromagnetic, weak, and strong interactions have been devised and tested. These theories, which are collectively known as the standard model, are almost certainly the correct description of Nature, to first approximation, down to a distance scale 1/1000th the size of the atomic nucleus. There are also speculative but encouraging developments in the attempt to unify these interactions into a simple underlying framework, and even to incorporate quantum gravity in a parameter-free "theory of everything." In this article we shall attempt to highlight the ways in which information has been organized ,and to sketch the outlines of the standard model and its possible extensions .Classification of Particles The particles that have been identified in high-energy experiments fall into distinct classes. There are the leptons (see Electron, Leptons, Neutrino, Muonium),all of which have spin12. They may be charged or neutral. The charged leptons have electromagnetic as well as weak interactions; the neutral ones only interact weakly. There are three well-defined lepton pairs ,the electron (e−) and the electron neutrino (νe), the muon (μ−) and the muon neutrino (νμ), and the(much heavier) charged lepton, the tau (τ), and its tau neutrino (ντ). These particles all have antiparticles, in accordance with the predictions of relativistic quantum mechanics (see CPT Theorem). There appear to exist approximate "lepton-type" conservation laws: the number of plus the number of νemi-nus the number of the corresponding anti particle se +and ̄νeis conserved in weak reactions, and similarly for the muon and tau-type leptons. These conservation laws would follow automatically in the standard model if the neutrinosare massless. Recently, however, evidence for tiny non zero neutrino masses and subtle violation of these conservations laws has been observed. There is no understanding of the hierarchy of masses in Table 1 or why the observed neutrinosare so light. In addition to the leptons there existhadrons (see Hadrons, Baryons, Hyperons, Mesons, Nucleon), which have strong interactions as well as the electromagnetic and weak. These particles have a variety of spins, both integraland half-integral, and their masses range from the value of 135 MeV/c2for the neutral pionπ0to 11 020 MeV/c2for one of the upsilon (heavy quark) states. The particles with half-integral spin are called baryons, and there is clear evidence for baryon conservation: The number of baryons minus the number of antibaryons is constant in any interaction. The best evidence for this is the stability of the lightest baryon, the proton (if the proton decays, it does so with a lifetime in excess of 1033yr). In contrast to charge conservation, there is no 2Table 1: The leptons. Charges are in units of the positron (e+) charge =1.602×10−19coulomb. In addition to the upper limits, two of the neutrinos have masses larger than 0.05 eV/c2and 0.005 eV/c2, respectively. There ,νμ, and ντare mixtures of the states of definite mass. Particle Q Masse1 0.51 MeV/c2μ−−1 105.7 MeV/c2τ−−1 1777 MeV/c2νe0<0.15 eV/c2νμ0<0.15 eV/c2ντ0<0.15 eV/c2Table 2: The quarks (spin-12constituents of hadrons). Each quark carries baryon number B=13, while the antiquarks have B=−13.ParticleQMassu(up)231.5−5 MeV/c2d(down)−135−9 MeV/c2s(strange)−1380−155 MeV/c2c(charm)231−1.4 GeV/c2b(bottom)−134−4.5 GeV/c2t(top)23175−180 GeV/c2deep principle that makes baryon conservation compelling,and it may turn out that baryon conservation is only approximate. The particles with integer spinare called mesons, and they have baryon number B= 0. There are hundreds of different kinds of hadrons, some almost stable and some (known as resonances) extremely short-lived. The degree of stability depends mainly on the mass of the hadron. If its mass lies above the threshold for an allowed decay channel ,it will decay rapidly; if it does not, the decay will proceed through a channel that may have a strongly suppressed rate, e. g., because it can only be driven by the weak or electromagnetic interactions. The large number of hadrons has led to the universal acceptance of the notion that the hadrons, in contrast to the leptons, are composite. In particular, experiments involving lepton–had ronscattering ore+e−annihilation into hadrons have established that hadrons are bound states of point-like spin-12particles of fractional charge, known as quarks .Six types of quarks have been identified (Table 2). As with the leptons, there is no understanding of the extreme hierarchy of quark masses. For each type of quark there is a corresponding antiquark. Baryons are bound states of three quarks (e. g., proton =uud; neutron =udd), while mesons consist of a quark and an antiquark. Matter and decay processes under normal terrestrial conditions involve only the e−,νe,u, and. However, from Tables 2 and 3 we ELEMENTARY PARTICLES IN PHYSICS3see that these four types of fundamental particle are replicated in two heavier families, (μ−,νμ,c,s) and (τ−,ντ,t,b). The reason for the existence of the seheavier copies is still unclear.

Video





Reference

https://www.physics.upenn.edu/~pgl/e27/E27.pdf