FEDERAL DEMOCRATIC
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MINISTRY OF EDUCATION

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Physics Student Textbook – Grade 12

Physics

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Grade 12

FEDERAL DEMOCRATIC
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Physics

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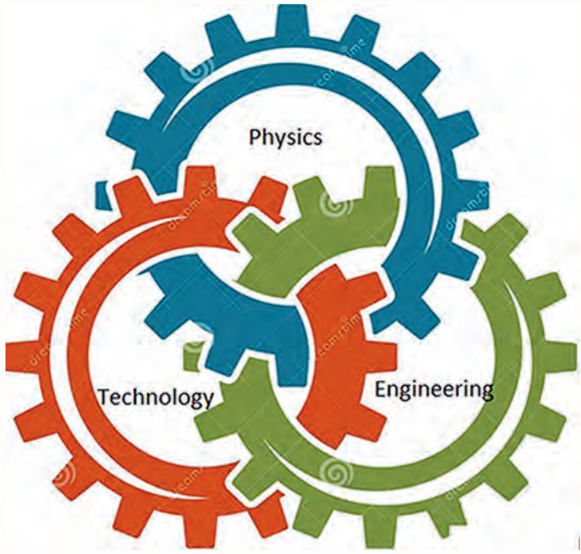


Unit 1

Application of physics in other fields

Introduction

Science is a collection of different scientific fields, or disciplines. It is the union of these fields that helps us to understand the world in which we live. Although there are many scientific disciplines with a special character and history of their own, each discipline is dependent on and reinforces the other disciplines. Scientific disciplines do not have fixed borders. Each discipline benefits from advances in other areas of science. Understanding the contribution that a scientific discipline can make to others is important for the collaborative development all scientific disciplines, and their contribution to society and the environment.

At the end of this unit, you will be able to:

- *Comprehend the contribution of physics to the betterment of society.*
- *Understand the relation of physics to other sciences.*
- *Recognize and appreciate the place of physics in advancement of Technology.*
- *Appreciate the contribution of Technology to the advancement of Physics.*
- *Advocate physics as an important field of study to address societal issues and challenges.*

Brainstorming question1.1

(i) List as many other sciences or specializations as possible in which the word physics appears in their names.

(ii) How is knowledge of physics used or applied in these sciences or specializations?

1.1 Physics and other sciences

Physics is the most essential field of science and it has a strong influence on most scientific developments. We can find different concepts of physics in many of the modern sciences.

Brainstorming question 1.2

(i) Identify some relationships between physics and chemistry.
(ii) What physics concept is applied in separation of dissolved salt from water by evaporation method?

At the end of this section, you will be able to:

- *explain the relationship of physics with chemistry, biology, geology and astronomy.*

Physics and chemistry

Physics and chemistry may overlap when the system under study involves matter composed of electrons and nuclei. Fundamental laws that govern the behavior of matter apply to both chemistry and physics. Both physics and chemistry are concerned with matter and its interaction with energy. The theory and various rules about atoms which are important in chemistry are ultimately explained in principle by atomic and subatomic particle physics. Chemists and physicists use similar method to study the interaction of large number of particles which have complicated interaction beyond the capacity of any computer, and the capacity of the human mind.

Discussion question 1.1

☞Dear students, chemistry studies minute entities like elements, atoms, molecules and ions which cannot be seen with your naked eyes. How do chemists collect information, like composition, structure, properties and the changes they undergo during a reaction with other substances, from these minute invisible particles?

The physics of atoms and subatomic particles is critically important for understanding how individual atoms are joined by covalent bonds to form molecules. The physics of atoms and subatomic particles can also provide quantitative insight into ionic and covalent bonding processes by explicitly showing which molecules are energetically favorable to which others and the magnitudes of the energies involved.

The physics of energy related to heat tells chemists whether a particular reaction is energetically possible in the direction in which it is written, and it gives the composition of the reaction system at equilibrium. The physics of heat energy provides a bridge between the macroscopic properties of a substance and the individual properties of its constituent molecules and atoms.

Spectroscopy is the study of the interaction between matter and electromagnetic radiation as a function of the wavelength or frequency of the radiation.

Spectroscopy is a fundamental examining tool in many fields including physics and chemistry. Most of what we know about the structure of atoms and molecules comes from spectroscopic study. The spectroscopic techniques are developed by collaborative work of physicists and chemists.

In general, the study of matter and electricity in physics is fundamental towards the understanding of concepts in chemistry, such as atomic structure, molecular structure, X-ray diffractions, radioactivity, periodic properties of elements, nature of valency, chemical bonds in molecules, crystal structure of solids and others. This shows that chemistry is rooted in atomic and molecular physics.

Physics and biology

To understand how life works, it is essential to understand physics. Physics can explain the human body like the mechanics of human motion, the energetics of metabolism, the fluid dynamics of blood flow through vessels, the mechanisms for speaking and hearing, and the optical imaging system we call the eye. In this section some of the physics concepts within a living things are briefly explained.

Brainstorming question 1.3

List some physics concepts in our body.

Physics of Newtonian mechanics and biology

The Newtonian mechanics tells us how different animals and their body parts move. The combination of knowledge of physics and biology help to explain how athletes run fast and why the fastest animal in the world, cheetah, runs fast. Newtonian mechanics tells us that a body is in stable equilibrium under the action of gravity if its center of mass is directly over its base of support. Under this condition, the reaction force at the base of support cancels the force of gravity and the torque produced by it. If the center of mass is outside the base, the torque produced by the weight tends to fall the body. A person falls when his center of gravity is displaced beyond the position of the feet. The wider the base on which the body rests and the closer the center of gravity of it to the base, the more stable it is; that is, the more difficult it is to fall it. How we can use our limbs to do different jobs can also be explained by Newtonian mechanics .

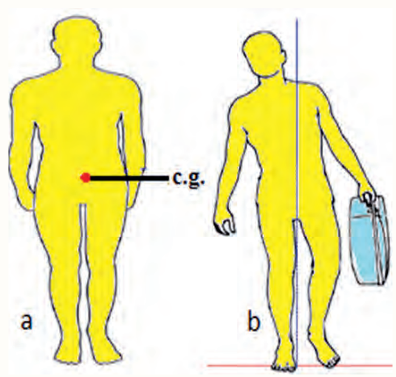


Figure 1.1 (a) Center of gravity of a freely standing person (b) A person carrying unbalanced load stands bending

Discussion question 1.2

(i) Why it is difficult to stand on one foot than the two feet? Why we are more stable when we sleep than we are standing?
(ii) Figure 1.1 (a) shows freely standing person and Figure 1.1 (b) shows the way a person carrying a load stands. Why the person carrying the load stands bending in Figure 1.1(b) than the person in Figure 1.1(a)?

Physics of fluid flow and biology

Discussion question 1.3

(i) Have you observed when the earthworm moves? How do earthworms locomote without limbs?
(ii) How a blood moves against gravity from the feet to the heart or from the heart to the brain when a person stands erect?

The physics of fluid flow, like viscosity, equation of continuity and turbulent flow, is very important in understanding the circulation of blood and blood pressure in the multicellular organisms. Soft-bodied animals (such as the sea anemone and the earthworm) that lack a firm utilize Pascal's principle to produce body motion.

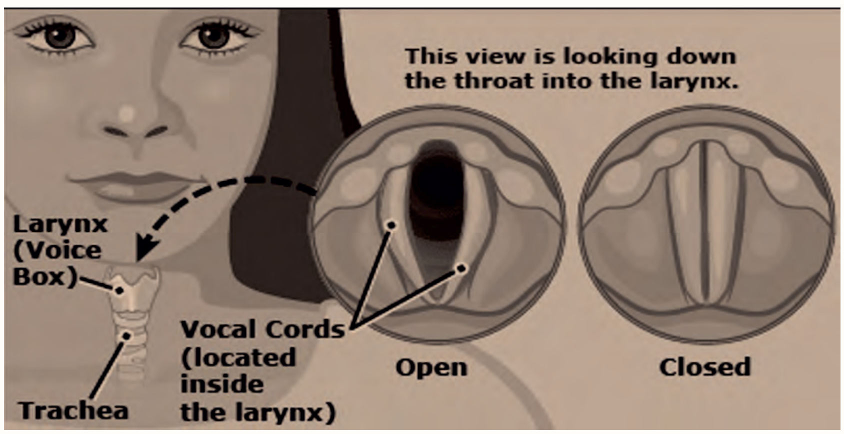


Figure 1.2 Sound wave generating organ in human being.

Activity 1.1

Dear students, please check whether inhalation or exhalation of air enables formation of a controlled sound.

Physics of sound wave and biology

Sound is a mechanical wave produced by vibrating bodies. The vocal cords produce sound when they come together and then vibrate as air passes through them during exhalation of air from the lungs. This vibration produces the sound wave for your voice. When the human vocal cords (Figure 1.2) set into vibrational motion, the surrounding air molecules are disturbed and are forced to follow the motion of the vibrating body. The vibrating molecules in turn transfer their motion to adjacent molecules causing the vibrational disturbance to propagate away from the source. When the air vibrations reach the ear, they cause the eardrum to vibrate; this produces nerve impulses that are interpreted by the brain.

Physics of electricity and biology

Many life processes involve electrical phenomena. The nervous system of animals and the control of muscle movement, for example, are both governed by electrical interactions. The very important electrical phenomena in living organisms are found in the nervous system of animals. Specialized cells called neurons form a complex network within the body which receives, processes, and transmits information from one part of the body to another. The center of this network is located in the brain, which has the ability to store and analyze information. Based on this information, the nervous system controls various parts of the body. The messages are electrical pulses transmitted by the neurons. When a neuron receives an appropriate stimulus, it produces electrical pulses that are propagated along its cablelike structure.

Optical physics and biology

Light is the electromagnetic radiation in the wavelength region between about 400 nm and 700 nm. Although light is only a tiny part of the electromagnetic spectrum, it is very important in both physics and biology. Light has fundamental roles in living system because of its paramount importance. Most of the electromagnetic radiation from the sun that reaches the Earth's surface is in this region of the spectrum, and life has evolved to utilize it. In photosynthesis, plants use light to convert carbon dioxide and water into organic materials, which are the building blocks of living organisms. Animals have evolved light-sensitive organs, like the eyes, which are their main source of information about the surroundings. Some bacteria and insects can even produce light through chemical reactions. Optical physics, which is the study of light, includes topics such as microscopes, telescopes, vision, color, pigments, illumination, spectroscopy, and lasers, all of which have applications in the life sciences.

Discussion question 1.4

Discuss how our eyes use light to see objects?

Physics and astronomy

Astrophysics is the study of the physics of heavenly objects, called astronomical objects, in the sky like the solar system and its constituents, the properties, birth, life and death of stars, interstellar gas and dust, galaxies and clusters of galaxies, and finally the study of the Universe as a whole.

Brain storming question 1.4

Most of the astronomical objects are far from the earth where astronomers live. How can astronomers get information about these far objects? What physics concepts do astronomers use to study astronomical objects?

Newton's laws of motion and astronomy

Newton's law of gravitation is used to describe the motion of the moon around a planet and the motion of the planets around the sun. Newton was able to explain why Kepler's Laws described planetary motion using his laws of motion and gravity. The knowledge of centripetal force and centrifugal force from our physics knowledge greatly help as to understand what keeps objects in orbit around others. This applies to planets orbiting the Sun, moons orbiting planets, and artificial satellites in Earth′s orbit.

Brainstorming question 1.5

What information do you expect from studying the electromagnetic wave which comes from astronomical objects?

Physics of electromagnetic wave and astronomy

Astronomers collect information about the radiation from space objects to study the birth and death of stars, how hot objects are, how far away they are, even how the universe was formed. Astronomers use telescopes that detect different parts of the electromagnetic spectrum. Each type of telescope can only detect one part of the electromagnetic spectrum. There are radio telescopes, infrared telescopes, optical (visible light) telescopes and so on. We can't see most of the radiation detected, so computers turn data into images we can see. The colour we observe on these image are called false colours because computers have taken the data from wavelengths we can't see and presented them as colours that can be seen as shown in Figure 1.4.

Figure 1.3 Entoto space observatory telescope

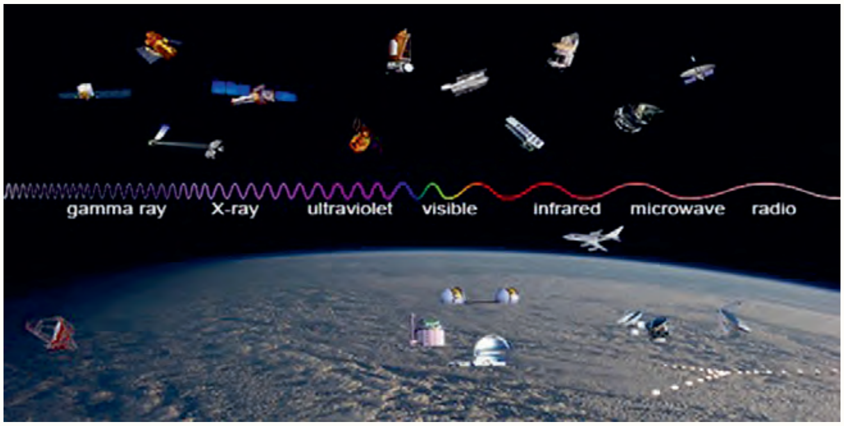


Figure 1.4 Detection of different components of electromagnetic radiation by telescope

Astronomers use light to measure distance of astronomical objects. For more distant objects, we can measure distances by using brightness of objects, since objects will appear fainter if they are at larger distances than identical nearby object. Measuring the apparent brightness of an object gives its distance if we know its true brightness.

$$\text{apparent brightness} \propto \frac{\text{true brightness}}{\text{distance}^2}$$

This is known as the inverse square law of apparent brightness. The true brightness is also known as the luminosity. Astronomers also used light year as an alternate astronomical distance measuring unit. A light year is the distance that light travels in one year.

Exercise 1.1

What is the distance that light can travel in one year in kilometer?

Physics of atoms and astronomy

Atomic astrophysics is concerned with performing atomic physics calculations that will be useful to astronomers and using atomic data to interpret astronomical observations. The astronomers' only information about a particular object comes through the light that it emits, and this light arises through atomic transitions.

Brain storming question 1.6

What do emission and absorption of light by an object tell us?

The physics that explains emission and absorption of radiation is closely related to the structure and energies of individual atoms that form the astronomical objects. When electrons of atoms jump from higher to a lower atomic orbit, photon is emitted. Photon is absorbed if electron jumps from lower electron orbit to higher electron orbit (Figure 1.5). The emission and absorption of radiation depends on the characteristics of individual atoms, and helps to measure something about the compositions, temperatures, and motions of stars by studying their spectra. You can visit the link: https://phet.colorado.edu/en/simulations/hydrogen-atom to observe the Bohr atomic model for hydrogen atom.

In the interstellar matter, atoms are heated by nearby stars. This results in knocking of electrons to higher energy orbits. These electrons fall down to lower energy orbits emitting light of precisely the wavelength that corresponds to the energy change between the two orbits. The nature of the emitted light depends on the temperature. Thus, emitted light can be used to determine both compositions and temperatures of astronomical objects.

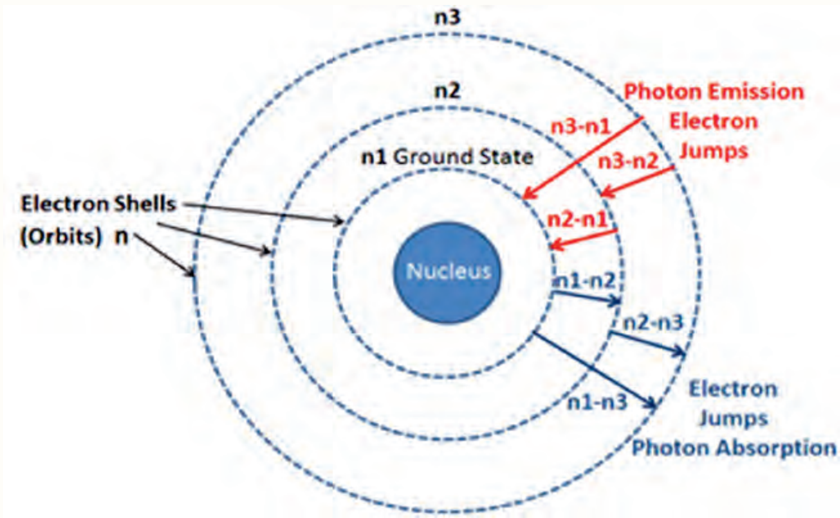


Figure 1.5 The Bohr atomic structure and electron transitions

Figure 1.6 Mineralogists focus on all kinds of minerals.

> **Activity 1.2**
>
> Dear students, please organize yourself in five groups to visit your other science teachers like chemistry, biology, geography, history and ICT to ask them how the knowledge of physics is used in their disciples. Your teacher will help you how to proceed in your activities.

Physics and geology

The study of different parts of Earth is called Earth science. Earth Science deals with all aspects of the Earth including molten lava, icy mountain peaks, steep valleys and towering waterfalls, the atmosphere high above the earth as well as the Earth's core far beneath the surface. Geology is a branch of Earth science that studies the solid and liquid matter that makes up Earth and the different processes on these matters.

The understanding of geological processes demand the understanding of the different concepts of physics like force, optics, atomic structure, electromagnetic radiation, heat and heat flow, electricity and magnetism, stress and strain, waves including sound wave and fluid flow. In geology, these physics concepts are used to study the following properties of rocks and minerals: electrical properties, density, magnetization, radioactivity, elasticity and more. To study these properties of rocks and minerals,the geologist take samples from different layers of the earth through excavation. They can also study different properties of rocks and minerals by sending different types of waves from the surface of the earth without excavation.

Geology has so many branches that most geologists become specialists in one area. For example, a mineralogist studies the composition and structure of minerals such as halite (rock salt), quartz, calcite, and magnetite (Figure1.6). Geological knowledge is also used to detect or infer the presence and position of economically useful geological deposits, such as ore minerals, fossil fuels and other hydrocarbons, geothermal reservoirs, and groundwater reservoirs.

1.2 Physics and engineering

At the end of this section, you will be able to:

- *Relate the Newtonian mechanics with civil engineering*
- *List different concepts of physics used in mechanical engineering*
- *Relate electromagnetism to electrical and electronics engineering*
- *Explain how technology contributes to the development of physics*

Brainstorming question 1.7

(i) List importance of physics in engineering.
(ii) Should we learn physics before we learn engineering?

Physics generates fundamental knowledge that can be used by different branches of engineering. Physical concepts, such as Mechanics, Thermodynamics, Electromagnetism, Atomic Physics, Molecular Physics, Optics, Nuclear Physics etc., are important knowledge inputs in different engineering branches. Engineering branches such as civil, mechanical, electrical, etc., are basically governed by physical laws. It is difficult to solve many of the complex engineering problems without understanding the physics behind it. If one understands the laws of nature using physics, then one can use that knowledge to predict what will happen to the things one builds in engineering.

Figure 1.8 Civil Engineering in (a) Suspension Bridge (Abay Bridge) (b)Building construction (Africa Union Head Quarter, Addis Ababa) (c) Transportation Engineering (Gotera interchange road)

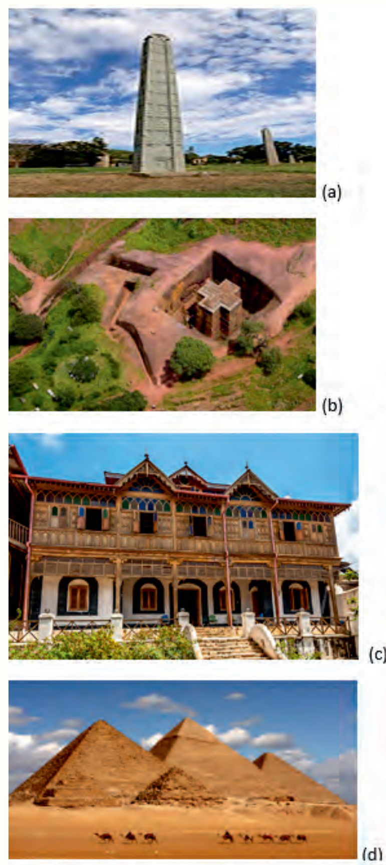


Figure 1.7 Civil Engineering in ancient civilization(a) Axumite Obelisks (b) Lalibela Betegiorgis rock hewen church (c) Harar Jugol (The Arthur Rimbaud Cultural center) (d) Egyptian Pyramids

Civil engineering

Civil engineering concerns designing and building skyscrapers, roads,bridges, dams, and railways using our physics knowledge of forces, fluid pressure, gravity, and others. Civil engineering has been known since ancient civilizations in Ethiopia, Egypt and others (Figure1.7), where large buildings were built such as temples, pyramids and palaces with engineering designs. However, the major change in civil engineering resulted from the development of physics particularly after the development of laws of motion, power and energy in the eighteenth century. Advance in accuracy of measurements and calculations in Civil engineering results in construction of complex sky scraper buildings, transportation/traffic systems/ engineering, suspension bridges and others in worldwide.

Mechanical engineering

Mechanical engineering uses knowledge of mathematics, science mostly physics and materials science to create mechanical systems like engines, manufacturing equipment and vehicles. The physics concepts like mechanics, dynamics, thermodynamics, forces, stresses and aerodynamics are mostly used in mechanical engineering in dealing with aircraft, watercraft, engines, robotics, weapons, cars, hydraulics and others. A mechanical engineer takes one or more of these concepts to create a mechanical system that operate without failure.

Figure 1.10 Mechanical engineering design products

(a)

(b)

(c)

Figure 1.9 Areas electrical engineering concerns (a)electrical system for installation and maintainance (b) Electric power transmission and management (c) Electric circuit

Electrical engineering

Electrical engineering involves designing electrical circuits including motors, electronic appliances, optical fiber networks, computers, and communication links. Electrical engineers often need to convert electrical energy to other forms of energy like mechanical and thermal energy. Therefore electrical engineering demands the understanding of some physics concepts like electromagnetism, mechanics, thermodynamics and others.

Chemical engineering

Chemical engineering involves the production of products through chemical processes. This includes designing equipment, systems, and processes for refining raw materials and for mixing, compounding, and processing chemicals. The laws of physical chemistry and physics govern the practicability and efficiency of chemical engineering operations. Particularly, chemical engineering requires an understanding of the physical properties of molecules, the chemical bonds between atoms as well as the molecular dynamics which are dealt by molecular physics. Furthermore, concept of energy changes, deriving from thermodynamic considerations, are very important in chemical engineering.

Figure 1.11 Some chemical Engineering products (a) plastics (b) petroleum products (c) detergents and (d)paints

Brainstorming question 1.8

What is the contribution of technology in the development of physics?

Technology generating new physics

There is a fundamental connection between physics and technology. Without knowledge of physics, most of the technologies we know well today could not be available for the society. Dear students, do you think the revere also is true i.e., can technology give rise to new physics?

Science and technology are two things that are completely interwoven. Science seeks to understand the natural world using technology. Engineering uses scientific discoveries to design products and processes to solve the societal problems. This products and processes are what we call technology which are important for the scientists as well as for the engineers. Technology wouldn't exist without science, and science wouldn't be as effective without technology. The technology that was developed using science can help to do even more science. Many modern scientific experiments wouldn't be possible without technology. The rocket technology allowing blasting off from the earth enables us to take scientific measurements in space. The discovery of X-ray technology helped in further development of physics. Technology helped in study of atomic structure, spectral analysis, etc. The relation of science/physics, Engineering and technology can be schematized as shown in Figure 1.12.

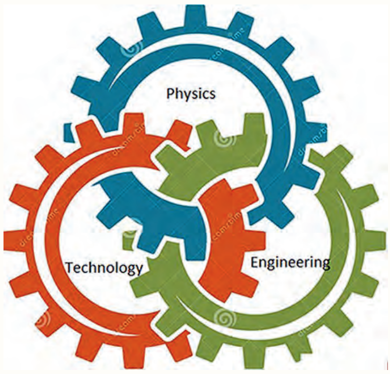


Figure 1.12 Interrelation of physics, engineering and technology

Activity 1.3

Dear students, Carefully think about your living area including your school.

(i) What technologies and engineering products are available? Explain how physics is used in these technologies and engineering products.

(ii) Try to find also the latest technology and engineering products based on physics discoveries. You can use sources like internet, library, expert visit and media. Your work has to be presented in group.

(iii) Present a poster on the title "Contribution of different technologies on the advancement of physics".

Brainstorming question 1.9

List as many medical diagnostic instruments you know. Try to explain what information do these instruments collect from the body part being diagnosed?

1.3 Medical physics

At the end of this section, you will be able to:

- *Explain the relation of physics with medicine*
- *Explain how the magnetic property of water is used in MRI for diagnosis*
- *Differentiate the working principle of conventional x-ray and computer tomography (CT) scan*
- *Discuss how sound wave is used for diagnosis*
- *Explain how radiation is used for cancer and tumor treatment*

Medical physics is a branch of physics that deals the applications of principles of physics to medical diagnosing and treating abnormal tissues. The discovery of X-rays by Wilhelm Conrad Roentgen in 1895 brought a revolution in the fields of science and medicine and it has opened a path to a new interdisciplinary branch, medical physics. The first X-ray photograph was made by Roentgen himself in late 1895 (Figure 1.13).

Figure 1.13 Wilhelm Conrad Roentgen′s hand first x-ray image

Medical imaging refers to several different technologies that are used to view the human body in order to diagnose, monitor, or treat medical conditions. There are several imaging techniques that can provide imaging of biological samples. Some techniques used for imaging are electromagnetic (optical, X-ray, magnetic resonance imaging (MRI), thermography); other techniques are acoustic (ultrasound), chemical, and electrical. Among the most prolific ones are MRI, X-ray computed tomography (CT scan), and high-frequency ultrasound.

Magnetic Resonance Imaging (MRI)

Magnetic resonance is absorption or emission of electromagnetic radiation by electrons or atomic nuclei in response to the application of certain magnetic fields. MRI uses the physical principle of magnetic resonance that was first described by Felix Bloch and Edward Purcell in 1946. Paul Lauterbur and Peter Mansfield described how to acquire MR images from the human body.

How is MRI working?: Getting an MRI image depends upon the presence of protons in the body. Protons are free hydrogen atom (proton without electrons). They are abundant in the body as most part of our body consists of water which contains two hydrogen and one oxygen atoms. With their net positive charge, protons are small magnets each having a north and a south pole.

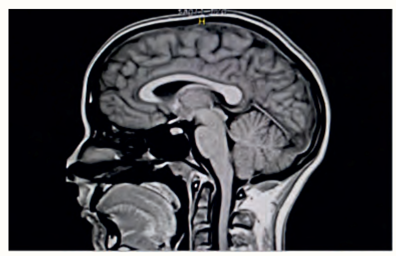


Figure 1.14 An MRI image of the brain. The MRI technique yields detailed visualization of soft tissue structures with a resolution of about 0.5 mm.

How do we get an image from these oscillation of flipped hydrogen protons in the brain? MRI uses the movement of these small magnets within a magnetic field to generate an image. Within the constant magnetic field of an MRI scanner, these small magnets arrange themselves parallel to constant magnetic field. When a current pulse (a current that flows for very short period of time) is applied to the patient's tissue, this parallel arrangement of the small magnets is disturbed. When the current pulse is off the small magnets back to their parallel arrangement releasing energy that they absorbed from the pulse. Different tissues in the body give off different amounts of energy. A special device detects the released energy as an electrical current. The electrical current is transformed in to an image via a

Discussion question 1.5

How can magnetic vibration be used to form MRI image of the body part and used for diagnosis?

computer. Because protons in the different kinds of tissues in the brain, such as gray matter, white matter and blood, all give off different amounts of energy, the result of the transformed energy is a highly detailed image of the tissue inside the brain.

X-Ray computerized tomography (CT) scan

Brainstorming question 1.10

Dear student, share your X-ray and CT scan diagnostic experience.

An X-ray imaging is based on the absorption of X-rays as they pass through the different parts of a patient's body. Differences in the densities of body tissue allow us to see inside the body by creating a shadow gram. The body is composed of tissues containing many different elements, which vary by atomic number (the number of protons in the nucleus). The higher the atomic number, the denser the element and the more effectively the X-ray is blocked. For example, when X-ray strikes the calcium in cortical bone, it is blocked, and on the radiographic image the bone will appear white. When an X-ray strikes less dense element like nitrogen, it passes all the way through. Therefore, the air-containing lung will appear darker, approaching black on the radiographic image. When a fracture extends through the bone, the fracture line will be dark while the intact bone will remain white.

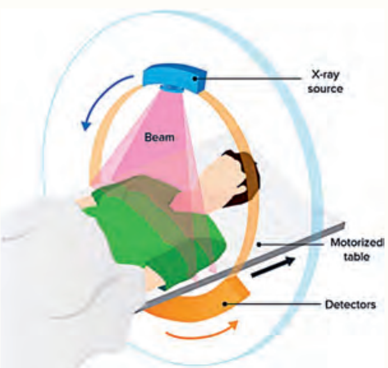


Figure 1.15 Relative arrangement and motion of X-ray source and detectors in CT scan.

During a regular X-ray procedure, a stationary machine sends X-rays through the body to make a single shadow picture. A computed tomography (CT) scan uses computers and rotating X-ray machines to make many successive images (called tomograms) of the inside of body along different directions. In CT scan, the X-ray source and the detectors rotate simultaneously in opposite direction as shown in Figure 1.18. A motorized table moves the patient (Figures 1.15 and 1.16) through a circular opening in the CT imaging system. As the patient passes through the CT imaging system, a source of X-rays rotates around the inside of the circular opening while the detectors on the other side of the patient record the X-rays exiting the section of the patient's body being irradiated. The CT scan images provide more detailed information than normal X-ray.

Figure 1.16 Image of CT scan machine

Discussion question 1.6

What is the basic difference between conventional X-ray and CT scan?

Clinical uses of sound: stethoscope and ultrasound

The most familiar clinical use of sound is in the analysis of body sounds with a stethoscope (Figure 1.17). This instrument consists of a small bell-shaped cavity attached to a hollow flexible tube. The bell is placed on the skin over the source of the body sound (such as the heart, intestines, or lungs). The sound is then conducted by the pipe to the ears of the examiner who evaluates the functioning of the organ. The stethoscope was developed in 1816 by a French physician, Rene Laennec. A stethoscope can be used to listen sounds made by the heart, lungs or intestines, as well as blood flow in arteries and veins. A stethoscope can detect sound waves with frequency ranging from tens to thousands of Hertz.

Brainstorming question 1.11

Have you ever brought your ears very near to a person's chest? What sounds could you hear? What simple equipment do medical doctors use to listen these sounds? What information could doctors get from these sounds?

Figure 1.17 Stethoscopes

Ultrasound

If the frequency of sound is higher than 20 KHz (0.02 MHz), it is called ultrasonic or ultrasound. Typical frequencies used in medical ultrasound are 3.5-10 MHz. Ultrasonic waves penetrate tissue and are reflected, scattered and absorbed within it. The scattered and reflected ultrasound contains information about the form and structure of the tissue.

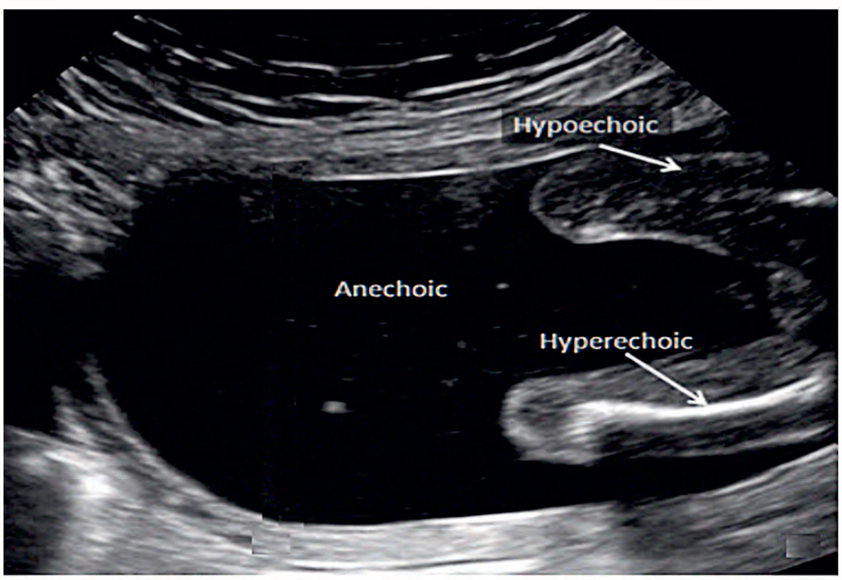


Figure 1.18 Ultrasound image showing hyperechoic, hypoechoic and anechoic regions.

An ultrasound machine sends an ultrasound wave into a body tissue and detects the reflected wave. The detector generates a tiny electric current that is amplified to generate an ultrasound image on the monitor. An ultrasound image is commonly described by three words: anechoic, hypoechoic and hyperechoic as shown in Fig. 1.18.

Anechoic These areas appear black on ultrasound because they do not send back any sound waves (echoless region). Anechoic regions are resulted from fluid-filled regions.

Hypoechoic Gives off fewer echoes; These areas appear dark gray because they don't send back a lot of sound waves (echoes).

Hyperechoic These areas bounce back many sound waves. They appear as light gray on the ultrasound image.

Brainstorming question 1.12

Have you ever heard a medical treatment curing internal body cancer without surgery and medicine? How can be possible to do this?

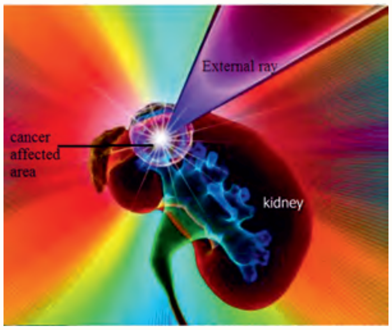


Figure 1.19 Radiotherapy of kidney cancer.

Radiation therapy

The photons of X-rays and gamma-rays and the particles emitted by radioactive nuclei all have energies far greater than the energies that bind electrons to atoms and molecules. As a result, when such radiation penetrates into biological materials, it can rip off electrons from the biological molecules and produce substantial alterations in their structure.

In controlled doses radiation can be used therapeutically. In the treatment of certain types of cancer, an ampul containing radioactive material such as radium or cobalt 60 is implanted near the cancerous growth. By careful placement of the radioactive material and by controlling the dose, the cancer cell can be destroyed without greatly damaging the healthy tissue.

An externally applied beam of gamma rays or X-rays can also be used to destroy cancerous tumors. The advantage here is that the treatment is administered without surgery 1.19. The effect of radiation on the healthy tissue can be reduced by frequently altering the direction of the beam passing through the body. The tumor is always in the path of the beam, but the dosage received by a given section of healthy tissue is reduced.

1.4 Physics and defense technology

At the end of this section, you will be able to:

- *List different defense technologies*
- *Explain how physics is used in radar, missile and infra-red detection for night vision*

Brainstorming question 1.13

What do physicists do in military?

The modern defense force has different branches like Air Force, Army, Navy and Space Force. All of these defense forces demand different knowledge and advancement of physics like laser guidance and satellite technology, modern electronics, optics, sensing systems, high-energy-density physics, atomic and nuclear physics, hydrodynamics, and physics of advanced materials. The Navy demands oceanographic physics, the propagation of sound through water, deep-ocean currents, and meteorology. Air Force demands turbulent fluid flows, navigation, long-range observation, and pattern recognition. The Army force demands night and all-weather vision and techniques for avoiding detection. Advanced optical physics is important in space-based satellite surveillance systems. Advanced optical physics is also important in manned and unmanned aircraft, in missiles, and even on rifles.

Brainstorming question 1.14

Dear students you are familiar with the traffic police and traffic light to control the ground vehicles traffic. Do you have any knowledge of the air traffic control mechanism? Share with your colleagues.

Radar technology

The word RADAR is an acronym derived from the phrase RAdio Detection And Ranging. It applies to electronic equipment designed for detecting and tracking the presence of objects like ships, vehicles, aircraft, missiles, etc which are at certain distances from the location of the radar. It collects the information related to the object or target like its range (R) and location by radiating electromagnetic signal and examining the echo received from the distant object.

Let the time taken for the signal to travel from Radar to target and back to Radar be 't'. The two-way distance between the Radar and target will be 2R. The range can be calculated using the speed-distance formula with the speed equal to the speed of light(c).

$$\text{speed} = \frac{\text{distance}}{\text{time}}, \quad \text{distance} = \text{speed} * \text{time}; \; 2R = c * t \text{ and } R = \frac{ct}{2}$$

Figure 1.20 Radar system

As shown in the Figure 1.21, Radar mainly consists of a transmitter and a receiver. It uses the same antenna for both transmitting and receiving the signals. The transmitter transmits the radar signal in the direction of the target. The target reflects this received signal in various directions. The signal, which is reflected back to the antenna is received by the receiver and displayed on the radar display.

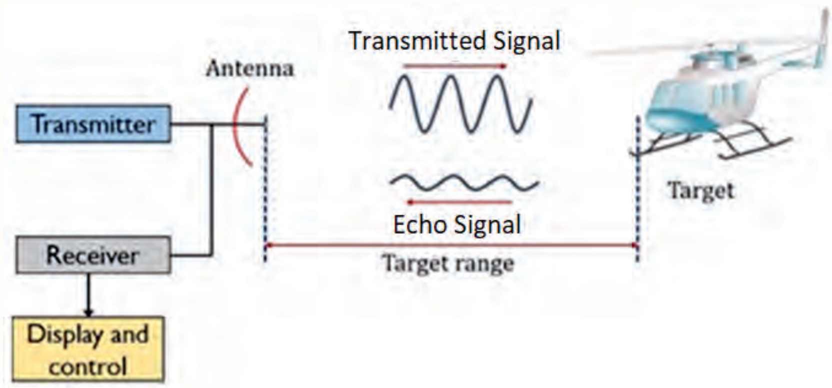


Figure 1.21 Basic principles of radar

Discussion question 1.7

What is the basic principle of radar?

Military applications of Radar

Radar is mostly used for military purpose and is one of the most important parts of the air defense system. Its major function is to detect target and guiding the defensive and offensive weapons. Radar can also be utilized in civilian applications particularly in controlling air traffic, observation of weather, navigation of ship, environment, sensing from remote areas, observation of planetary, etc.

Missiles

A missile is a rocket-propelled or jet-propelled weapon designed to deliver an explosive weapon with great accuracy at high speed. Jets get the oxygen to burn fuel from the air while rockets carry their own oxygen. Missiles are different types. The well-known ones are cruise missile and ballistic missile. Cruise missiles are jet-propelled throughout their flights. Ballistic missiles are rocket-powered only in the initial phase of flight, after which they move under the influence of gravity and air resistance following an arc trajectory to the target. It is governed by Newtonian mechanics. The motion of cruise missile can be controlled by altering the thrust (accelerating a mass of gas) from its engine (or engines) to conserve momentum. A missile is a combination of many electronic, digital and mechanical subsystems that perform many operations to guide the missile from its launcher to its target. There is continuous radio communication between the internal missile controlling unit and the launch controller to track the target and the proper functioning of each unit of the missile.

Infra-red wave detection for night vision

Human eyes are sensitive to visible light: red, orange, yellow, green, blue, and violet light. Infrared, is just out of range of what the human eye can detect. It is detected by infrared detecting devices. All people, places, and things give off infrared light in an amount proportional to their temperature. Infrared (IR) devices will typically use heat emissions to identify objects that cannot be detected using available light sources. Infrared vision is used extensively by the military for various purposes like night vision, navigation, hunting, hidden-object detection and targeting. Infrared imaging systems like infrared imaging goggles create an electronic image based on the temperature differences in the radiating object; hotter objects appear brighter than cooler objects. You cannot see the actual color of the objects but temperature difference in the target is represented by different colors that are not related to the actual color of the target. Night vision image is green this is because green is the best wavelength for enhancing the natural night vision in humans to see the targets.

Figure 1.22 A helicopter as observed by Night Vision Goggles

Brainstorming question 1.15

Do you know any mechanisms that enable us to see objects at dark night without available light source?

Discussion question 1.8

What are the major physics concepts used in Radar and infra-red night vision?

Activity 1.4

Visit a nearby military establishment and develop a report on instruments and methods applying physics.

Brain storming question 1.16

List all the communication technologies you have ever used. Do you know other communication technologies you have not yet used?

1.5 Physics in communication

At the end of this section, you will be able to:

- *Explain the working principle of different communication technologies.*
- *Explain the relation of physics and communication technology*

This day, our lives would be very difficult without the use of the communication technologies like telephone, cell-phone, mobile and computers. Communication is transferring of information (message) from one point to another. To transfer the information to the receiver, medium of transmission is required. Depending on the communication medium, the communication system is classified as wired and wireless communication system. Wireless communication systems use radio waves, microwaves and infrared waves. Satellite communication and ground wave communication are common examples of wireless communications. The wire communication system uses wire and optical fiber.

Discussion question 1.9

How wireless communication is possible?

All forms of communication technologies demand the knowledge of physics. The demanded physics knowledge depends on the type of message and the medium of transmission. The knowledge of electromagnetic theory is crucial to understand radio waves, microwaves, infrared waves and visible light which are used in wireless and fiber optics communication. Electricity and magnetism, electrical circuit, energy, electronics and wave phenomena like reflection, diffraction, refraction, interference, rarefaction and compression of wave propagation are also very important.

Unit summary

- Different scientific fields are dependent on and reinforces the other fields.
- Physics has a strong influence on many scientific developments and many modern sciences arose from physics.
- The study of matter and electricity in physics is fundamental towards the understanding of concepts in chemistry, such as atomic structure, molecular structure, X-ray diffractions, radioactivity, periodic properties

of elements, nature of valency, chemical bonds in molecules, crystal structure of solids and others.

- In biology, the motion of animals and their body parts, flow of blood through blood vessels,sound production and transmission as well as receiving by special living tissues, communication networks in the body, reaction of living tissue with light, the development of scientific instrument to study living cell demands different concepts of physics
- Astronomers use the physics of light, atomic physics and Newtonian mechanics for the study of astronomical objects.
- Geologists use basic physics concepts like force, optics, atomic structure, electromagnetic radiation, heat and heat flow, electricity and magnetism, stress and strain, sea waves, acoustics and fluids and fluid flow to study common geological processes and the analytical techniques.
- Physicists discover facts and laws, develop methods of measurement, determine various constants, propose and work out in detail mathematical theories and hypotheses, etc., while engineers later apply some of these valuable facts and theories to design and build machines, construction, and operation of various practical devices.
- In Civil Engineering, the laws of physics can tell you about forces, tension, harmonic vibrations and oscillations, tensile strength, elasticity, and all kinds of other concepts that you can use to make calculations about your designing and construction work.
- As many of the current technologies wouldn't be existed without physics, many modern physics experiments also wouldn't be possible without technology.
- Medical physics is a branch of physics that concerns the applications of principles of physics to medical diagnosing and treating abnormal tissues. The modern medical equipment like X-ray, MRI, CT scan, ultrasound and others are developed by the application of physics knowledge.
- Defense technologies like Radar and Infra-red night vision uses the physics of electromagnetic waves.

- Mechanical Engineering need the concepts of physics like mechanics, dynamics, thermodynamics, materials science, structural analysis, and electricity to design aircraft, watercraft, engines, robotics, weapons, cars, pneumatics, hydraulics and others.
- Electrical and electronic engineers demand the basic knowledge of physics in electromagnetism and semiconductor physics.

End of unit questions

1. Explain the following biological process in terms of some physics knowledge.
   - How our brain receives information from the whole body and send information to other body?
   - Which part of our body tells us the temperature of our environment? What instrument is used to measure the exact value of our body temperature? What is the physics in this instrument?
   - What physics knowledge is needed to understand how a sound is created and transmitted to the listener?
   - What energy transformation occurs in human body?
   - What energy transformation occurs in photosynthesis?
2. List as many concepts of physics that can be used in designing modern vehicles.
3. How physics of light is important to study the astronomical objects?
4. As physics is the basis for the development of many technologies, how technologies contribute for the development of science particularly physics?
5. What major physics knowledge is used in defense radar system to detect the enemy target?
6. List at least three modern medical devices and explain their working principles.

7. List as much physics knowledge and engineering as possible to build a modern building for residence.
8. Identify the difference between the diagnostic and therapeutic medical device.
9. What are the possible applications of radar system?

Unit 2

Brain storming question 2.1

1 . Consider a ball shot horizontally from a very high building at a high speed. Assume that there is no force of gravity acting on the ball. What would the motion of the ball be like? Explain its motion?

2 . The ball is projected horizontally from the top of the same building. This time, the force of gravity is acting on the ball. What will the motion of the ball be like? Will gravity affect the ball's horizontal motion? Will the ball travel a greater (or shorter) horizontal distance due to the influence of gravity?

Two-dimensional motion

Introduction

Kinematics is the study of motion without considering its causes. For example, studying the motion of a football without considering what forces cause or change its motion. Two-dimensional kinematics are simple extensions of the one-dimensional kinematics developed for motion in a straight line in Grade 11. This simple extension will allow us to apply physics to many more situations, and it will also yield unexpected insights about nature.

A ball kicked by a football player, the orbital motion of planets, a bicycle rounding a curve,the rotation of wheels of a car are a few examples of two-dimension motion. In fact, most motions in nature follow curved paths rather than straight lines. Such types of motion along a curved plane are described by two-dimensional kinematics.

At the end of this unit, you will be able to:

- *Understand the basic ideas of two-dimensional motions.*
- *Describe the motion of objects in horizontal and inclined projectiles;*
- *Describe uniform rotational motion,rotational dynamics and Kepler's laws*
- *Describe Newton's law of Universal gravitation.*
- *Develop pertinent problem-solving skills.*

2.1 Projectile motion

At the end of this section, you will be able to:

- *Explain the motion of the projectile with respect to the horizontal and vertical components of its motion.*
- *Derive equations related to projectile motion.*
- *Apply equations to solve problems related to projectile motion*

Discussion question 2.1

Which motion is different from the others? Explain Why?

a) A ball thrown horizontally into the air.

b) A bullet fired from a gun.

c) A javelin thrown by an athlete.

d) A bird flying in the air.

A projectile is a thrown, fired, or released object that moves only under the influence of gravitational force. The projectile accleration is $g = 9.8m/s^s$. Anyone who has observed the motion of a ball kicked by a football player (Figure 2.1b) has observed projectile motion. The ball moves in a curved path and returns to the ground. Other examples of projectile motion include a cannonball fired from a cannon, a bullet fired from a gun, the flight of a golf ball and a jet of water escaping a hose.

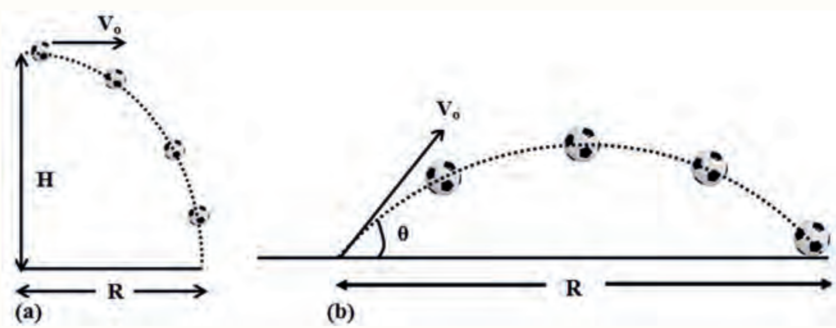


Figure 2.1 a) A ball thrown horizontally b) A football kicked in a game

Projectile motion of an object is simple to analyze if we make three assumptions:

1. The free-fall acceleration is constant over the range of motion, and it is always directed downward. It is the acceleration due to gravity (g)=9.8m/s^2.
2. The effect of air resistance is negligible.
3. The horizontal velocity is constant because the acceleration of the object does not have vertical component. With these assumptions, we find that the path of a projectile, which we call its trajectory, is a parabola as shown in Figure **??**.

The horizontal and vertical components of a projectile's motion are completely independent of each other and can be handled separately, with time t as a common variable for both components.

Horizontal Projection

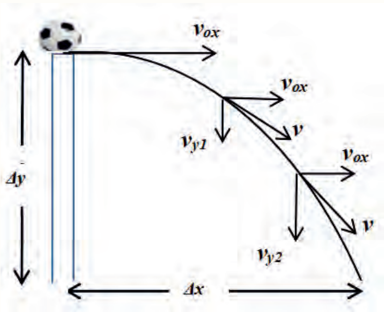


Figure 2.2 The motion of a ball projected horizontally.

In this type of motion the projectile is projected horizontally from a certain height as shown in Figure 2.2. Its initial velocity along the vertical direction is zero and it possesses only horizontal velocity at the beginning. As the time progresses, due to the impact of gravity, it acquires the vertical component of velocity (Figure 2.2).

Equations for the horizontal component of motion

The projectile has zero acceleration along x direction. Therefore, the initial velocity v_{0x} remains constant throughout the motion. We use constant acceleration motion equations. The final horizontal velocity, v_x after a time t is:

$$v_x = v_{0x}(\text{constant})$$

The horizontal distance traveled by the projectile at a time t is given by the equation

$$\Delta x = v_{0x}t \tag{2.1}$$

Discussion question 2.2

Assume that an airplane flying horizontally drops a package to a remote village.
What kind of motion is performed by the package?
Draw the trajectory of the package.
As the package hits the ground at the village, where is the aircraft?

Equations of vertical motion

The vertical motion is a constant accelerated motion. We use the kinematic equations of motion for constant accelerated motion. The final vertical velocity v_y after time t is:

$$v_y = v_{oy} + gt \tag{2.2}$$

Where v_{0y} is the initial vertical velocity.

The initial vertical velocity has no downward component (v_{0y}=0). Therefore

$$v_y = gt$$

From the kinematics equations, the vertical displacement, Δy has a form:

$$\Delta y = v_{0y}t + \frac{1}{2}gt^2 \tag{2.3}$$

But $v_{0y} = 0$, therefore

$$\Delta y = \frac{1}{2}gt^2$$

Remember: When you use equations to answer questions on vertical motion, upwards motion is positive (+) and downwards motion is negative (-).

Time of flight

The time of flight is the time taken by the projectile to hit the ground.
We know that:

$$\Delta y = \frac{1}{2}gt^2$$

Then

$$t = \sqrt{\frac{2\Delta y}{g}}$$

Range

The range is the maximum horizontal distance traveled by the projectile.
Once we find the time of flight t, we can solve for the horizontal displacement using:

$$\Delta x = v_{0x}t$$

In projectile motion, the time to cover both the x and y displacement is the same.
By substituting the total time flight, we get:

$$R = v_{0x}\sqrt{\frac{2\Delta y}{g}}$$

Example 2.1

A rifle is aimed horizontally at a target 30m away as shown in Figure 2.3. The bullet hits the target 2 cm below the aiming point.
(a) What is the bullet's time of flight?
(b) What is the initial velocity of the bullet?
Assume gravity *(g)* =$10 m/s^2$.

Solution:
The givens in this question are: ΔX=30 m, ΔY=2 cm =0.02 m, g=$10 m/s^2$.
(a) The equation for the vertical displacement is:

Activity 2.1

Place two tennis balls at the edge of a tabletop. Sharply snap one ball horizontally off the table with one hand while gently tapping the second ball off with your other hand. Measure the height *(y)* of the table and the horizontal distance between the table's edge and the balls landing location *(R)*. Determine the following from your measurements:

a) The time of flight of both tennis balls. Explain your result.
b) The initial horizontal velocity of the balls when they leave the edge of the table.

$$\Delta y = \frac{1}{2}gt^2$$

$$-0.02\text{ m} = \frac{1}{2}(-10)t^2$$

The vertical displacement is in the negative direction, which gives:

$$t=0.06\text{ s}$$

Since this is the time of impact with the target, the time of flight of the bullet is also the same.

(b) The equation for $x-$motion is:

$$\Delta x = v_{ox}t$$

$$v_{ox} = \frac{\Delta x}{t} = \frac{30m}{0.06s}$$

The initial velocity of the bullet is 500 m/s.

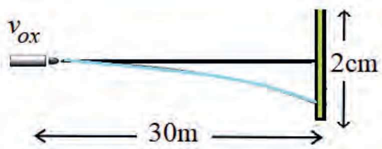


Figure 2.3 A bullet fired horizontally.

Example 2.2

A rescue airplane travelling at 360 km/h horizontally dropps a food package from a height of 300 m when it passes over a car driver stranded in the desert. Assumming *(g)*=$10 m/s^2$.

(a) How long will it take the food package to reach the ground?

(b) How far from the car driver should the food package be dropped ?

Solution:

(a) The package has the same horizontal velocity as the airplane. Therefore, the initial vertical velocity is zero.

The equation for the vertical displacement is:

$$\Delta y = \frac{1}{2}gt^2$$

$$-300\text{ m} = \frac{1}{2}(-10)t^2$$

The vertical displacement is in the negative direction, which gives:

$$t = 7.74\text{ s}$$

(b) The equation for the horizontal displacement is:

$$\Delta x = v_{0x} t$$
$$\Delta x = 100 \text{ m/s x } 7.74 \text{ s}$$
$$\Delta x = 774 \text{ m}$$

Activity 2.2

Use this activity to investigate horizontal projection.
Materials

- Ruler
- A cannon ball made from scrunched up aluminum foil.
- Rubber band.
- A tube made from paper or cardboard with diameter larger than the diameter of the ball.

Procedures:

1. Put the tube near the edge of the table.
2. Use the rubber band to shoot the ball out of the tube.
3. Stretch the rubber band the same amount each time to make sure the initial velocity is constant.
4. You can increase the stretching of the rubber band to increase the initial horizontal velocity of the projectile.
5. Measure the height of the table. Use this height to calculate the time of flight (assume there is no air resistance).
6. Measure the horizontal distance traveled by the canon ball. Use this distance to calculate the initial velocity of the projectile.

Inclined projectile motion

This is a type of motion in which an object is projected with an initial velocity v_0 which makes an angle θ with the horizontal (Figure **??**).The initial velocity can be resolved into two components, vertical and horizontal component. The vertical component of the velocity changes with time as a result there is acceleration due to gravity.

The horizontal component of the velocity is constant throughout the flight; this is because there is no force acting along the horizontal direction of the projectile as a result there is no acceleration along x-axis. The analysis of the motion involves dealing with the two motions.

As shown in Figure 2.4, the projectile has velocity components at different positions. At the top where it reaches its maximum height the vertical component of the velocity becomes zero. After V_y becomes zero the projectile changes its direction and make free fall.

Discussion question 2.3

Balls A and B are kicked at an angle of 37^0 and 53^0 with the horizontal respectively, with the same initial velocity v_0. Which ball has:

a) the maximum horizontal displacement?

b) the maximum height?

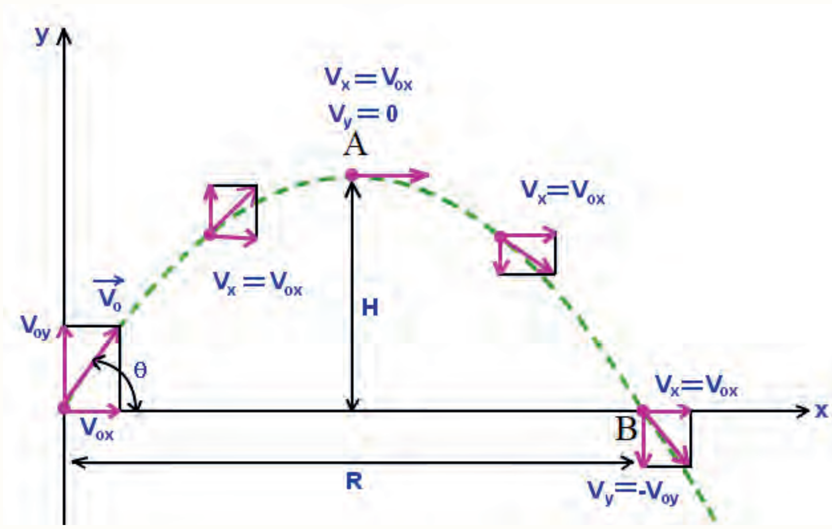


Figure 2.4 Inclined projectile motion.

Equations of inclined projectile motion

The initial velocity can be expressed as x component and y component:

$$v_{0x} = v_0 \cos\theta$$
$$v_{0y} = v_0 \sin\theta$$

The horizontal velocity at any time t is:

$$v_x = v_0 \cos\theta \quad \text{(constant)}$$

The vertical velocity at any time t is:

$$v_y = v_o sin\,\theta + gt \tag{2.4}$$

Displacements of the projectile

There are two different types of displacement of the projectile motion:
Horizontal displacement at any time t:

$$\Delta x = v_0 cos\theta t \tag{2.5}$$

Vertical displacement at any time t:

$$\Delta y = v_0 sin\theta t + \frac{1}{2} g t^2 \tag{2.6}$$

The time to reach the maximum height is:

$$v_y = v_0 \sin\theta + gt$$

Since $v_y = 0$ at maximum height and g is negative:

$$t = \frac{v_0 \sin\theta}{g}$$

Time of flight

The time of flight is the total time for which the projectile remains in flight. The time of flight depends on the initial velocity of the object and the angle of the projection, θ.

$$\Delta y = v_0 \sin\theta\ t + \frac{1}{2} g t^2$$

When the point of projection and point of return are on the same horizontal level, the net vertical displacement of the object is zero, ΔY=0.

$$0 = v_0 \sin\theta\ t + \frac{1}{2} g t^2$$

Apply factorization, we have:

$$0 = t(\mathrm{v}_0 \sin\theta + \tfrac{1}{2} g t)$$

Since t cannot be zero and g is negative,solving for t gives us:

$$\mathrm{t}_{total} = \frac{2 v_0 \sin\theta}{g}$$

This last equation does not apply when the projectile lands at a different elevation from the one at which it was launched.

Horizontal range and maximum height of a Projectile

Let us now consider a special case of projectile motion. Assume a projectile is launched from the origin at O, as shown in Figure 2.4, and returns to the same horizontal level. This situation is common in sports, where baseballs, footballs and golf balls often land at the same level from which they were launched. Two points in this motion are especially interesting to analyze: the peak point A, which has Cartesian coordinates $(R/2, H)$, and the point B, which has coordinates $(R, 0)$. The distance R is called the horizontal range of the projectile, and the distance H is its maximum height. Let us find R and H mathematically in terms of v_0, θ, and g.

Range *(R)*

The range of the projectile is the maximum displacement in the horizontal direction. There is no acceleration in this direction since gravity only acts vertically.

$$\Delta x = v_0 \cos\theta \ t$$

When Δx is maximum, $\Delta x = R$.
Since the time to cover the range is the total time of flight:

$$t_{total} = \frac{2 v_0 \sin\theta}{g}$$

$$R = v_0 \cos\theta \ t_{total}$$

$$R = \frac{{v_0}^2 \sin 2\theta}{g}$$

This equation is valid for launch and impact on a horizontal surface, as shown in Figure 2.5. We can see in Figure 2.5a the range is directly proportional to the square of the initial speed v_0 and $\sin 2\theta$. Furthermore, we can see from the factor $\sin 2\theta$ that the range is maximum at 45°.

In Figure 2.5 (a) we can see that the greater the initial velocity, the greater the range. In Figure (b) the range is maximum at 45°. This is true only for conditions ignoring air resistance. It is interesting that the same range is found for two initial launch angles that add up to 90°. The projectile launched with the smaller angle has a lower peak than the higher angle, but they both have the same range.

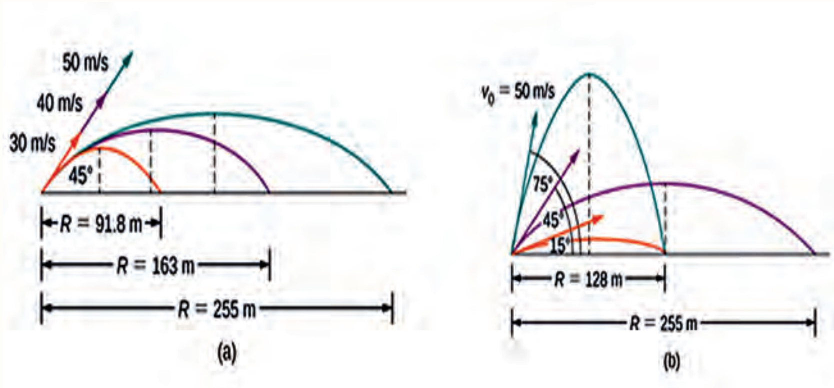


Figure 2.5 Trajectories of projectiles on leveled ground. (a) The effect of initial velocity v0 on the range of a projectile with a given initial angle. (b) The effect of initial angle θ on the range of a projectile with a given initial speed.

Maximum height *(H)*

The maximum height of a projectile trajectory occurs when the vertical component of velocity, v_y equals zero. As the projectile moves upwards it goes against gravity, and therefore the velocity begins to decrease. Eventually the vertical velocity will reach zero, and the projectile is immediately accelerated downward under gravity. Thus, once the projectile reaches its maximum height, it begins to accelerate downward.

$$\Delta y = v_0 \sin\theta \; t + \frac{1}{2} g t^2$$

The time to cover the maximum height is: $t = \dfrac{v_0 \sin\theta}{g}$

When Δy is maximum, $\Delta y = H$

$$H = \frac{{v_0}^2 \sin^2\theta}{2g}$$

Discussion question 2.4

1. A projectile is fired in such a way that its horizontal range is equal to three times its maximum height. What is the angle of projection?
2. A ball is kicked into the air from the ground at an angle θ with the horizontal. When the ball reaches its highest point, which statement is true ? (a) Both the velocity and acceleration of the ball are zero.

(b) Its velocity is not zero, but its acceleration is zero. (c) Its velocity is perpendicular to its acceleration. (d) Its acceleration depends on the angle at which the ball was thrown.

3. One ball is thrown horizontally. At the same time, a second ball is dropped from the same height. Ignoring air resistance and assuming the ground is level, which ball hits the ground first? Explain why.

Activity 2.3

Use this activity to investigate inclined projection.

You need the materials listed in Activity 2.2.

Procedures:

(a) Adjust the tube at different angles from the horizontal.

(b) As before keep the stretching of the rubber band constant.

(c) Vary the angle of projection.

(d) Measure the relationship between the angle of projection, range and maximum height reached by the projectile.

Relation between range and maximum height

Consider a projectile motion as shown in Figure 2.4. The initial velocity of the projectile is v_0, H is the maximum height and R is its horizontal range. We know that the maximum height of the projectile H is given by the equation:

$$H = \frac{{v_0}^2 \sin^2 \theta}{2g}$$

And horizontal range is given by the equation:

$$R = \frac{{v_0}^2 \sin 2\theta}{g}$$

Divide the maximum height of the projectile by the horizontal range.
(In the equation, $\sin^2\theta$ can be written as $\sin\theta\sin\theta$, and $\sin 2\theta$ can be written as $2\sin\theta\cos\theta$).

$$\frac{H}{R} = \frac{sin\theta}{4cos\theta}$$

$$H = \frac{R\tan\theta}{4}$$

Example 2.3

A football player kicks a ball at angle of 37^0 with the horizontal. The initial velocity of the ball is 40 m/s.

a) Find the maximum height reached by the ball.

b) Find the horizontal range of the ball.

Solution:
In this problem the given quantities are: $v_0 = 40$ m/s, $\theta = 37^0$ and g=10 m/s^2
a) The maximum height reached is:

$$H = \frac{V_0{}^2 \sin^2 \theta}{2g}$$

$$H = \frac{(40m/s)^2 \sin 37^0 \sin 37^0}{2x10m/s^2}$$

H=28.8 m

b) The horizontal range is:

$$R = \frac{V_0{}^2 \sin 2\theta}{g}$$

$$R = \frac{(40m/s)^2 \sin 74^0}{10m/s}$$

R=153.8 m

Example 2.4

A ball is kicked from the ground with an initial speed of 25 m/s at an angle of 53^0 above the horizontal directly toward a wall, as shown in Figure 2.6. The wall is 24 m from the release point of the ball.
(a) How long does the ball take to reach the wall?
(b) How far above the ground level does the ball hit the wall?
(c) What are the horizontal and vertical components of its velocity as it hits the wall?
(d) What is the resultant velocity with it hits the wall?

Solution:
In this problem the given quantities are:

$\Delta x = 24$ m, θ =53^0, v_0 =25 m/s

(a) The horizontal displacement of the ball is given by the equation

$\Delta x = v_0 \cos\theta t$

Solving for the time at which $\Delta x = 24$ m:

$$t = \frac{\Delta x}{v_0 cos\theta} = \frac{24m}{(25m/s)x0.6}$$

$t = 1.6$ s

Thus, the ball reaches the wall 1.6s after being thrown.

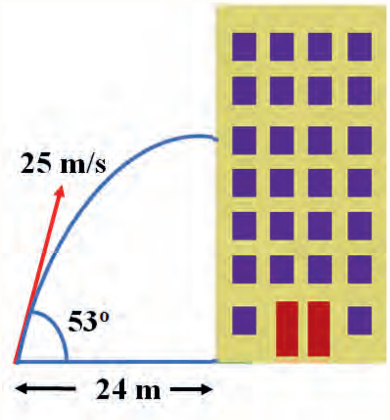


Figure 2.6 A ball thrown toward a wall.

(b) We can answer this question if we can find the *y* coordinate of the ball at the time it hits the wall, namely at $t = 1.6$ s. We need the y equation of motion.

$\Delta y = v_0 \sin\theta\ t + \frac{1}{2}gt^2$

$\Delta y = 25$ m/s x0.8 x 1.6 s + $\frac{1}{2}$x$(-10m/s^2)$x$(1.6s)^2$

$\Delta y = 19.2$ m

This tells us that the ball hits the wall at 19.2 m above the ground level.

(c) The *x* and *y* components of the ball's velocity at the time of impact (t=1.6 s)

$v_x = v_0 \cos\theta$

$v_x =$ 25 m/s x 0.6

$v_x = 15$ m/s

$v_y = v_0 \sin\theta + gt$

$v_y =$ 25m/s x 0.8 +$(-10m/s^2)$x1.6 s

$v_y = 4$ m/s

(d) The resultant velocity is the vector sum of the *x* and *y* components.

$v = \sqrt{v_x^2 + v_y^2}$

$v = \sqrt{(15m/s)^2 + (4m/s)^2}$

$v =$ 15.5 m/s

Activity 2.4:

Use this activity to investigate inclined projection. In this activity you use the law of conservation of mechanical energy that you learned in grade 11.

Materials required

- Ruler
- V-shaped track with a shorter launch track.
- Small ball (e.g. tennis ball).
- protractor

Procedures:

1. Adjust the shorter end of the track to the edge of the surface of a table.
2. Use a short segment of the track at an angle; say 45 degrees with respect to the surface of a table.

3. Measure the height of the longer end of the track where the ball is to be released and also measure the height of the shorter end where the ball is going to leave the surface of the table.

4. Put the ball in motion down the track.

5. Calculate the speed of the ball on the track just as it leaves the level of the surface of the table using conservation of energy ($mgh = \frac{1}{2}mv^2$).

6. Calculate the time it takes to fall back to the surface of the table $t=\frac{2V_0 \sin\theta}{g}$.

7. Predict where the ball will land using, $x=\frac{{V_0}^2 \sin 2\theta}{g}$.

8. Put a cup there to catch the ball. Put the ball in motion down the track again.

9. Change the velocity of the ball by changing the inclined angle of the longer arm of the track (this is to reduce the height from which the ball is released).

Discussion question 2.5

1. As a projectile moves in its parabolic path, is there any point along the path where the velocity and acceleration vectors are (a) perpendicular to each other (at right angles)? (b) parallel to each other?

2. Which of the following statements about projectile motion are true? (ignoring air resistance).

   (a) The horizontal and vertical motions are independent.
   (b) The force on the projectile is constant throughout the flight.
   (c) The acceleration of the projectile is constant throughout the flight.
   (d) The path depends upon the initial velocity, but not upon the mass of the projectile.
   (e) All of the above statements are true.

3. A projectile is fired on Earth with some initial velocity. Another projectile

is fired from the surface of the Moon with the same initial velocity. If air resistance is ignored, which projectile has the greater range? Why? Which reaches the greater height? Why? (Note that the free-fall acceleration on the Moon is about 1.6 m/s^2).

Exercise 2.1

Use g=10m/s^2 where necessary.

1. At which position in its flight will a ball experience its minimum speed during inclined projection? A. at the beginning B. at maximum height C. at the end D. the same speed at all positions

2. A gun with a muzzle velocity of 500 m/s shoots a bullet at a target 50 m away. To hit the target the gun should be aimed: A.directly towards the target along the line joining the gun and target. B.10 cm high above the target. C. 5 cm high above the target. D. 5cm below the target.

3. A ball is thrown horizontally with a velocity of 20m/s from a top of building 90 m high. Calculate:
   a) the time taken to reach the ground.
   b) the horizontal displacement.
   c) The resultant velocity with which it strikes the ground.

4. A long jumper leaves the ground at an angle of 20.0^o above the horizontal and at a speed of 11.0 m/s.
   a) How far does he jump in the horizontal direction?
   b) What is the maximum height reached?

5. An object projected at an angle θ with velocity 30 m/s reaches its maximum height in 1.5 s. Calculate its range.

2.2 Rotational Motion

At the end of this section, you will be able to:

- *Describe the motion of a rigid object around a fixed axis.*
- *Derive equations of motion with constant angular acceleration.*
- *Apply equations to solve problems related to rotational motion.*

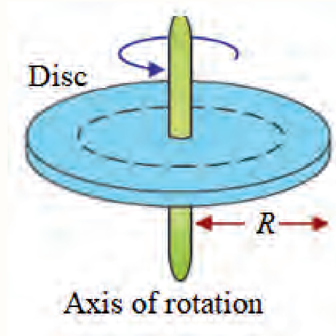


Figure 2.7 Rotation of a disc of mass M around a fixed axis.

Rotational motion is the motion of an object in a circle around a fixed axis. For example, the rotation of Earth around its axis, the rotation of the flywheel of a sewing machine, rotation of a ceiling fan, rotation of wheels of a car, and so on.

The disc in Figure 2.7 is performing rotational motion because all of its particles are rotating around a fixed axis, called its axis of rotation. An object can rotate around a fixed point in two directions: a clockwise or an anticlockwise direction (also known as counterclockwise).

Rigid body is n object with a perfectly defined and unchanging shape. NO matter the size of the force , the distance between any two particles within the object remains constant.

Angular displacement and angular velocity

Angular displacement($\Delta\theta$)

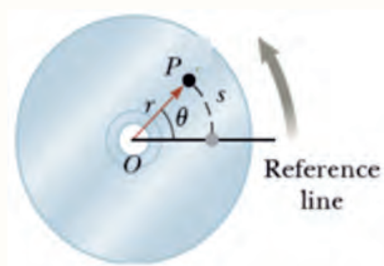


Figure 2.8 A CD rotating about a fixed axis through O perpendicular

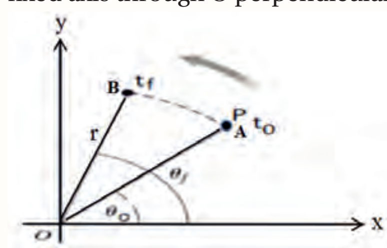


Figure 2.9 A particle P on a rotating disc moves from A to B along the arc of a circle.

Figure 2.8 is a view from above of a rotating compact disc, or CD . The disc rotates around a fixed axis perpendicular to the plane of the figure, passing through the center of the disc at O. One particle of the disc P, is kept at a fixed distance r from the origin and rotates around O in a circle of radius r.

Because the disc is a rigid object, as the particle moves through an angle θ from the reference line, every other particle on the object rotates through the same angle . Therefore, we can associate the angle θ with the entire rigid object as well as with an individual particle.

As the particle travels from position A to position B in a time interval Δt ,as shown in Figure 2.9, the line joining the particle to the center sweeps out an angle $\Delta\theta$. This quantity $\Delta\theta$ is defined as the angular displacement of the rigid object.

$$\Delta\theta = \theta_f - \theta_0 \tag{2.7}$$

Because rotational motion involves studying circular paths, rather than using meters to describe the angular displacement of an object, physicists use radians or degrees. A radian is convenient because it naturally expresses angles in terms of π since one complete turn of a circle (360 degrees) equals 2π radians.

$$1\text{revolution} = 2\pi\text{rad} = 360^0$$

Angular velocity(ω)

How fast an object is rotating can be calculated using the concept of angular velocity. If the disc spins rapidly, the angular displacement can occur in a short time interval. If it rotates slowly, the angular displacement occurs in a longer time interval. The rate at which angular displacement occurs can vary. These different rotation rates can be quantified by defining the average angular velocity ω_{av} (Greek letter *omega*) as the ratio of the angular displacement of a disc to the time interval Δt during which the displacement occurs.

$$\omega_{av} = \frac{\theta_f - \theta_0}{t_f - t_0} = \frac{\Delta\theta}{\Delta t} \tag{2.8}$$

Angular velocity has units of radians per second (rad/s).

Angular acceleration

If the angular velocity of an object changes from ω_0 to ω_f in the time interval Δt, the object has an angular acceleration. The angular acceleration α (Greek letter *alpha*) of a rotating rigid object is defined as the ratio of the change in the angular speed to the time interval Δt during which the change in the angular speed occurs:

$$\alpha = \frac{\omega_f - \omega_0}{t_f - t_0} = \frac{\Delta\omega}{\Delta t} \tag{2.9}$$

Angular acceleration has units of radians per second squared (rad/s^2).

Direction of angular velocity and angular acceleration

Angular velocity and angular accelerations can be treated as a vectors, so we must include magnitude and direction. For rotation around a fixed axis, the direction of rotational motion is specified in relation to the direction along the axis of rotation. Therefore, the directions of ω and α are along this axis.

To illustrate this convention, it is convenient to use the *right-hand rule* demonstrated in Figure 2.10. When the four fingers of the right hand are wrapped in the direction of rotation, the extended right thumb points in the direction of ω. The direction of α follows from its definition $\alpha = \Delta\omega\ /\Delta t$. It is in the same direction as ω if the angular speed is increasing in time, and it is antiparallel (parallel but moving in the opposite direction) to ω if the angular speed is decreasing in time.

Discussion question 2.6

In small group, discuss how to find the direction of angular velocity and angular acceleration.

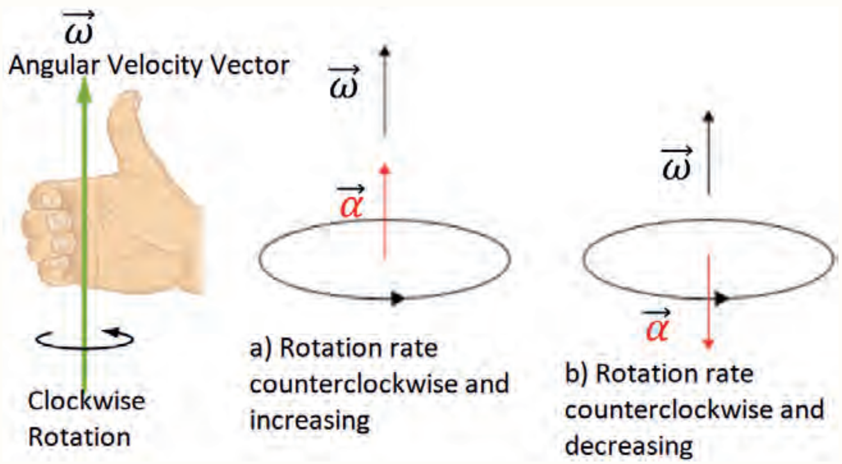


Figure 2.10 The right-hand rule for determining the direction of the angular velocity vector.

Equation of motion for constant angular acceleration

Consider a rigid object such as the CD rotating around a fixed axis with a constant angular acceleration. A set of kinematic equations exist for rotational motion just as they do for translational motion. They have a similar form and are derived in a similar fashion.

$$\alpha = \frac{\omega_f - \omega_0}{t_f - t_0} \qquad \text{(constant angular acceleration)} \qquad (2.10)$$

Then, by rearranging, we get an equation

$$\omega_f = \omega_o + \alpha \Delta t \tag{2.11}$$

where ω_o is the angular speed of the rigid object at time $t = 0$. This equation allows us to find the angular speed ω_f of the object at any later time t.
If the angular acceleration is constant, the average angular velocity is obtained by:

$$\omega_{av} = \frac{\omega_o + \omega_f}{2}$$

$$\omega_{av} = \frac{\Delta\theta}{\Delta t}$$

Combining these two equations, you we get:

$$\frac{\Delta\theta}{\Delta t} = \frac{\omega_o + \omega_f}{2}$$

When we substitute $\omega_f = \omega_o + \alpha\Delta t$

$$\Delta\theta = \omega_o \Delta t + \frac{1}{2}\alpha \Delta t^2 \tag{2.12}$$

This equation allows us to find the angular displacement of the object at any later time t.
We know that: $\Delta\theta = \left(\frac{\omega_o + \omega_f}{2}\right)\Delta t \; and \; \Delta t \; = \; \frac{\omega_f - \omega_o}{\alpha}$
Combining these two equations, we get:

$$\Delta\theta = \left(\frac{\omega_o + \omega_f}{2}\right) \left(\frac{\omega_f - \omega_o}{\alpha}\right)$$

$$\omega_f^2 = \omega_0^2 + 2\alpha\Delta\theta \tag{2.13}$$

This equation allows us to find the angular speed ω_f of the rigid object for any value of its angular position $\Delta\theta$.

Example 2.5

What is the average angular velocity of a rotating wheel if its angular speed changes from 30 rad/s to 50 rad/s in 2 s?

Solution:
In this problem the given quantities are: ω_i =30 rad/sec, ω_f = 50 rad/s and t=2 s

$$\alpha_{av} = \frac{\omega_f - \omega_0}{\Delta t}$$

$$\alpha_{av} = \frac{50 rad/s - 30 rad/s}{2s}$$

$$\alpha_{av} = 10\ rad/s^2$$

Example 2.6

A rotating wheel has an initial angular velocity of 10 rad/s and accelerates at 2.5 rad/s^2.

(a) How many revolutions are completed in 30 s?

(b) What is angular speed of the wheel at t =20 s?

Solution:
The given quantities are ω_o = 10 rad/s, α = 2.5 rad/s^2, t=30 s

(a) $\Delta\theta = \omega_o \Delta t + \frac{1}{2}\alpha \Delta t^2$

Substitute the known values to find the angular displacement.

$\Delta\theta$=10rad/sx30s $+\frac{1}{2} x 2.5 rad/s^2 x 900 s^2$

$\Delta\theta$ = 300 rad + 1125 rad

$\Delta\theta$ = 1425 rad

Convert rad in to revolution

1rev = 2π rad

$\Delta\theta$ = 1425 rad $\left(\frac{1 rev}{2\pi rad}\right)$

$\Delta\theta$ = 226.9 rev

(b) The final speed at t = 20 s is asked $\omega_f = \omega_o + \alpha \Delta t$

ω_f = 10 rad/s + 2.5 rad/s^2 x20 s

ω_f = 60 rad/s

Example 2.7

A car's wheel has an initial angular velocity of 6 rad/s and a constant angular acceleration of 3 rad/s^2. Calculate the angular velocity after 100 rev ?

Solution:

The given quantities are: ω_o = 6 rad/s, α = 3 rad/s^2, $\Delta\theta$ = 100 rev

First convert rev to rad.

1rev = 2πrad

$\Delta\theta$ = 100 rev $\left(\frac{2\pi rad}{1rev}\right)$

$\Delta\theta$ = 628 rad

$\omega_f^2 = \omega_0^2 + 2\alpha\Delta\theta$

ω_f^2=$(6rad/s)^2 + 2x(3rad/s^2)^2 x628rad$

ω_f = 61.68 rad/s

Kinematic equations for rotational and linear motion

The kinematics for rotational motion is completely analogous to linear (or translational) kinematics. Many of the equations for the mechanics of rotating objects are similar to the motion equations for linear motion. When solving problems involving rotational motion, we use variables that are similar to linear variables (distance, velocity and acceleration) but take into account the curvature or rotation of the motion. We defined:

- the angular rotation $\Delta\theta$, which is the angular equivalence of distance, Δs;
- the angular velocity ω, which is the angular equivalence of linear velocity v;
- the angular acceleration α, which is the angular equivalence of linear acceleration, a.

Example 2.8

A wheel has a radius of 20 cm and accelerates from rest to 15 rev/s in 30 s. What is the magnitude of the tangential acceleration of a point at the tip of the wheel.

Solution:

The angular acceleration is:

$$\alpha = \frac{\omega_f - \omega_o}{\Delta t} = \frac{15rev/s - 0}{30s}$$

α =0.5 rev/s^2

Table 2.1 shows the analogy between linear and angular motion equations.

Linear motion with constant acceleration	Angular motion with constant angular acceleration
$v_f = v_0 + a\Delta t$	$\omega_f = \omega_o + \alpha\Delta t$
$V_{av} = \frac{v_f + v_0}{2}$	$\omega_{av} = \frac{\omega_f + \omega_0}{2}$
$\Delta s = \left(\frac{v_f + v_0}{2}\right)\Delta t$	$\Delta\theta = \left(\frac{\omega_f + \omega_0}{2}\right)\Delta t$
$\Delta s = v_0 t + \frac{1}{2}a\Delta t^2$	$\Delta\theta = \omega_o\Delta t + \frac{1}{2}\alpha\Delta t^2$
${v_f}^2 = {v_0}^2 + 2a\Delta s$	${\omega_f}^2 = \omega_0^2 + 2\alpha\Delta\theta$

Since 1rev = 2π rad α =3.14 rad/s^2 Therefore, the tangential acceleration is

$a_t = \alpha r$

$a_t = 3.14\ \text{rad/s}^2 \text{ x } 0.2\ \text{m}$

$a_t = 0.6\ \text{m/s}^2$

Example 2.9

A car accelerates from 20 m/s to 24 m/s in 5 s. Calculate the angular acceleration of the wheels of the car if the radius of a wheel is 40 cm.

Solution:

First, we calculate the tangential acceleration of a point on the rim of the wheel.

The equation to use is:

$$a_t = \frac{v_f - v_o}{\Delta t} = \frac{24m/\sec - 20m/s}{5s}$$

$a_t = 0.8\ m/s^2$

Then the angular acceleration of the wheels is:

$$\alpha = \frac{a_t}{r}$$

$$\alpha = \frac{0.8m/s^2}{0.4m}$$

$\alpha = 2\ rad/s^2$

Example 2.10

A boy rides a bicycle for 5 minutes. The wheel with radius of 30 cm completes 2000 rev during this time. Calculate.

(a) the average angular velocity of the wheel.

(b) the linear distance traveled by the bicycle in 5 minutes.

Solution:

$r = 30$ cm $= 0.3$ m, $\Delta\theta = 2000$ rev

$\Delta t = 5$ min $= 5\times60 = 3000$ s

(a) $\omega_{av} = \frac{\Delta\theta}{\Delta t} = \frac{2000 rev}{3000 s} = 6.67$ rev/s

1rev=2π rad

$\omega_{av} = 41.9$ rad/s

(b) Convert 2000 rev into rad

$\Delta\theta = 12560$ rad

Then $\Delta s = r\Delta\theta$

$\Delta s = 0.3$ m $\times$ 12560 rad

$\Delta s = 3768$ m

Relationship between angular motion and translational motion quantities

In this section, we derive some useful relationships between the angular quantities θ, ω and α of a rotating rigid object and the corresponding linear quantities s, v, and a of a point,p in the object. To do so, we must keep in mind that when a rigid object rotates around a fixed axis as in Figure 2.11, every particle of the object moves in a circle whose center is on the axis of rotation.

As the particle moves along the circle through an angular displacement of θ, it moves through an arc length s.

The arc length s is related to the angle θ through the equation:

$$s = r\theta \tag{2.14}$$

Note that in this equation the angular displacement must be expressed in rad (not degrees or revolutions).

Because point p, in the figure moves in a circle, the translational velocity vector $\vec{v}$ is always tangent to the circular path, and hence is called tangential velocity.

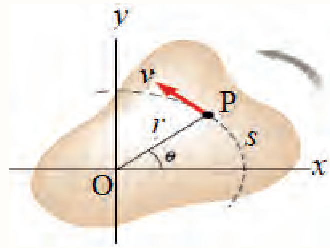


Figure 2.11 As a rigid object rotates around the fixed axis (the *z* axis) through *O*, the point *P* has a tangential velocity $\vec{v}$ that is always a tangent to the circular path of radius.

The magnitude of the tangential velocity of the point *P* is by definition the tangential speed $v = \Delta s/\Delta t$, where *s* is the distance traveled by this point measured along the circular path. Recalling that $\Delta s = r\Delta\theta$ and noting that *r* is constant, we get:

$$\mathrm{v} = \frac{\Delta \mathrm{s}}{\Delta \mathrm{t}} = r\frac{\Delta\theta}{\Delta t} \tag{2.15}$$

Because $\omega = \dfrac{\Delta\theta}{\Delta t}$, it follows that:

$$v = \omega r \tag{2.16}$$

Therefore, the tangential speed of a point on a rotating rigid object equals the radius multiplied by the angular speed. Although every point on the rigid object has the same angular speed, not every point has the same tangential speed because *r* is not the same for all points on the object. The tangential speed of a point on the rotating object increases as it moves outward from the center of rotation.

We can relate the angular acceleration of the rotating rigid object to the tangential acceleration of the point *P* by taking the rate of change *v*.

$$\mathrm{a} = \frac{\Delta \mathrm{v}}{\Delta \mathrm{t}} = r\frac{\Delta\omega}{\Delta t} \tag{2.17}$$

Because $\alpha = \dfrac{\Delta\omega}{\Delta t}$, it follows that

$$a = r\alpha \tag{2.18}$$

That is, the tangential component of the translational acceleration of a point on a rotating rigid object equals the radius multiplied by the angular acceleration.

Example 2.11

A rope is wrapped many times around a pulley of radius 50 cm as shown in Figure 2.12. How many revolutions of the pulley are required to raise a bucket to a height of 20 m?

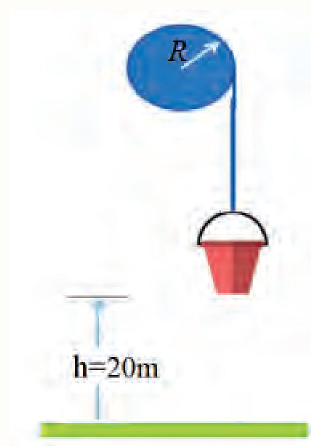


Figure 2.12 A rope wrapped a around a pulley of radius 50 cm.

Solution:

$$\Delta\theta = \frac{\Delta s}{r}$$

When the bucket is raised to 20 m the same length of rope is wrapped around the pulley.

Thus Δs=20 m

$\Delta\theta = \frac{20}{0.5}$

$\Delta\theta$=40 rad

1 rev=2π rad

$\Delta\theta$=6.34 rev

Example 2.12

The angular velocity of a bicycle wheel is 18 rad/s. If the radius of the wheel is 40 cm, what is the speed of the bicycle in m/s?

Solution:

r = 40 cm=0.4 m

ω=18 rad/s

The linear speed of the bicycle is

$v = \omega r$

Δs = 0.4 m x 18 rad/s

v=7.2 m/s

Example 2.13

Consider two particles, A and B, on a flat rotating disk as shown in Figure 2.13. Particle A is 20cm and particle B is 40cm from the center. The disc starts from rest and its angular speed increases to 20rad/s in 4s.

(a) What is the average angular and linear acceleration for particle B?

(b) What is the average angular and linear acceleration for particle A?

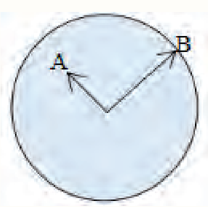


Figure 2.13 Particle A and B on the rotating disc are at different radius.

Solution:

(a) $\alpha_{av} = \frac{\omega_f - \omega_o}{\Delta t}$

$\alpha_{av} = \frac{(20-0)rad/s}{4s}$

$\alpha_{av} = 5 rad/s^2$

$a = \alpha r$

$a = (5\ \text{rad/s}^2)(0.4\ \text{m})$

$\text{a} = 2\ \text{m/s}^2$

(b) The angular acceleration is the same for all particles about the axis of rotation but the linear accleration depends on *r*.

$\text{a} = \alpha\text{r}$

$\text{a} = (5\ \text{rad/s}^2)(0.2\ \text{m})$

$\text{a} = 1\ \text{m/s}^2$

Discussion question 2.7

1. What is the angular speed of the second hand of a clock? What is the direction of $\vec{\omega}$ as you view a clock hanging vertically?
2. A wheel rotates counterclockwise in the xy plane. What is the direction of $\vec{\omega}$? What is the direction of $\vec{\alpha}$ if the angular velocity is decreasing in time?
3. When a wheel of radius R rotates about a fixed axis, do all points on the wheel have (a) the same angular speed? and (b) the same linear speed?

Exercise 2.2

1. When a wheel of radius *R* rotates about a fixed axis, all points on the wheel have the same angular speed. True or False.
2. Which of the following can not be a unit for angular displacement ? A. deg B. rad . rev D. rpm
3. A rope is wrapped many times around a pulley of radius 20 cm. What is the average angular velocity of the pulley if it lifts a bucket to 10 m in 5 s?
4. A particle moves in a circle 1.50 m in radius. Through what angle in radians does it rotate if it moves through an arc length of 2.50 m? What is this angle in degrees?
5. A wheel is under a constant angular deceleration of $5 rad/s^2$. Its initial speed is 3 rad/s. What angular distance will it travel just before coming

to rest?

6. A wheel initially turning at 200 rpm uniformly increases its speed to 600 rpm in 8s. Calculate:
(a) the angular acceleration of the wheel in rad/s^2. (b) the number of revolutions turned by the wheel during the 8 s interval.

2.3 Rotational Dynamics

At the end of this section, you will be able to:

- *Define the physical concept of torque in terms of force and distance from axis of rotation.*
- *Define the physical concept of moment of inertia in terms of point mass and distance from the axis of rotation.*
- *Express torque in terms of moment of inertia and angular acceleration.*
- *Solve problems involving torque and rotational kinematics.*

Having developed the kinematics of rotational motion, we now turn to the dynamics of rotational motion. Just as force played a big role in linear dynamics, we have a torque in rotational dynamics. We begin by defining this quantity and showing how it acts on objects in rotational motion. Next, we relate torque to our study of kinematics through an equation very similar to Newton's second law.

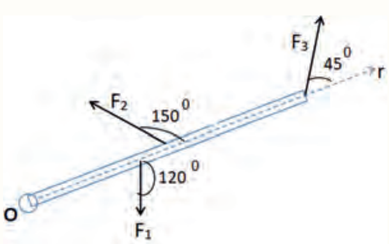


Figure 2.14 Counterclockwise rotation by F around the pivot point.

Torque

Torque is the rotational effect of force. Torque is what causes an object to acquire angular acceleration. If F is the force acting on an object and r is the distance from the axis of rotation to the point of application of the force, as shown in Figure 2.14, the magnitude of the torque is given by:

$$\tau = rF\sin\theta \qquad (2.19)$$

where θ is the angle between r and F when they are drawn from the same origin. Torque is a vector quantity, meaning it has both a direction and a magnitude. Its SI unit is Nm. The direction of the torque is along the axis of rotation. It is determined by a right-hand-rule: when you curl the fingers of your right hand in the direction of the rotation, your thumb points in the direction of the torque.

Example 2.14

The object in Figure 2.15 is pivoted at O. Three forces act on it in the directions shown: F_1 = 10 N at 3.0 m from O; F_2 = 16 N at 4.0 m from O; and F_3= 19 N at 8.0 m from O. What is the net torque about O?

Solution:
F_2 andF_3 give a torque in the counterclockwise direction (positive, usually) and F_1 gives a torque in the clockwise direction (negative torque).

$\tau_1 = r_1 F_1 sin\theta$
$\tau_1 = 3mx10Nxsin(120)^0$
$\tau_1 = -25.9Nm$

$\tau_2 = r_2 F_2 sin\theta$
$\tau_2 = 4mx16Nxsin(150)^0$
$\tau_2 = 32Nm$

$\tau_3 = r_3 F_3 sin\theta$
$\tau_3 = 8mx19Nxsin(45)^0$
$\tau_2 = 107.4Nm$
$\tau_{net} = \tau_1 + \tau_2 + \tau_3$
$\tau_{net} = -25.9Nm + 32Nm + 107.4Nm$
$\tau_{net} = 113.5Nm$ (counterclockwise direction)

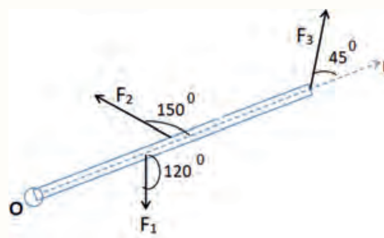


Figure 2.15 Three forces acting on an object pivoted at O.

Moment of inertia (I)

The moment of inertia of an object is the quantitative measure of rotational inertia, just as mass is the quantitative measure of linear inertia inertia in translational motion. The greater the moment of inertia of a rigid object or system of particles, the greater is its resistance to change in angular velocity about a fixed axis of rotation.
The moment of inertia depends on the mass and axis of rotation of the body.The moment of inertia is given the symbol *I*. For a single point mass, as shown in

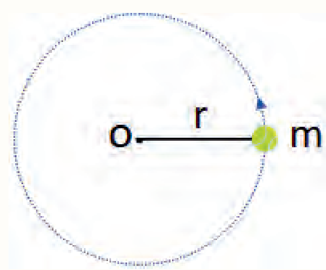


Figure 2.16 Point mass rotating about O

Figure 2.16, rotating at radius r from the axis of rotation the moment of inertia is:

$$I = mr^2 \tag{2.20}$$

From the formula, the SI unit of moment of inertia is kgm^2. Moment of inertia is a scalar quantity.
The moment of inertia for more than one particle around a fixed axis is:

$$I = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 ...$$

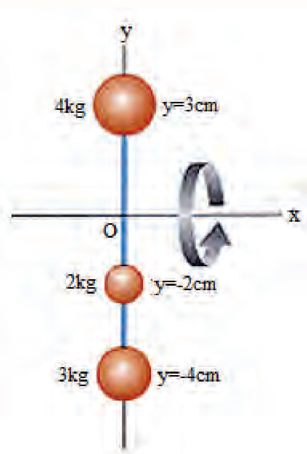


Figure 2.17 Three particles rotating around the x-axis.

Example 2.15

Three particles are connected by rigid rods of negligible mass lying along the y-axis as shown in Figure 2.17. If the system rotates about the x-axis with angular speed of 2 rad/s, find the moment of inertia about the x-axis.

Solution:

$I = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2$
$I = 4kg(3m)^2 + 2kg(2m)^2 + 3kg(4m)^2$
$I = 164\ kgm^2$

Torque and angular acceleration

When a number of individual forces act on a rotating object, we can calculate the net torque:

$$\tau_{net} = \tau_1 + \tau_2 + \tau_3 ...$$

We can relate the net torque to angular acceleration α, by analogy with Newton's second law of motion (F = ma). We replace m by I and a by α.

$$\tau = I\alpha \tag{2.21}$$

The angular acceleration of a rotating object is proportional to the net torque on the object.

Example 2.16

When a torque of 36 Nm is applied to a wheel, the wheel acquires an angular acceleration of $24 rad/s^2$. Find the rotational inertia of the wheel.

Solution:

$\tau = I\alpha$

$I = \frac{36Nm}{24 rad/s^2}$

$I = 1.5\ kgm^2$

Example 2.17

A motor capable of producing a constant torque 100 Nm and a maximum rotation speed of 150 rad/s is connected to a flywheel with rotational inertia 0.1 kgm^2.

(a) What angular acceleration will the flywheel experience as the motor is switched on?

(b) How long will the flywheel take to reach the maximum speed if starting from rest?

Solution:

(a) The angular acceleration is:

$\alpha = \frac{\tau}{I}$

$\alpha = \frac{100Nm}{0.1 kgm^2}$

$\alpha = 1000\ rad/s^2$

(b) The time to reach the maximum speed is:

$\omega_f = \omega_o + \alpha \Delta t$

$t = \frac{\omega_f - \omega_o}{\alpha} = \frac{150 rad/s - 0}{1000 rad/s^2}$

$t = 0.15$ s

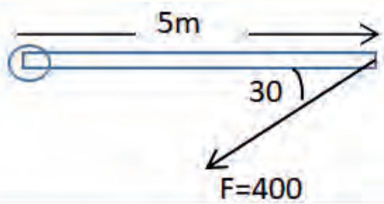


Figure 2.18 Torque on a beam by 400 N force.

Exercise 2.3

1. A force of 400 N is applied to a beam at a distance of 5 m from the pivot point, as shown in Figure 2.18. Calculate the magnitude of the torque which turns the bar around pivot.

2. Three point masses, each of mass *m*, are placed at the corners of an equilateral triangle of side *L*. Find the moment of inertia of the system about an axis passing through one of the corners perpendicular to the plane of the triangle.

3. A disc with moment of inertia 2 kgm^2 changes its angular speed from 3 rad/s to 8rad/s by a net torque of 50 Nm.How long will the disc take to change its angular speed?

2.4 Planetary motion and Kepler's laws

At the end of this section, you will be able to:

- *Describe the motion of the planets around the Sun.*
- *State Kepler's three laws.*
- *Apply equations to solve problems related to orbital motion.*

The planets orbit the Sun. They maintain their respective distances from the Sun. They do not cross each other as they revolve around the Sun. Kepler's laws describe how planetary bodies orbit around the Sun.

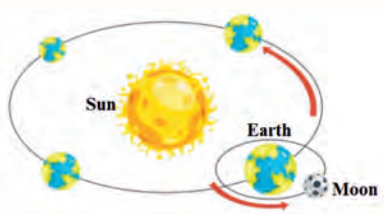


Figure 2.19 Earth with its Moon revolving around the Sun.

Kepler's laws

Humans have observed the movements of the planets, stars, and other celestial objects for thousands of years. In early history, these observations led scientists to regard Earth as the center of the Universe. This geocentric model was elaborated and formalized by the Greek astronomer Claudius Ptolemy (c.100–c.170) in the second century and was accepted for the next 1400 years.

In 1543, Polish astronomer Nicolaus Copernicus (1473–1543) suggested that Earth and the other planets revolved in circular orbits around the Sun (the heliocentric model).

Danish astronomer Tycho Brahe (1546–1601) wanted to determine how the universe was constructed and pursued a project to determine the positions of both stars and planets. His observations of the planets and stars visible from Earth were carried out using only a large sextant and a compass. (The telescope had not yet been invented.)

German astronomer Johannes Kepler was Brahe's assistant for a short while before Brahe's death, where upon he acquired his mentor's astronomical data. Kepler spent 16 years trying to deduce a mathematical model for the motion of the planets. Such data are difficult to sort out because the moving planets are observed from a moving Earth. After many lengthy calculations, Kepler found that Brahe's data on the revolution of Mars around the Sun led to a successful model. Kepler's complete analysis of planetary motion is summarized in three statements known as Kepler's laws.

Discussion question 2.8

In small group discuss the following questions.
What is the shape of an orbit?
What's in the middle of the orbit?
What is the difference between circle and ellipse?

Kepler's first law

Kepler's first law is sometimes referred to as the law of ellipses. It states that the orbit of a planet around the Sun is an ellipse (near circular, oval) with the Sun at one focus (Figure 2.20a).

The planet follows the ellipse in its orbit, meaning that the planet-to-Sun distance is constantly changing as the planet goes around its orbit. An ellipse is a closed curve such that the sum of the distances from a point on the curve ($r_1 + r_2$) to the two foci, f_1 and f_2 is constant, as shown in Figure 2.20b.

Discussion question 2.9

Think of the planets orbiting the Sun. Do all the planets move at the same speed? At which position are the planets' orbital speeds greatest? Explain why.

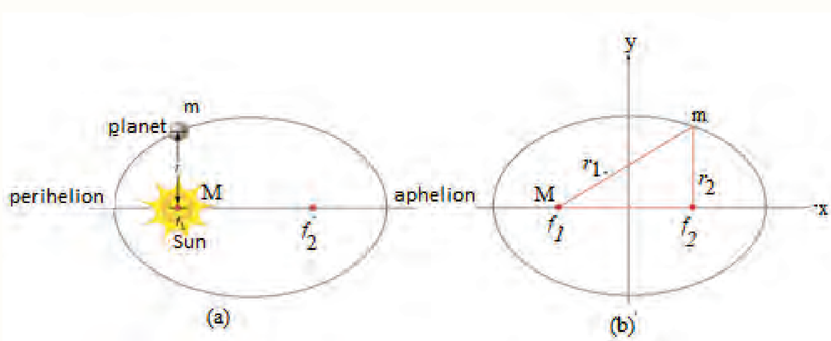


Figure 2.20 (a) The motion of a planet about the Sun. (b) Any distance drawn from f_1 and f_2 to a point on the curve add up to a constant.

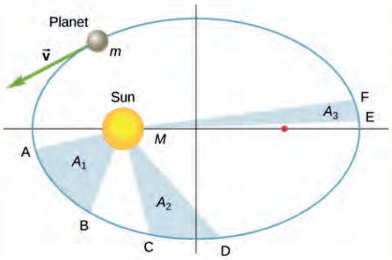


Figure 2.21 The shaded regions shown have equal areas and represent the same time interval.

Kepler's second law

Kepler's second law is sometimes referred to as the law of equal areas. It describes the speed at which any given planet will move while orbiting the Sun. Basically, it states that planets do not move with constant speed along their orbits. Instead, their speed varies so that the line joining the centers of the Sun and the planet sweeps out equal area in equal times. The point at which a planet is nearest the Sun is called perihelion. The point of greatest separation is aphelion. Hence Kepler's second Law, a planet is moving fastest when it is at perihelion and slowest at aphelion.

Kepler's second law states that each planet moves so that an imaginary line drawn from the sun to the planet sweeps out equal areas in equal times interval.

Consider Figure 2.21. The time it takes a planet to move from position A to B, sweeping out area A_1,is exactly the time taken to move from position C to D, sweeping area A_2 and to move from E to F, sweeping out area A_3. These areas are the same: $A_1 = A_2 = A_3$

Comparing the areas in the Figure 2.21 and the distance traveled along the ellipse in each case, we can see that in order for the areas to be equal, the planet must speed up as it gets closer to the Sun and slow down as it moves away.

Discussion question 2.10

In small groups discuss the following questions.
What is the period of Earth?
What is meant by the orbital period of a planet?
Which planet has the shortest orbital period: Earth or Pluto?
Is there a systematic relationship between period and radius for the planets?

Kepler's Third law

Kepler's third law compares the orbital period and the average radius of orbit of a planet to those of other planets. Unlike Kepler's first and second laws that describe the motion characteristics of a single planet, the third law makes a comparison between the motion characteristics of different planets. The period (T) of a planet is the time for one complete revolution around the Sun.

Kepler's third law implies that the period for a planet to orbit the Sun increases rapidly with the radius of its orbit. Thus we find that Mercury, the innermost planet, takes only 88 days to orbit the Sun. Earth takes 365 days, while Saturn requires 10,759 days to do the same.

Kepler's third law states that the ratio $\frac{T^2}{R^3}$, where T is the time period and R is the average distance from the sun is the same for all planets:

$$\frac{T^2}{R^3} = K \tag{2.22}$$

K is a proportionality constant which is nearly the same for all planets.

Kepler's third law equation is valid for both circular and elliptical orbits. Notice that the constant of proportionality is independent of the mass of the planet. Therefore, the equation is valid for any planet.

As an illustration, consider the orbital period and average distance from Sun (orbital radius) for Earth and Mars as given in table 2.2.

Table 2.2 The orbital period and average distance from the Sun for Earth and Mars.

	Period(s)	Average distance (m)	$T^2/R^3 ({}^2/m^3)$
Earth	3.156×10^7	1.4957×10^{11}	2.977×10^{-19}
Mars	5.93×10^7	2.278×10^{11}	2.975×10^{-19}

Observe that the T^2/R^3 ratio is the same for Earth as it is for Mars. In fact, the T^2/R^3 ratio is the same for the other planets.

Example 2.18

Earth has an orbital period of 365 days and its mean distance from the Sun is 1.495×10^8 km. The planet Pluto's mean distance from the Sun is 5.896×10^9 km. Using Kepler's third law, calculate Pluto's orbital period in Earth days?

Solution:

The given quantities are: $T_E = 365 \quad daya,\ \ r_E = 1.495 \times 10^8 \quad km \ \ , r_P = 5.896 \times 10^9 \quad km$

We use Kepler's third law to calculate Pluto's orbital period.

$$\frac{T_E^2}{R_E^3} = \frac{T_p^2}{R_p^3}$$

$$\frac{365\text{days}}{(1.495x10^8 km)^3} = \frac{T_p^2}{(5.896x10^9 km)^3}$$

To solve for T_p, we cross-multiply and take the square root.

$$\text{Thus}: T_P = 9.0 \times 10^{14} \text{ days}$$

Example 2.19

If Saturn is on average 9 times farther from the Sun than Earth is, what is this distance in Earth years?

Solution:

$r_S = 9r_E$, T_E = 1year

$T_S = ?$

$$\frac{T_E^2}{R_E^3} = \frac{T_S^2}{R_S^3}$$

$$\frac{1\text{Year}}{R_E^3} = \frac{T_S^2}{(9R_E)^3}$$

$T_S = 27$ years

Exercise 2.4

1. According to Kepler's laws of planetary motion, a satellite increases its speed as it approaches the Sun and decreases its speed as it moves away from the Sun. True or False.
2. Given that the Moon orbits Earth every 27.3 days and that it is an average distance of 3.84×10^8 m from the center of Earth, calculate the period of an artificial satellite orbiting at an average altitude of 1,500 km above Earth's surface. (Radius of Earth is 6380 km.)
3. How would the period of an object in a circular orbit change if the radius of the orbit doubled?

   A. The period would increase by a factor of 2.

   B. The period would decrease by a factor of 4.

   C. The period would increase by a factor of $2\sqrt{2}$.

   D. The period would decrease by a factor of $2\sqrt{2}$.

https://phet.colorado.edu/sims/html/gravity-and-orbits/latest/gravity-and-orbits_en.html

2.5 Newton's law of universal Gravitation

At the end of this section, you will be able to:

- *Explain what determines the strength of gravity.*
- *Describe how Newton's law of universal gravitation extends our understanding of Kepler's laws.*
- *Apply equations to solve problems related to Newton's law of universal gravitation.*

Brainstorming question 2.2

Imagin the Sun's gravity is suddenly switched off. What will happen to the planets?

Planets orbit the Sun. If we look more closely at the Solar System, we see almost unimaginable numbers of stars, galaxies, and other celestial objects orbiting one another and interacting through gravity. All these motions are governed by gravitational force.

Galileo Galilei (1564-1642) pointed out that heavy and light objects fall toward Earth at the same rate (so long as air resistance is the same for each). But it took Sir Isaac Newton (in 1666) to realize that this force of attraction between masses is universal.

Discussion Question 2.11

What keeps the planets in orbit? Explain your answer.

Newton proved that the force that causes, for example, an apple to fall toward the ground is the same force that causes the Moon to fall around, or orbit, Earth. This universal force also acts between the Earth and the Sun, or any other star and its satellites. Each attracts the other.

Newton defined this attraction mathematically. The force of attraction between two masses is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centers.

$$F_g = \frac{Gm_1 m_2}{r^2} \tag{2.23}$$

where G is a constant, called the universal gravitational constant, m_1 is the first mass, m_2 is the second mass, and r is the distance between the two masses. G is a universal constant, meaning that it is thought to be the same everywhere in the Universe. The value G in SI units is $G = 6.67 \times 10^{-11} Nm^2/kg^2$.

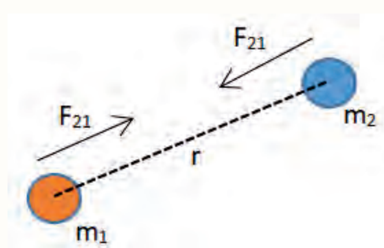


Figure 2.22 Gravitational attraction is along a line joining the centers of mass of the two bodies.

The gravitational force is always attractive, and it depends only on the masses involved and the distance between them. The force is directed along the line joining the two masses, as shown in Figure 2.22. The magnitude of the force on each body is the same but the direction is opposite, consistent with Newton's third law, action-reaction (F_{12} = -F_{21}.)

Example 2.20

A 10 kg mass and a 100 kg mass are 1 meter apart. What is the force of attraction between them?

Solution:
G is given above, m_1 = 10 kg, and m_2 = 100 kg. Putting these values into Newton's gravitational force

$$F_g = \frac{Gm_1 m_2}{r^2}$$

$$F_g = \frac{\left(\frac{6.673x10^{-11}Nm^2}{kg^2}\right)x10kgx100kg}{(1m)^2}$$

$$F_g = 6.67 \text{ x } 10^{-8} \text{ N}$$

Example 2.21

If a person has a mass of 60.0 kg, what would be the force of gravitational attraction on him at Earth's surface?

Solution:
G is given above, Earth's mass M_E is 5.97 × 10^{24} kg, and the radius r_E of Earth is 6.38 × 10^6 m. Putting these values into Newton's gravitational law:

$$F_g = \frac{GM_E m}{{r_E}^2}$$

$$F_g = \frac{(6.673x10^{-11}Nm^2/kg^2)x5.97x10^{24}kgx60kg}{(6.38x10^6 m)^2}$$

$$F_g = 584N$$

We can check this result with the relationship: $F_g = mg$

$$F_g = 60 \text{ kgx}9.8 \text{ m/s}^2$$

$$F_g = 588 \text{ N}$$

You may remember that g, the acceleration due to gravity, is another important constant related to gravity. By substituting g for a in the equation for Newton's second law of motion ($F = ma$) we get: $F_g = mg$.
Combining this with the equation for universal gravitation force gives

$$mg = \frac{GM_E m}{{r_E}^2} \quad (2.24)$$

Cancelling the mass m on both sides of the equation and filling in the values for the gravitational constant, mass and radius of the Earth, gives the value of g on the surface of the earth. which may look familiar.

$$g = \frac{(6.673x10^{-11} Nm^2/kg^2)x5.97x10^{24} kg}{(6.38x10^6 m)^2} = 9.8\, m/s^2 \quad (2.25)$$

Discussion question 2.12

By what factor would a person's weight at the surface of Earth change if Earth had its present mass but eight times its present volume? By what factor would a person's weight at the surface of Earth change if Earth had its present size but only one-third its present mass?

Centripetal Force

It is possible to derive Kepler's third law from Newton's law of universal gravitation. A force that pulls an object towards the centre of a circle is called centripetal force as shown in Figure 2.23. The source for the centripetal force in the Solar System is the gravitational force of the Sun. Without the centripetal force from the Sun the planets would travel in a straight line. The velocity of the planets is high enough so that they continuously accelerate towards the Sun without ever leaving their orbits. It is for this reason that the planets do not fall into the sun from its strong gravitational force of attraction. Applying Newton's second law of motion to circular motion gives an expression for centripetal force.

$$F_c = \frac{mv^2}{r} \quad (2.26)$$

where v is the tangential speed and r is the radius of the orbit and m is mass of the planet.

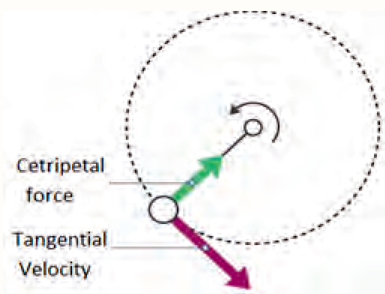


Figure 2.23 Centripetal force constantly pulls the object towards the center of the circle.

The gravitational attraction of the Sun provides the centripetal force needed to keep planets in orbit around the Sun. Earth's gravity keeps the Moon and all types of satellite in orbit around Earth. Because the gravitational force provides the centripetal acceleration of the planet, it follows that:

$$\frac{m_p v^2}{r} = \frac{GM_s m_p}{r^2} \quad (2.27)$$

M_p is mass of the planet, M_s is mass of the sun ($M_s \approx 1.989x10^{30}$kg) and v is the speed of the plane about the sun.

$$v^2 = \frac{GM_s}{r} \quad (2.28)$$

The orbital speed of the planet is

$$v = \frac{2\pi r}{T} \quad (2.29)$$

where T is the period of the planet about the Sun.

Thus

$$\frac{(2\pi r)^2}{T^2} = \frac{GM_s}{r} \quad (2.30)$$

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM_s} = 2.97x10^{-19}$$

This equation is Kepler's third law: the square of the period is proportional to the cube of the distance of the planet from the Sun. The proportionality constant K takes the value:

$$K = \frac{4\pi^2}{GM_s} \approx 2.97x10^{-19}$$

The above equation is therefore valid for any planet. If we were to consider the orbit of a satellite such as the Moon about the Earth, the constant would have a different value, with the Sun's mass replaced by the Earth's mass; that is, $\frac{4\pi^2}{GM_E}$.

Exercise 2.5

1. The gravitational force between a 60 kg man and Earth is not equal because Earth is more massive than the man therefore, it exerts the greatest force. True or False.

2. Two objects are attracted to each other by a gravitational force F. If the distance between the objects is doubled, what is the new gravitational force between the objects in terms of F ?

   A. 4 F B. 1/4F C. 16F D. 1/16F

3. Newton's law of gravitation applies to:

   A. Small bodies only. B. Plants only. C. All bodies irrespective of their size. D. Moon and satellites only

4. Suppose the gravitational force between two spheres is 30 N. If the

magnitude of each mass doubles, what is the force between the masses?

5. Calculate the mass of the Sun, noting that the period of Earth's orbit around the Sun is 3.156 x 10^7 s and its distance from the Sun is 1.496 x 10^{11} m.

6. A hypothetical planet has a mass of four times that of the Earth and radius of twice that of the Earth? What is the acceleration due to gravity on the planet in terms of the acceleration on Earth?

https://phet.colorado.edu/sims/html/gravity-force-lab/latest/gravity-force-lab_en.html

Unit summary

- Projectile refers to an object that is in flight with acceleration due to gravity after being thrown or projected.
- A football kicked in a game, a bullet fired from a gun, the flight of a golf ball, a jet of water escaping a hose are a few common examples of projectile motion
- The horizontal component of the velocity is constant throughout the projectile motion.
- The vertical motion has a constant acceleration which is the accleration due to gravity.
- In projectile motion the time to cover both the horizontal and vertical displacement is the same.
- When the angle of projection is measured with the horizontal axis: given by:
  - The vertical displacement is: $\Delta y = v_0 \sin\theta \; t + \frac{1}{2} g t^2$
  - The horizontal displacement is: $\Delta x = v_0 \cos\theta \, t$

  - The vertical velocity is:
    $v_y = v_0 \sin\theta + gt$
  - The horizontal velocity is:
    $v_x = v_0 \cos\theta$

- When a rigid object rotates about a fixed axis, the angular position, angular speed, and angular acceleration are related to the translational position, translational speed, and translational acceleration through the relationships

  $s = r\theta$, $v = r\omega$, $a = r\alpha$

- For a body rotating around a fixed axis, every particle on the body has the same rotational quantities $\Delta\theta$, ω, and α. That is $\Delta\theta$, ω, and α describe the rotational motion of the entire body.

- ω and α are vector quantities.

- The direction of $\vec{\omega}$ is given by the right-hand-rule (RHR) and the direction of $\vec{\alpha}$ follows from its definition: $\alpha = \frac{\Delta\omega}{\Delta t}$

- Right-hand rule: Wrap your four right-hand fingers in the direction of rotation. Your extended thumb points in the direction of $\vec{\omega}$.

- Mathematically, we have defined the rotational quantities θ, ω, and α similar to how we defined the linear quantities s, v, and a for linear motion. Therefore, the rotational equations of motion with constant angular acceleration, should also be similar.

- The speed at which any planet moves through space is constantly changing. A planet moves fastest when it is closest to the Sun and slowest when it is furthest from the Sun.

- Kepler's laws apply to any celestial body orbiting any other celestial body. For example, any planet around a Sun, the Moon around Earth, any satellite around Earth.

- A planet in the Solar System is in orbit around the Sun, due to the gravitational force on the planet exerted by the gravitational force of the Sun.

- Every object in the Universe attracts every other object with a force directly proportional to the product of their masses and inversely proportional to the square of the distance between them.
- Torque is the rotational effect of force.
- Moment of inertia is a measure of an object's resistance to changes to its rotation.
- The motion of planets around the Sun governed by the gravitational force the Sun and the planets.
- Newton's universal law of gravitation states that any particle of matter in the universe attracts any other with a force varying directly as the product of the masses and inversely as the square of the distance between them.
- The gravitational force is always attractive.
- The source for the centripetal force in the solar system is the gravitational force of the sun. Without the centripetal force from the sun the planets would travel in a straight line.

End of unit Problems

1. A ball is thrown horizontally from the top of a building 45 m high. Calculate:

(a) the time taken to reach the ground.

(b) the horizontal displacement from the foot of the building to the strike point.

(c) The resultant velocity with which it strikes the ground.

2. A football is kicked at angle 30^0 with the horizontal with an initial velocity of 20 m/s. Calculate:

(a) the horizontal and vertical component of initial velocity.

(b) the time of flight

(c) the range

(d) the horizontal displacement at t=1.5 s.

3. The launching speed of a certain projectile is five times the speed it has at its maximum height. Calculate the elevation angle at launching.

4. During volcanic eruptions, pieces of solid rock can be blasted out of a volcano; these projectiles are called volcanic bombs (Figure 2.24).

(a) At what initial speed would the bomb have to be ejected, at 35^0 to the horizontal, from the hole at A in order to fall at the foot of the volcano at B? (Ignore the effects of air resistance on the bomb's travel.)

(b) What would be the time of flight?

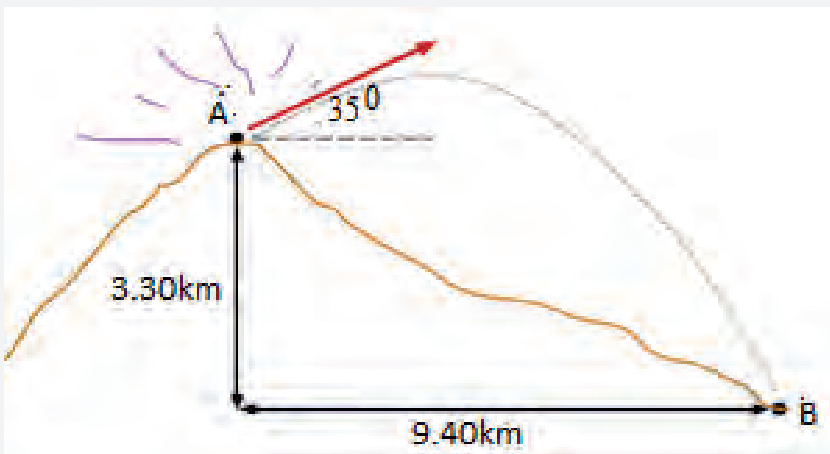


Figure 2.24 Volcanic bombs away.

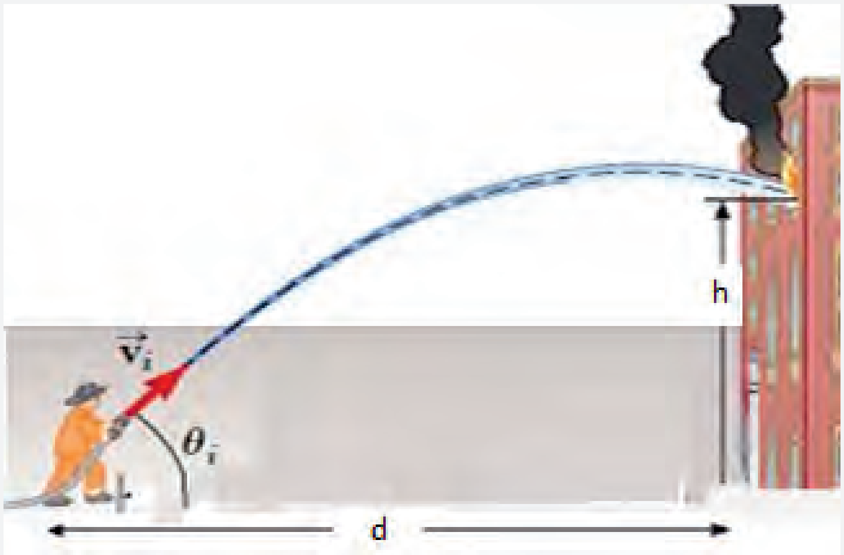


Figure 2.25 A firefighter directs a stream of water from a fire hose.

5. A firefighter, a distance d from a burning building, directs a stream of water from a fire hose at angle θ_i above the horizontal, as shown in Figure 2.25. If the initial speed of the stream is v_i, at what height h does the water strike the building?

6. A rotating fan completes 1200 revolutions every minute. Consider a point on the tip of a blade, at a radius of 0.15 m.

(a) Through what linear distance does the point move in one revolution?

(b) What is the linear speed of the point?

7. A car traveling at 80 km/h has wheels with a 40 cm radius. If the car can be brought to stop within 30 revolutions, what is the angular acceleration of the wheels?

8. The angular velocity of the belt of a grindstone is 40 rad/s. To what angle does the belt rotate in one minute. Given your answer a) in rad b) in rev and c) in degree.

9. A cyclist rides a bicycle with a wheel radius of 0.50 m across campus. If the wheel completes 320 rotations between her apartment and the cafeteria, how far has she traveled?

10. A spinning wheel is slowed down by a brake, giving it a constant angular acceleration of -5.60 rad/s^2. During a 4.20 s time interval, the wheel rotates through 62.4 rad. What is the angular speed of the wheel at the end of the 4.20 s interval?

11. Titan, the largest moon of Saturn, has a mean orbital radius of 1.22x10^9 m. The orbital period of Titan is 15.95 days. Hyperion, another moon of Saturn, orbits at a mean radius of 1.48x10^9 m. Use Kepler's third law of planetary motion to predict the orbital period of Hyperion in days.

12. The planet Mercury travels around the Sun with a mean orbital radius of 5.8x10^{10} m. The mass of the Sun is 1.99x10^{30} kg. How long does it take Mercury to orbit the Sun. Give your answer in Earth days.

13. Two identical isolated particles, each of mass 2.00 kg, are separated by a distance of 30.0 cm. What is the magnitude of the gravitational force exerted by one particle on the other?

Unit 3

Fluid Mechanics

Introduction

Matter most commonly exists as solids, liquids or gases. Liquid and gas are both fluids: in contrast to solids they lack the ability to resist deformation. As a result fluid moves, or flows under the action of the force. Fluid mechanics refers to the study of fluid behavior at rest and in motion. Fluid mechanics has a wide range of applications in mechanical and aerodynamic engineering, in biological systems, and in many more fields.

Brainstorming question 3.1

1. Why do over-inflated balloon bursts?
2. How does a plane move upwards, against gravity?

At the end of this unit, you will be able to:

- *Develop knowledge and understanding of the concepts related to fluids and pressure.*
- *Gain knowledge and understanding of Pascal's principle and Archimedes' principle.*
- *Understand the behaviors of fluid flow.*
- *Develop skills of solving problems related to fluid mechanics.*

3.1 Fluid Statics

At the end of this section, you will be able to:

- *Explain the properties of solids, liquids and gases.*
- *Define pressure.*

- *Convert values of pressure from one pressure unit to another.*
- *Explain causes of pressure in gas and liquids.*
- *Define absolute, atmospheric and gauge pressure.*
- *Define density and relative density.*
- *Solve problems related to pressure, density and specific gravity.*

Brainstorming question 3.2

Why are gases easy to compress, while liquids and solids are almost incompressible?

Properties of solids, liquids and gases

Atoms in solids are very close to each other. The forces between them acts as a spring that allow the atoms to vibrate without changing positions relative to their neighboring atoms (Figure 3.1 a). Thus, a solid resist all types of stress because the atoms are not able to move about freely. Solids also resist compression, because their atoms are relatively fixed distance apart. Under compression, the atoms would be forced into one another.

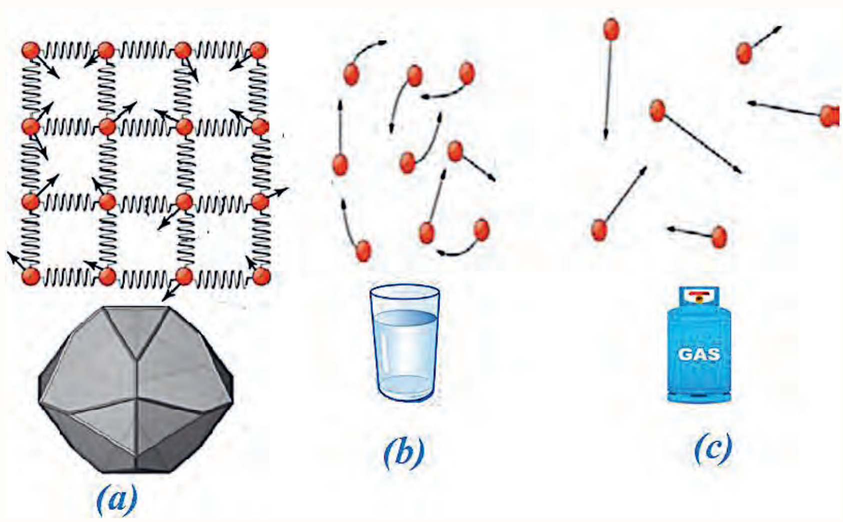


Figure 3.1 (a) Atoms in a solid always have the same neighbors, held near equilibrium position by forces represented here by springs. (b) Atoms in a liquid are also in close contact but can slide over one another. Forces between them strongly resist attempts to push them closer together and also hold them in close contact. (c) Atoms in a gas are separated by distances that are considerably larger than the size of the atoms themselves, and they move about freely.

The molecular spacing in the liquid phase is not much different from that of the solid phase except the molecules are no longer at fixed positions relative to each other and they can rotate and translate freely.

In a liquid, the intermolecular forces are weaker relative to solids, but still strong compared with gases. Liquids deform easily when stressed and do not spring back to their original shape once the force is removed because the atoms are free to slide about and change neighbors. That is, they flow (so they are a type of fluid), with the molecules held together by their mutual attraction (Figure 3.1b).

Atoms in gases are separated by distances that are large compared with the size of the atoms (Figure 3.1c). The forces between gas atoms are therefore very weak, except when the atoms collide with one another. Gases thus not only flow but they are relatively easy to compress because there is much space and little force between atoms. A gas also expands until it encounters the walls of the container and fills the entire available space (Figure 3.2a). In contrast, if we move the liquid filling a small container to a much larger container, the liquid volume remains the same independent of the container's shape (Figure 3.2b). Solids maintain not only their volume but also their shape. The properties of solids, liquids and gases can be observed from the following simulation link: https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html.

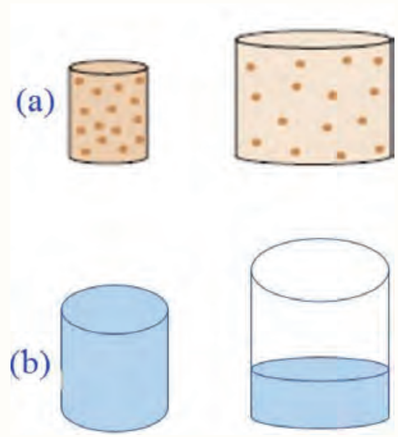


Figure 3.2 (a) The same gas fills completely different volume (b) The liquid volume remains the same regardless of volume and shape of container.

Activity 3.1: Compressibility of gases and liquids

Materials required:
Two syringes of equal size and water.
Procedures:

- Fill a first syringe with water by pushing the piston into the syringe casing until it stops.
- Put the open end of the syringe in to water and then pull water in to it by pulling the piston back to its maximum limit.
- Close the water filled syringe tightly by your finger and push the piston. Notice how far does the piston move.
- Fill a second syringe with air by pushing the piston into the syringe casing until it stops.

- Pull air in to it by pulling the piston back to its maximum limit.
- Close the air filled syringe tightly by your finger and push the piston. Notice how far does the piston move.

Precaution:

(i) Please do not use a syringe with needle to keep yourself safe.

(ii) Closed the water and air filled syringe tightly so that no water and air comes out from the syringes while you are pushing the piston,

Questions:

(i) How far does a piston move in water and air filled syringe?

(ii) What can you say about the compressibility of water and air from the distance moved by the piston?

Discussion question 3.1

(i) Explain the difference between solids, liquids and gases in terms of distance between particles, intermolecular force, their shape and their compressibility.

(ii) What is the difference between fluids and solids?

Fluid statics deals with nature of fluids at rest. The fluid can be either gaseous or liquid. In fluid statics, there is no relative motion between adjacent fluid layers, and no shear (tangential) stresses. The only stress in fluid statics is the normal stress, which is the pressure.

Fluid statics is used to determine the forces acting on floating or submerged bodies and the forces developed by devices like hydraulic presses and car jacks. The design of many engineering systems such as water dams and liquid storage tanks requires the determination of the forces acting on their surfaces using fluid statics.

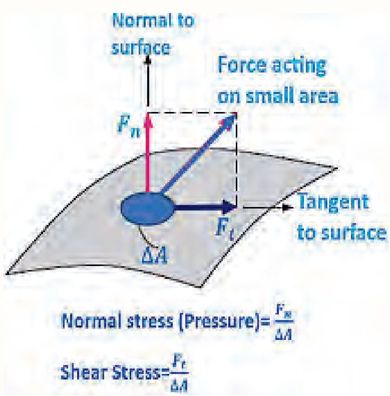


Figure 3.3 The normal stress and shear stress at the surface of a fluid element. For fluids at rest, the shear stress is zero and pressure is the only normal stress.

Pressure in Fluid

Brainstorming question 3.3

(i) Why does a mattress sink more when a person is standing on it compared with when he is lying (Figure 3.4) ?

(ii) Why Scissors, blade, saw and knives cut objects easily?

(iii) Why nails, syringes and pins penetrate into objects easily?

The normal component of a force acting on a surface per unit area is called the normal stress, and the tangential component of a force acting on a surface per unit area is called shear stress (Figure 3.3). For fluid at rest, the shear stress is zero and the only existing stress is the normal stress and is called pressure.

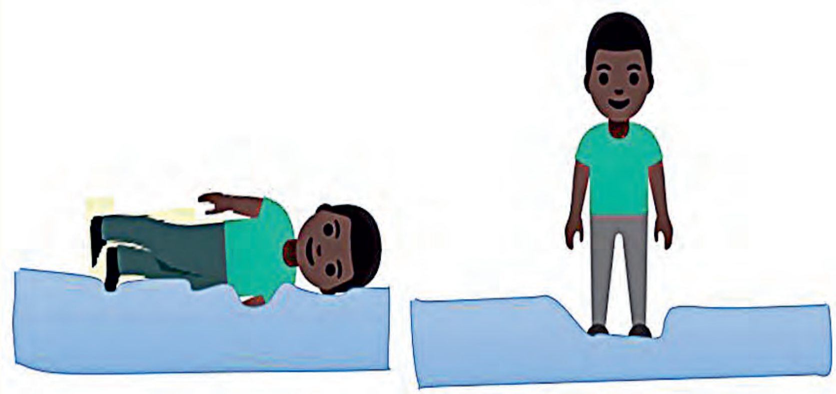


Figure 3.4 Effect of lying and standing on a mattress.

Pressure is defined as a normal force exerted by a fluid (or a solid) per unit area. If F is the magnitude of the force exerted on the fluid (or solid) at a particular point and A is the surface area at which this force is applied, the pressure P at this particular point is defined as the ratio of the force to the contact area A over which that force is exerted:

$$P = \frac{F}{A} \tag{3.1}$$

Pressure is a scalar quantity because it is proportional to the magnitude of the force. If a large force acts on a small area, the pressure is large.

The unit of pressure is newtons per square meter (N/m^2) in the SI system. Another name for the SI unit of pressure is the pascal (Pa):

$$1Pa = 1N/m^2 \tag{3.2}$$

In addition to pascal there are other units of pressure such as millimeter mercury (mmHg), torr, atmosphere (atm) and pounds per square meter (psi) with their relation shown as follow:

$$1\ atm = 760\ mmHg = 760\ torr = 101.3\ KPa = 14.7\ psi \tag{3.3}$$

Activity 3.2:

Hold a sharp pencil between your two fingers and start pressing it from both sides. Notice how you feel on both the fingers. Do you feel pain in any one of your fingers? Notice the finger in which pencil leaves a deeper mark.

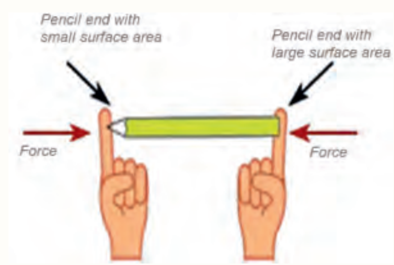


Figure 3.5 Effect of force varies with area

Example 3.1

As a woman walks, her entire weight is momentarily placed on one of her shoes. Calculate the pressure exerted on the floor by the shoe if it has an average width 10 cm and average length of 30 cm and the woman's mass is 55.0 kg.

Solution:

(a) Assuming the shoe is rectangular, its are is obtained by the relation

$$A = w \times l = 10\ cm\ \times 30\ cm = 300\ cm^2 = 0.03\ m^2$$

The force exerted on the floor is the wait of the woman, which is obtained from the relation

$$F = mg = 55.0\ kg \times 9.8\ m/s^2 = 539.00\ N$$

Therefore, the pressure

$$P\ =\ \frac{F}{A} = \frac{539.00\ N}{0.03\ m^2} = 1.8 \times 10^1\ KPa$$

Exercise 3.1

Repeat example 3.1, if the woman stands on her two shoes. Compare the result with example 3.1. What can you say about the difference between the results? Assume the shoes have equal area and her weight is balanced on her two shoes.

Example 3.2

Express the pressure obtained in example 3.1 in atm, torr, mmHG and psi.

Solution:

To express the pressure in other pressure units we have to use relations in Eq 3.3.

To convert pressure in pascal to other units:

$$P_{other} = \frac{P_{cons} \times P_{pascal}}{101.3\ KPa}$$

where P_{cons} is the constant value of pressure in other system of units excluding pascal, P_{pascal} is the given value of pressure in pascal, P_{other} is the value of pressure in the new system of unit. Here P_{pascal} is $1.8 \times 10^1\ KPa$. Therefore,

$$P_{atm} = \frac{1\ atm \times P_{pascal}}{101.3\ KPa} = \frac{1\ atm \times 1.8 \times 10^1\ KPa}{101.3\ KPa} = 0.18\ atm;$$

$$P_{mm\ Hg} = \frac{760\ mmHg \times P_{pascal}}{101.3\ KPa} = \frac{760\ mmHg \times 1.8 \times 10^1\ KPa}{101.3\ KPa} = 135.04\ mmHg;$$

$$P_{torr} = \frac{760\ torr \times P_{pascal}}{101.3\ KPa} = \frac{760\ torr \times 1.8 \times 10^1\ KPa}{101.3\ KPa} = 135.04\ torr;$$

$$P_{psi} = \frac{14.7\ psi \times P_{pascal}}{101.3\ KPa} = \frac{14.7\ psi \times 1.8 \times 10^1\ KPa}{101.3\ KPa} = 2.61\ psi;$$

Example 3.3

Nail tips exert tremendous pressures when they are hit by hammers because they exert a large force over a small area. What force must be exerted on a nail with a circular tip of 1.00 mm diameter to create a pressure of $3.00 \times 10^9\ N/m^2$.

Solution:
From the definition of pressure $P = F/A$, the force F is

$$F = PA.$$

Here, the pressure P is given, and the area of the end of the nail A is given by

$$A = \pi\left(\frac{d}{2}\right)^2.$$
Since $d = 1.00\ mm = 1x10^{-3} m$.

Thus,

$$A = (3.14)(5x10^{-4} m)^2 = 7.85x10^{-7} m^2$$

$$F = PA = (3.00 \times 10^9\ N/m^2)(7.85x10^{-7} m^2)$$

$$= 2.36 \times 10^3\ N$$

The result shows that the magnitude of pressure is far greater than the force applied. The reason is that the area of the tip of the nail is very small. This is why nails are easily hammered into a wood and concrete.

Pressure in Gases

As air particles move randomly in space, they eventually collide with the solid surfaces of any objects in that space. In each of these collisions, the particle exerts an impulsive force on the object (see Figure 3.6).

However, when a huge number of particles bombard a solid surface at a constant rate, these collisions collectively exert an approximately constant force on the object (Figure 3.6 b). This impulsive force must be what we feel when we are trying to squeeze the balloon.

Brainstorming question 3.4

Try to crush air-filled balloon a little bit. Can you feel the balloon resisting the crushing, as if something inside it pushes back on your fingers. How can we explain this “resistance” of the air inside the balloon,and how pressure of the gas is formed?

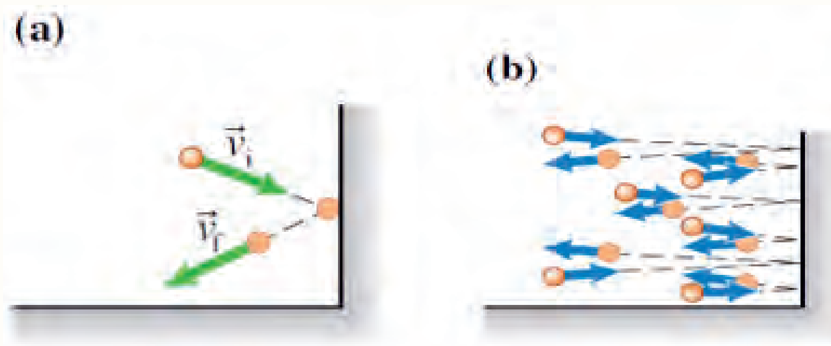


Figure 3.6 a) Each particle exerts an impulsive force on the wall (b) collective collision of gas particles on a wall.

As we blow a balloon, we add air particles to the interior of the balloon; thus there are more particles inside colliding with the walls. This greater collision rate results in a larger outward average force on each part of the balloon's surface, causing it to expand outward. The force exerted by the gas on the walls of the container per unit contact area gives the pressure of the gas.

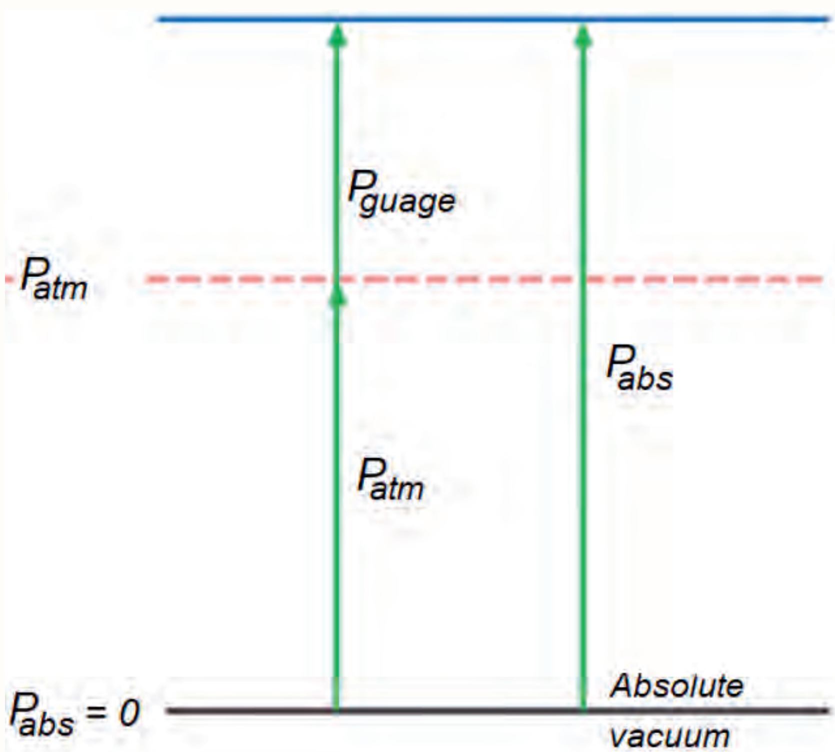


Figure 3.7 Absolute, gauge, and vacuum pressures.

The actual pressure at a given position is called the absolute pressure, and it is measured relative to absolute vacuum (i.e., absolute zero pressure). Most pressure-measuring devices, however, are calibrated to read zero in the atmosphere, and so they indicate the difference between the absolute pressure and the local atmospheric pressure. This difference is called the gauge pressure (P_{gage}). Absolute and gauge pressures are related to each other by

$$P_{gage} = P_{abs} - P_{atm} \tag{3.4}$$

This is illustrated in Figure 3.7.

Like other pressure gauges, the gauge used to measure the air pressure in an automobile tire reads the gauge pressure. Therefore, the common reading of 32.0 psi indicates a pressure of 32.0 psi above the atmospheric pressure.

Figure 3.8 Measuring a gauge pressure of a car.

Example 3.4

What is the absolute pressure at a location where the atmospheric pressure is 14.3 psi and the gauge pressure of an automobile tire is 32.0 psi?

Solution:

The absolute pressure is determined by rearranging Eq. 3.4 as:

$$P_{abs} = P_{atm} + P_{gage} = 14.3\ psi + 32.0\ psi = 46.3\ psi$$

Example 3.5

The absolute pressure in water at a depth of 8 m is read to be 175 kPa. Determine the local atmospheric pressure if the guage pressure at this depth is 78.4 KPa.

Exercise 3.2

Determine the absolute pressure where gauge pressure is 61.152 KPa and atmospheric pressure is 14.0 psi.

Solution:

The absolute pressure in a water at a depth of 8 m is given as 175 KPa

The local atmospheric pressure is to be determined.

It can be obtained from Eq. 3.4

$$P_{loc.atm} = P_{abs} - P_{gauge}$$

$$= 175\ Kpa - 78.4\ KPa = 96.6\ KPa$$

We can observe that the local atmospheric pressure is less than the atmospherics pressure at sea level.

Brainstorming question 3.5

Why some objects float and others sink?

Density

Density is an important characteristic of substances. It is crucial, for example, in determining whether an object sinks or floats in a fluid. It directly affects pressure of fluids (gases and liquids). Density is a much more useful physical quantity for gases.

Density, ρ, is the mass, m, per unit volume, V, of any object. It is calculated by dividing the mass of an object by its volume.

$$\rho = \frac{m}{V} \tag{3.5}$$

The unit of density is kg/m^3.

Density measures the mass of one cubic meter of a substance. For example, at sea level and 0°C the mass of 1.0 m^3 of air is 1.3 kg. We say that the density of air is 1.3 kg/m^3. If we had 2.0 m^3 of air at sea level, its mass would be 2.6 kg. Its density is still 1.3 kg/m^3.

Discussion question 3.2

When three liquids with densities $\rho_1 < \rho_2 < \rho_3$ are mixed together, which liquid will be at the top, middle and bottom layer?

The density of most gases is proportional to pressure and inversely proportional to temperature. Liquids and solids, on the other hand, are essentially incompressible substances, and the variation of their density with pressure is usually negligible.

Example 3.6

Assume the following about a person: mass is 80 kg; dimensions are 1.8 m tall, 0.3 m wide, and 0.1 m thick; and volume is $V = 1.8\ m \times 0.3\ m \times 0.1\ m = 0.054\ m^3$, What is the density of this person.

Solution: The person's density is given by Eq. 3.5:

$$\rho = \frac{m}{V}$$

Substitute the person's mass and volume into the above to get

$$\rho = \frac{80\ kg}{0.054\ m^3} = 1500\ kg/m^3$$

Table 3.1 Densities of some common substance at standard temperature (°C) and pressure (1 atm)

Substance	$\rho\ (kg/m^3)$	substance	$\rho (kg/m^3)$
Air	1.29	Iron	7.86 x10^3
Aluminum	2.70x10^3	carbon Steel	7.84 x10^3
Benzene	0.879x10^3	mercury	13.6 x10^3
Brass	8.4 x10^3	oxygen	1.43
copper	8.92 x10^3	nitrogen	1.25
Fresh water	1.00 x10^3	Sea water	1.03 x10^3
Gold	19.3 x10^3	silver	10.5 x10^3
Ice	0.917 x10^3	Tin	7.30 x10^3

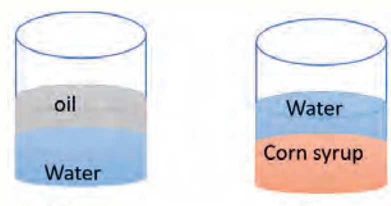


Figure 3.9 Less dense materials floats on denser matter.

As you can see from Table 3.1, the density of an object may help identify its composition. The density of gold, for example, is about 2.5 times the density of iron. The density of iron is about 2.5 times the density of aluminum. Density also indicates about the phase of the matter and its particles arrangement. The densities of liquids and solids are roughly comparable, consistent with the fact that their atoms are in close contact.

Understanding density allows us to answer questions like: "why does oil form a film on water?". If you pour oil into water or water into oil, they form layers (see Figure 3.9 a). Independently of which fluid is poured first, the layer of oil is always on top of the water. The density of oil is less than the density of water.

Similar phenomena occur with gases. Helium-filled balloons accelerate upward in air while air-filled balloons accelerate (slowly) downward. The mass of helium atoms is much smaller than the mass of any other molecules in the air. At the same pressure and temperature, atoms and molecules of gas have the same concentration; because helium atoms have much lower mass, their density is lower. The air-filled balloon must be denser than air. The rubber with which the skin of any balloon is made is denser than air. We can ignore the slight compression of the gas by the balloon, because even though it increases the density of the gas, the effect is the same for both the air and helium in the balloons. You can study more about density from the simulation: https://phet.colorado.edu/sims/html/density/latest/density_en.html.

Relative density

Sometimes the density of a substance is given relative to the density of an another substance. Then it is called specific gravity, or relative density, and is defined as the ratio of the density of a substance to the density of some standard substance at a specified temperature (usually water at 4°C, for which $\rho_{H_2O} = 1000 kg/m^3$).

That is;

$$\text{specific gravity} = S_G = \frac{\rho}{\rho_{H_2O}}$$

Note that the specific gravity of a substance does have any unit. In SI units, the numerical value of the specific gravity of a substance is exactly equal to its density in g/cm^3. For example the density of mercury at 20°C is 13.6 x10^3 kg/m^3). Its relative density is 13.6 x10^3 kg/m^3 divided by density of water, 1 x10^3 kg/m^3, which is 13.6. The density of mercury in g/cm^3 is also 13.6.

The specific gravities of some substances at 20°C are given in Table 3.2. Note that substances with specific gravities less than 1 are lighter than water, and thus they would float on water.

Ideal gas equation

The simplest and best-known equation in the gas phase that relate density and pressure of gases is the ideal-gas equation of state, expressed as

$$PV = nRT = \frac{m}{M}RT = mR_{specific}T$$

Table 3.2 The specific gravity of some substances at 20℃ and 1 atm unless stated otherwise

Substance	SG	Substance	SG
Air	0.00129	Seawater	1.025
Blood (at 37℃)	1.06	Gasoline	0.68
Ethyl alcohol	0.790	mercury	13.6
Gold	19.3	bones	1.7-2.0
Ice (0℃)	0.916		

This gives us

$$P = \frac{m}{V} R_{specific} T = \rho R_{specific} T \tag{3.6}$$

where P is the absolute pressure, V is the gas volume, n is number of mole, T is the thermodynamic (absolute) temperature, $\rho = \frac{m}{V}$ is the density, and $R_{specific} = R/M$ is the specific gas constant. The specific gas constant is different for different gases and R is the universal gas constant whose value is R = 8.314 J/mol. K and M is the molar mass of the gases.

The relation of pressure, volume, temperature and number of moles of gases can be observed from the simulation: https://phet.colorado.edu/sims/html/gas-properties/latest/gas-properties_en.html.

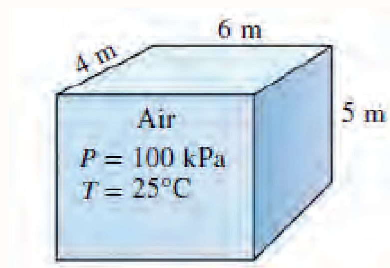


Figure 3.10 Dimension of air at 25℃ and 100 kPa

Example 3.7

Determine the density, specific gravity, and mass of the air in a room whose dimensions are 4 m × 5 m × 6 m at 100 kPa and 25°C (Figure 3.10).

Solution:

Air can be treated as an ideal gas. The gas constant of air is R/M = 0.287 kPa·m^3/kg·K.

The density of the air is determined from the ideal-gas relation P = ??(R/M)T to be

$$\rho = \frac{P}{(R/M)\,T} = \frac{100\;Kpa}{(0.287\;KPa.m^3/kg.K)\,(25+273.15)\,K} = 1.17\;kg/m^3$$

Note that the temperature is converted to (absolute) unit K from (relative) unit °C before using it in the ideal-gas relation.

Then the specific gravity of the air becomes

$$SG = \frac{\rho}{\rho_{H_2O}} = \frac{1.17 kg/m^3}{1000\ kg/m^3} = 0.00117$$

The volume of the air is equal to the volume of the room

$$V = (4\ m)(5\ m)(6\ m) = 120\ m^3$$

Finally, the mass of the air in the room is

$$m = \rho V = (1.17\ kg/m^3)\left(120\ m^3\right) = 140\ kg$$

3.2 Pressure in fluids at rest

At the end of this section, you will be able to:

- *State Pascal's principle*
- *Explain how Pascal's principle is used in hydraulic press machine.*
- *Discuss how pressure depends on the depth of fluid.*
- *Discuss the working principles of pressure measuring devices like barometers and manometers.*
- *Perform simple experiments related to pressure.*
- *Solve problems related to Pascal's principle, fluid depth and atmospheric pressure.*

As gas particles collide with the walls of the container in which they reside, they exert pressure. In fact, if you place any object inside a gas, the gas particles exert the same pressure on the object as the gas exerts on the walls of the container. Do liquids behave in a similar way? The particles in a liquid are in continual random motion, somewhat similar to particles in gases.

Activity 3.3: Testing direction of pressure

Materials required:
A plastic bottle, five nails and water
Procedures:

- Pock five holes at the middle of the bottle along its perimeter using the nail as shown in (Figure 3.11).
- Close all the holes by nails.
- Fill the bottle with water while the it is opened.
- Remove the nails and observe what happens.

Precaution:
Take care to avoid the damage while pocking the bottle using nail.
Question
Try to explain your observation.

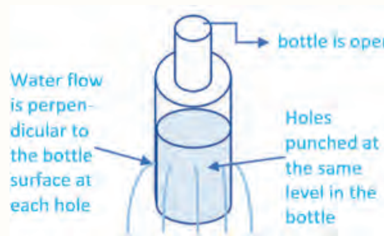


Figure 3.11 Arcs of water leaving holes at the same level in a bottle.

Pascal's principle

Pushing the piston in to a confined fluid in one direction causes a greater pressure in the fluid close to the piston. Almost immediately the pressure throughout the fluid increases uniformly, fluid is pushed out of all of the holes in the container (Figure 3.12 a and b)). This phenomenon was first discovered by French scientist Blaise Pascal in 1653 and is called $Pascal's$ principle.
Pascal's principle: States that a change in the pressure applied to a static fluid is transmitted undiminished to every point of the fluid and to the walls of the container.

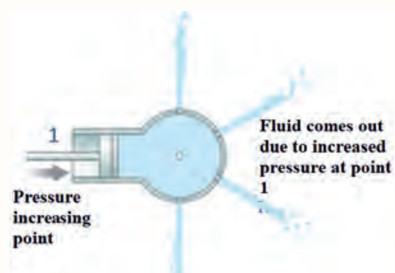


Figure 3.12 Pascal's principle: Increasing the pressure of a fluid at one location causes a uniform pressure increase throughout the fluid.

How can we explain this observation? The pressure applied at one point is sooner transmitted to the whole part of the fluid by a continuous collisions of neighboring molecules of the fluid.

Activity 3.4: Pressure in a pair of connected syringes

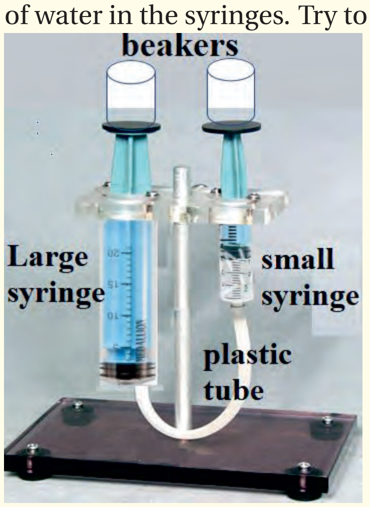
Materials required: Two syringes of different size, a piece of flexible plastic tube, two identical 250 ml transparent beakers and bucket partly filled with water

Procedures:

- Submerge the plastic tube and let it fill completely with water.
- Push the plunger of the small syringe all the way into it so there is no air in it. Fill it partially with water. Then insert its tip into one end of the submerged, water-filled plastic tube.
- Push the plunger of the larger syringe all the way into it so there is no air in it. Fill it partially with water. Then insert its tip into an other end of the submerged, water-filled plastic tube.
- Then take the entire assembly out of the water and arrange the syringes vertically as shown in the Figure below with their initial water level at the same height.
- Put identical beakers on the top of the syringes' plungers.
- Draw some water into the beaker on the plunger of small syringe. What do you observe about the water level in the two syringes?
- Draw water into the beaker on the plunger of the large syringe until the water level on the two syringes is the same.

Precaution: Syringes should not have needle to avoid damage.

Question: How much water is require on both beakers to balance the level of water in the syringes. Try to explain your observation.



Hydraulic press

One of the technical applications of Pascal's Principle is a hydraulic press which is a form of simple machine that converts small forces into larger forces, or vice versa. Automobile mechanics use hydraulic presses to lift cars, and dentists and barbers use them to raise and lower their clients' chairs. The hydraulic brakes of an automobile are also a form of hydraulic press. Most of these devices work on the simple principle illustrated in Figure 3.13, although the actual devices are usually more complicated in construction.

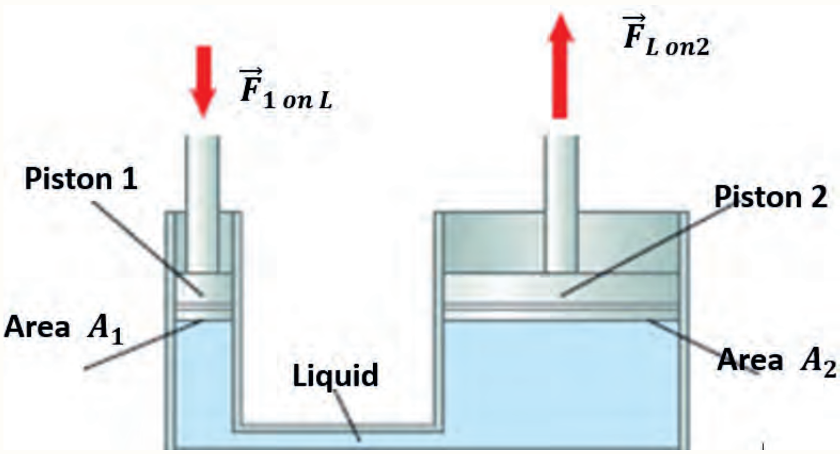


Figure 3.13 Schematic of a hydraulic press.

In Figure 3.13, a downward force $\vec{F}_{1\ on\ L}$ is exerted by piston 1 (with small area A_1) on the liquid. This piston compresses a liquid (usually oil) in the lift.

The pressure in the fluid just under piston 1 is

$$P_1 = \frac{F_{1\ on\ L}}{A_1} \tag{3.7}$$

Because the pressure changes uniformly throughout the liquid, the pressure under piston 2 is also $P = F_{1\ on\ L}/A_1$, assuming the pistons are at the same height. Since piston 2 has a greater area A_2 than piston 1, the liquid exerts a greater upward force on piston 2 than the downward force on piston 1:

$$F_{L\ on\ 2} = PA_2 = \left(\frac{F_{1\ on\ L}}{A_1}\right) A_2 = \left(\frac{A_2}{A_1}\right) F_{1\ on\ L} \tag{3.8}$$

Since A_2 is greater than A_1, the lift provides a significantly greater upward force

$F_{L\ on\ 2}$ on piston 2 than the downward push of the smaller piston 1 on the liquid $F_{1\ on\ L}$.

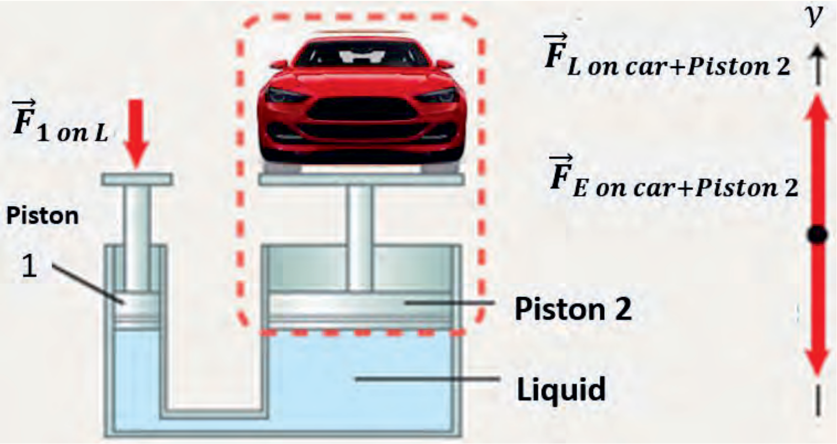


Figure 3.14 Hyraulic press

Example 3.8

A hydraulic lift has a small piston with surface area 0.0020 m^2 and a larger piston with surface area 0.20 m^2. Piston 2 and the car placed on piston 2 have a combined mass of 1800 kg. What is the minimal force that piston 1 needs to exert on the fluid to slowly lift the car?

Solution:

Assume that the levels of the two pistons are the same and that the car is being lifted at constant velocity. Use the force diagram for the car and piston 2 (see Figure 3.14) and Newton's second law to determine F_L on 2. Note that the force that the liquid exerts on the piston 2, $F_{L\ on\ 2}$, is equal in magnitude to the force that piston 2 and the car exert on the liquid $F_{2\ on\ L}$, which equals the downward gravitational force that Earth exerts on the car and piston:

$F_{E\ on\ Car+Piston2} = F_{2\ on\ L} = m_{Car+Piston}g$.

We rewrite the hydraulic press Eq. (3.8) to determine the unknown force:

$F_{1\ on\ L} = \left(\frac{A_1}{A_2}\right) F_{2\ on\ L} = \left(\frac{A_1}{A_2}\right) m_{Car+piston}g$

substituting the givens and solving

$$F_{1\ on\ L} = \left(\frac{0.0020\ m^2}{0.20\ m^2}\right)\left[(1800\ kg)(9.8\ N/kg)\right] = 180\ N$$

Exercise 3.4

Dear students, in example 3.8, if you needed to lift the car about 0.10 m above the ground, what distance would you have to push down on the small piston?

That is the force equal to lifting an object of mass 18 kg. This example shows that a six year old child of average mass 20 kg is more than capable of raising the car simply by sitting on the small piston.

A hydraulic press is a force multiplying machine. It reduces the amount of force needed to lift a load. A small force is applied at small piston to raise a heavy load at the larger piston. However, the work done by the two pistons is the same. That is

$W_{by\ Piston1} = W_{on\ Piston2}$

or

$F_{by\ Piston1}(d_1) = F_{on\ Piston2}(d_2),$

where W, F and d refer work done, force and distance traveled respectively.

Variation of pressure with depth

Activity 3.5: Variation of pressure with depth

Materials required:

Three identical plastic bottles, three identical nails, a table and water.

Procedures:

- Make a hole near to the bottom of each plastic bottle by identical nails. The holes should have identical height.
- Fill the three bottles with water to different height while the holes are closed by the nails.
- Put the bottles on the edge of a table facing the holes in the same direction, away the table.
- Remove the nails gently simultaneously and observe the distance the water shots hits the ground.

Precaution:

- Take care to avoid damage while making a hole using the nails.
- Keep the lids of the bottles open throughout your experiment.

Question

- Which water shot has the largest distance (wider arc) from the bottom of the table?

- What do you think the reason for that?
- How the distance of the water shots from each bottles vary with time and explain the result.

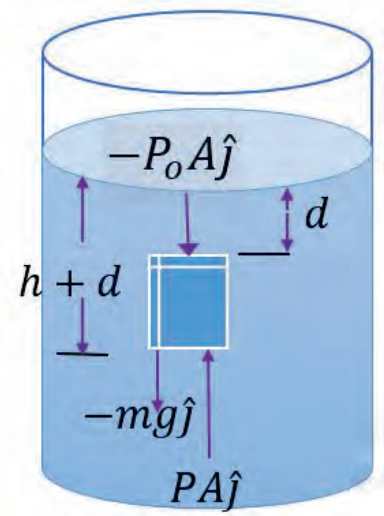


Figure 3.15 A parcel of fluid in a larger volume of fluid.

Consider a liquid of density ρ at rest as shown in Figure 3.15. We assume ρ is uniform throughout the liquid, which means the liquid is incompressible. Let us select a parcel of the liquid contained within an imaginary block of cross-sectional area A extending from depth d to depth $d + h$. The liquid external to our parcel exerts forces at all points on the surface of the parcel, perpendicular to the surface. The pressure exerted by the liquid on the bottom face of the parcel is P, and the pressure on the top face is P_o. Therefore, the upward force exerted by the outside fluid on the bottom of the parcel has a magnitude PA, and the downward force exerted on the top has a magnitude is P_oA. The mass of liquid in the parcel is $M = \rho V = \rho Ah$; therefore, the weight of the liquid in the parcel is $W = Mg = \rho Ahg$. Because the parcel is at rest and remains at rest, it can be modeled as a particle in equilibrium, so that the net force acting on it must be zero. The forces are the upward force at the bottom (PA), the downward force at the top (P_oA) and weight of the parcel (Mg). Choosing upward to be the positive y direction, we see that

$$\sum \vec{F} = PA\hat{\boldsymbol{j}} - P_oA\hat{j} - Mg\hat{\boldsymbol{j}} = 0$$

Or

$$PA - P_oA - \rho Ahg = 0$$

$$P = P_o + \rho hg \tag{3.9}$$

That is, as the depth increases by h, the pressure increases by ρgh. It depends on the depth as well as the density of the liquid. If the liquid is open to the atmosphere and P_o is the pressure at the surface of the liquid, then P_o is atmospheric pressure.

$$P_o = 1.00\ atm = 1.0133 \times 10^5\ Pa$$

Equation 3.9 implies that the pressure is the same at all points having the same depth, whatever shape the container posses. Because the pressure in a fluid depends on depth and on the value of P_o, any increase in pressure at the surface must be transmitted to every other point in the fluid by the Pascal's principle.

Thus the equation $P = h\rho g$ represents the pressure due to the weight of any fluid of average density ρ at any depth h below its surface. For liquids, which are nearly incompressible, this equation holds to great depths. For gases, which are quite compressible, one can apply this equation as long as the density changes are small over the depth considered. The pressure due depth of liquid is independent of the shape and size of the container, it only depends on the depth.

Activity 3.6: Independence of liquid pressure with size and shape of container

Materials required:

Three plastic bottles of different diameter, three identical nails and a table

Procedures:

- Make a hole near to the bottom of each plastic bottle by identical nails. The holes should have identical height.
- Fill the three bottles with water to the same level.
- Put the bottles on the edge of a table facing the holes in the same direction, away the table.
- Remove the nails gently simultaneously and observe the distance the water shots hits the ground.

Precaution:

- Take care to avoid damage while making a hole using the nails.
- Keep the lids of the bottles open throughout your experiment.

Question

- Which water shot has the largest distance (wider arc) from the bottom of the table?
- Explain the reason for your observation?

Example 3.9

Calculate the force on a circular area of diameter 0.40 m on the bottom of the ocean which is 25.0 m below the surface. Take atmospheric pressure and density of sea water at the bottom to be 1 atm and 1.03 K kg/m^3 respectively.

Solution:

The absolute pressure is obtained from the relation:

$$P_{abs} = P_{amt} + P_{gauge} = P_{amt} + \rho g h$$

where $P_{amt} = 1\ atm = 101.3\ KPa$, $\rho = 1.03 \times 10^3\ k/m^3$, $and\ h = 25\ m$. Therefore,

$$P_{abs} = 101.3\ KPa + (1.03 \times 10^3\ k/m^3)(9.8\ m/s^2)\ (25\ m)$$

$$= 101.3\ KPa + 252.35\ KPa = 353.65\ KPa$$

Similarly, the area is obtained as $A = \pi\left(\frac{d}{2}\right)^2 = (3.14)\left(\frac{0.4\ m}{2}\right)^2 = 0.1256\ m^2$

We can use the relation $P_{abs} = \frac{F_{net}}{A}$. Then, the force exerted is

$$F_{net} = P_{abs} A = 353.65\ KPa \times 0.1256\ m^2$$

$$= 4.44 \times 10^4\ N$$

Atmospheric pressure

Discussion question 3.3

A sealed empty plastic water bottle collapses as a plane descends from a higher elevation to a lower elevation as shown in Figure 3.16. Why this happens?

Figure 3.16 The plastic bottle (a) sealed at 4,300 m altitude, (b) the same sealed plastic bottle at an altitude of 2,700 m and (c) at the 300 m.

Activity 3.7: Effect of temperature on Pressure

Materials required:

Two identical plastic bottles, and hot water

Procedures:

- Fill one of the plastic bottle by hot water and cover tightly; then keep it to cool down to room temperature.
- Fill the other plastic bottle by hot water and keep it to cool down to room temperature while the lid is open.

Precaution:

Take care to avoid the damage of hot water by using heat resistance glove and using moderately hot water.

Question

- What happens to the closed plastic bottles at room temperature? Explain the reason.
- What happens to the opened plastic bottles at room temperature? Explain the reason.

At the Earth's surface, the air pressure exerted on you is a result of the weight of air above you. This pressure is reduced as you climb up in altitude and the weight of air above you decreases. There are two reasons why air pressure decreases as altitude increases: density and depth of the atmosphere.

Most gas molecules in the atmosphere are pulled close to Earth's surface by gravity, so gas particles are denser near the surface. With more gas particles in a given volume, there are more collisions of particles and therefore greater pressure.

The depth (distance from top to bottom) of the atmosphere is greatest at sea level and decreases at higher altitudes. With greater depth of the atmosphere, more air is pressing down from above. Therefore, air pressure is greatest at sea level and falls with increasing altitude. On top of Mount Everest, which is the tallest mountain on Earth, air pressure is only about one-third of the pressure at sea level.

Atmospheric pressure P_{atm} changes from 101.325 KPa at sea level to 89.88, 79.50, 54.05, 26.5, and 5.53 KPa at altitudes of 1000, 2000, 5000, 10,000, and 20,000 meters, respectively. Remember that the atmospheric pressure at a location is simply the weight of the air above that location per unit surface area.

Activity 3.8: Effect of atmospheric pressure on the flow of confined water

Materials required:

A Plastic bottle and nail or pin

Procedures:

- Fill a plastic bottle with water and cover the lid tightly.
- Make a small hole at the bottom of this bottle by a nail or a pin and take the nail/pin out.

Precaution:

Take care to avoid the damage while using the nail/ pin.

Question

- (i) Does all the water leave the plastic bottle? Why?
- (ii) What will happen if the bottle is open?

The decline of atmospheric pressure with elevation has far-reaching consequences in daily life. For example, cooking takes longer at high altitudes since water boils at a lower temperature at lower atmospheric pressures. For a given temperature, the density of air is lower at high altitudes, and thus a given volume contains less air and less oxygen. So it is no surprise that we tire more easily and experience breathing problems at high altitudes. To compensate for this effect, people living at higher altitudes develop more efficient lungs. Similarly, a 2.0-L car engine will act like a 1.7-L car engine at 1500 m altitude (unless it is turbocharged) because of the 15 percent drop in pressure and thus 15 percent drop in the density of air.

Measuring pressure

Under the water, the pressure exerted on you increases with increasing depth. In this case, the pressure being exerted upon you is a result of both the weight of water above you and that of the atmosphere above you. You may notice an air pressure change on an elevator ride that transports you many floors, but you need only dive one meter or below the surface of a pool to feel a pressure increase. The difference is that water is much denser than air, about 775 times as dense.

The Barometer

Atmospheric pressure is measured by a device called a barometer; thus, the atmospheric pressure is often referred to as the barometric pressure. The Italian Evangelista Torricelli (1608–1647) was the first to conclusively prove that the atmospheric pressure can be measured by inverting a mercury-filled tube into a mercury container that is open to the atmosphere, as shown in Figure 3.17(a). The pressure at point B is equal to the atmospheric pressure, and the pressure at point C can be taken to be zero since there is only mercury vapor above point C and the pressure is very low relative to P_{atm} and can be neglected to an excellent approximation. Writing a force balance in the vertical direction gives

$$P_{atm} = \rho g h \tag{3.10}$$

where ρ is the density of mercury, g is the local gravitational acceleration, and h is the height of the mercury column above the free surface. Note that the length and the cross-sectional area of the tube have no effect on the height of the fluid column of a barometer (Figure 3.17b).

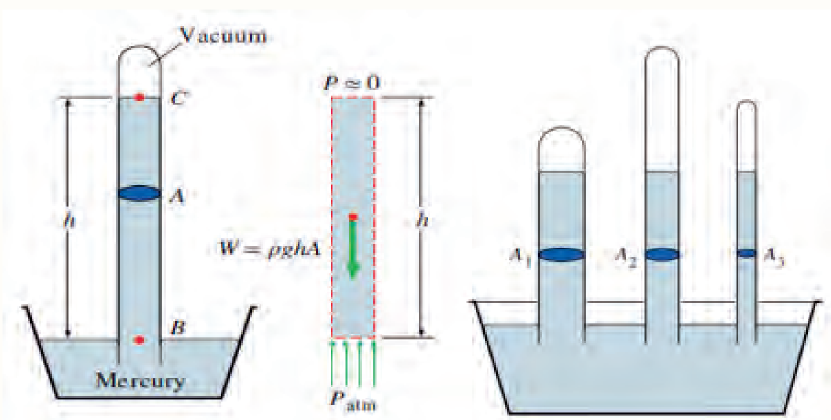


Figure 3.17 (a) The basic barometer. (b) The length or the cross-sectional area of the tube has no effect on the height of the fluid column of a barometer, provided that the tube diameter is large enough to avoid surface tension (capillary) effects.

Discussion question 3.4

(i) Why nosebleed is a common experience at high altitudes?
(ii) Federation International de Football Association (FIFA) had banned international matches played above an altitude of 2,800m in 2007. Why do you think the reason for this?

A frequently used pressure unit is the standard atmosphere, which is defined as the pressure produced by a column of mercury 760 mm in height at 0°C ($\rho_{Hg} = 13,595\ kg/m^3$) under standard gravitational acceleration ($g = 9.807\ m/s^2$). If water instead of mercury were used to measure the standard atmospheric pressure, a water column of about 10.3 m or 10300 mm would be needed. Pressure is sometimes expressed (especially by weather forecasters) in terms of the height of the mercury column. The standard atmospheric pressure, for example, is 760 mmHg at 0°C. The unit mmHg is also called the torr in honor of Torricelli. Therefore, 1 atm = 760 torr and 1 torr = 133.3 Pa.

Exercise 3.5

(i) The reading of a barometer in your room is 700 mm Hg. What does this mean? What is the pressure in pascals?
(ii) If oil of density 950 kg/m^3 is used in the barometer instead of mercury, what would be the height of the oil in the tube at 1 atm?

Example 3.10

Determine the atmospheric pressure at a location where the barometric reading is 740 $mmHg$ and the gravitational acceleration is $g = 9.805\ m/s^2$. Assume the temperature of mercury to be 10°C, at which its density is $13,595\ kg/m^3$).

Solution:

The temperature of mercury is assumed to be 10°C.

The density of mercury is given to be $13,595\ kg/m^3$.

From Eq. 3.11, the atmospheric pressure is determined to be

$$P_{atm} = \rho g h$$

$$= (13,570\ kg/m^3)(9.805 m/s^2)(0.740\ m)$$

$$= 98.5\ kPa$$

The manometer

A manometer is a device similar to a barometer that can be used to measure the pressure of a gas trapped in a container. A closed-end manometer is a U-shaped tube with one closed arm and the other arm connected to the gas whose pressure is to be measured, and a nonvolatile liquid (usually mercury) in between. The distance between the liquid levels in the two arms of the tube (h in Figure 3.18) is proportional to the pressure of the gas in the container. An open-end manometer (Figure 3.18) is the same as a closed-end manometer, but one of its arms is open to the atmosphere. In this case, the distance between the liquid levels corresponds to the difference in pressure between the gas in the container and the atmosphere.

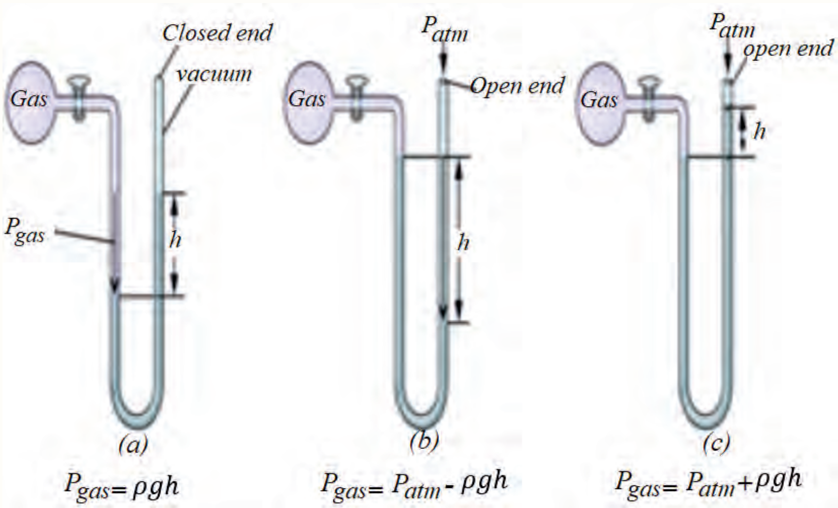


Figure 3.18 Measurement of gas pressure with manometer (a) closed end manometer (b) open end manometer with atmospheric pressure greater than gas pressure (c) open end manometer with atmospheric pressure less than gas pressure

This device is mainly used to measure low pressure differences accurately. In the Figure 3.18, let us use the principle of hydrostatic equilibrium. The pressure in the gas supply (P_{gas}) for the situations shown in Figure 3.18 are given as follow:

(a) For closed end manometer:

$$P_{gas} = \rho gh$$

(b) For open end manometer with atmospheric pressure greater than gas pressure:

$$P_{gas} = P_{atm} - \rho gh$$

(c) open end manometer with atmospheric pressure less than gas pressure:

$$P_{gas} = P_{atm} + \rho gh$$

where ρ denotes density of the liquid, g denotes gravitational constant, h is the height of the liquid column. Note that the cross-sectional area of the tube has no effect on the differential height h, and thus the pressure exerted by the fluid. However, the diameter of the tube should be large enough (more than several

Exercise 3.6

The pressure of a sample of gas is measured with a closed-end manometer, as shown in Figure 3.19. The liquid in the manometer is mercury. Determine the pressure of the gas.

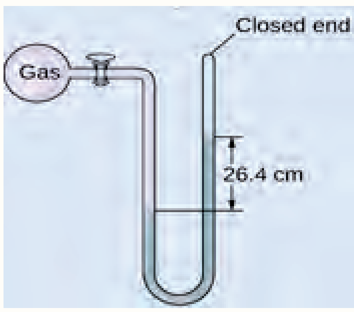


Figure 3.19 Fluid level in closed end manometer

Brainstorming question 3.6

Dear students, can you guess why objects like empty plastic bottle, plastic balls, some wooden and metallic objects like boats is difficult to submerge in to a water or other liquids?

millimeters) to ensure that the surface tension effect and thus the capillary rise is negligible.

Example 3.11

An open manometer is used to measure the pressure of a gas in a tank. The fluid used has a specific gravity of 0.85, and the fluid column in the open arm is 55 cm above the gas connected arm, as shown in Figure 3.18. If the local atmospheric pressure is 96 kPa, determine the absolute pressure within the tank.

Solution:

The reading of a manometer attached to a tank and the atmospheric pressure are given. The absolute pressure in the tank is to be determined.

The density of the gas in the tank is much lower than the density of the manometer fluid.

The specific gravity of the manometer fluid is given to be 0.85. We take the standard density of water to be 1000 kg/m^3.

The density of fluid is obtained by multiplying its specific gravity by the density of water,

$$\rho = SG(\rho_{H_2O}) = (0.85)(1000\ kg/m^3) = 850\ kg/m^3$$

Then from Eq. 3.12,

$$P = P_{atm} + \rho g h$$

$$= 96\ kPa + (850\ kg/m^3)(9.81\ m/s^2)(0.55\ m)$$

$$= 100.6 \text{ kPa}$$

Note that the gauge pressure in the tank is 4.6 kPa.

3.3 Archimedes' principle

At the end of this section, you will be able to:

- *Define the buoyant force.*
- *Classify floating and submerging objects comparing the objects and the fluid density.*
- *Solve problems related to buoyant force.*

Buoyant force

It is extremely difficult to push a ball down under water because of the large upward force exerted by the water on the ball. The upward force exerted by a fluid on any immersed object is called a **buoyant force**. Where does this buoyant force come from? Buoyant force is based on the fact that pressure increases with depth in a fluid. This means that the upward force on the bottom of an object in a fluid is greater than the downward force on the top of the object. There is a net upward, or buoyant force on any object in any fluid (See Figure 3.20). Buoyant force is also called up thrust force. How a buoyance force is exerted by gas particle can be observed from the link: https://phet.colorado.edu/en/simulations/balloons-and-buoyancy.

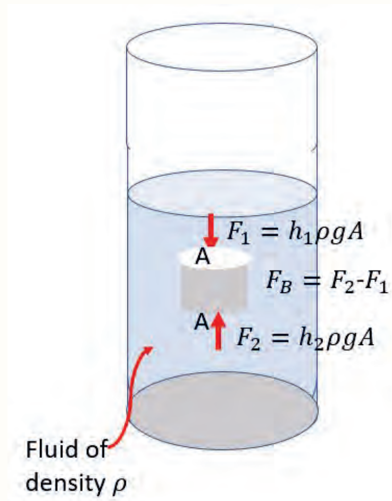


Figure 3.20 Pressure variation with depth resulting a buoyant force

How large is this buoyant force? To answer this question, think about what happens when a submerged object is removed from a fluid. The space it occupied is filled by fluid having a weight W_{fl} . Since this weight is supported by surrounding fluid, the magnitude of buoyant force on an object must equal the weight of the fluid displaced by the object.
It is a tribute to the Greek mathematician and inventor Archimedes (287–212 B.C.) that he stated this principle long before concepts of force were well established. Archimedes' principle is Stated as follows: The buoyant force on an object equals the weight of the fluid it displaces. In equation form, Archimedes' principle is given as:

$$F_B = W_{fluid} \tag{3.11}$$

Activities 3.9: Buoyancy

Materials required:
Two glass cups, table salt, spoon, two eggs and water.
Procedures:

- Fill 3/4 of both glass cups with ordinary water.
- Dissolve 4 to 5 spoons of salt in one of water filled glass cups.
- Put one of the egg into fresh water and the other in to a salt solution.

Question

- Which of the eggs floats and which one is sinking? Reason out your observation in both experiments.

To further understand the origin of the buoyant force, consider a cylinder of solid material immersed in a liquid as in Figure 3.20. The pressure P_2 at the bottom of the cylinder is greater than the pressure P_1 at the top by an amount $\rho_{fluid}gh$, where h is the height of the cylinder and ρ_{fluid} is the density of the fluid. The pressure at the bottom of the cylinder causes an upward force equal to P_2A, where A is the area of the bottom face. The pressure at the top of the cylinder causes a downward force equal to P_1A. The resultant of these two forces is the buoyant force F_B with magnitude

$$F_B = P_2A - P_1A = \rho_{fluid}ghA$$

$$F_B = \rho_{fluid}gV_{disp} \tag{3.12}$$

where $V_{disp} = Ah$ is the volume of the fluid displaced by the cylinder. Because the product $\rho_{fluid}V_{disp}$ is equal to the mass of fluid displaced by the object,

$$F_B = M_{disp}g \tag{3.13}$$

where $M_{disp}g$ is the weight of the fluid displaced by the cylinder.

Totally submerged object

When an object is totally submerged in a fluid of density ρ_{fluid}, the volume V_{disp} of the displaced fluid is equal to the volume of the object V_{obj}; so, the magnitude of the upward buoyant force is $F_B = \rho_{fluid}gV_{obj}$. If the object has a mass M and density ρ_{obj}, its weight is equal to $F_g = Mg = \rho_{obj}gV_{obj}$, and the net force on the object is $F_B - F_g = (\rho_{fluid} - \rho_{obj})gV_{obj}$. Hence, if the density of the object is less than the density of the fluid, the downward gravitational force is less than the buoyant force and the unsupported object accelerates upward. If the density of the object is greater than the density of the fluid, the upward buoyant force is less than the downward gravitational force and the unsupported object sinks.

If the density of the submerged object equals the density of the fluid, the net force on the object is zero and the object remains in equilibrium. It can be anywhere inside the fluid. Therefore, the direction of motion of an object submerged in a fluid is determined only by the densities of the object and the fluid.

Floating object

Now consider an object of volume V_{obj} and density $\rho_{obj} < \rho_{fluid}$ in static equilibrium floating on the surface of a fluid, that is, an object that is only partially submerged. In this case, the upward buoyant force is balanced by the downward gravitational force acting on the object. If V_{disp} is the volume of the fluid displaced by the object (this volume is the same as the volume of that part of the object beneath the surface of the fluid), the buoyant force has a magnitude $F_B = \rho_{fluid} g V_{disp}$. Because the weight of the object is $F_g = Mg = \rho_{obj} g V_{obj}$ and $F_g = F_B$, we see that $\rho_{fluid} g V_{disp} = \rho_{obj} g V_{obj}$, or

$$\frac{V_{disp}}{V_{obj}} = \frac{\rho_{obj}}{\rho_{fluid}} \tag{3.14}$$

This equation shows that the fraction of the volume of a floating object that is below the fluid surface is equal to the ratio of the density of the object to that of the fluid.

Example 3.12

An iceberg floats in seawater as shown in Figure **??**. What fraction of the iceberg lies below the water level?

Givens: Density of sea water and icebergs are 1030 kg/m^3 and 917 kg/m^3 respectively.

Solution:

From equation (3.14)

$$\frac{V_{disp}}{V_{ice}} = \frac{\rho_{ice}}{\rho_{sea\ waster}} = \frac{917\ kg/m^3}{1030\ kg/m^3} = 0.89 = 89\%$$

Therefore, the visible fraction of ice above the water's surface is about 11%. It is the unseen 89% below the water that represents the danger to a passing ship. This hidden ice can damage a ship that is still at a considerable distance from the visible ice.

Figure 3.21 (a) Much of the volume of this iceberg is beneath the water. (b) A ship can be damaged even when it is not near the visible ice.

Activities 3.10. Measuring buoyant force and density of liquid

Materials required: two 100 ml beakers, a pendulum bob, spring balance and water.

Procedures:

(i) Measure the weight of the pendulum using spring balance.
(ii) Fill a 100 ml beaker by pure water.
(iii) Measure the weight of a pendulum bob inside the water by suspending it on a spring balance while collecting the overflowing water.
(iv) Measure the weight of overflow water you have collected.
(v) Subtract the weight of the bob measured in pure water from its weight measured in air. This is equal to buoyant force.

Questions

- (a)Compare the weight of overflow water you measured in step (iv) and the buoyant force in step (v). Does your result verify Archimedes' principle?

- (b)Calculate the density of water using the relation

$$F_B = \rho_{sol} g V_{sol}$$

.
where F_B is the buoyant force you got in step (v), V_{sol} is the volume of the overflow water. ρ_{sol} is the density of water you are going to calculate and g is gravitational acceleration. Compare your result with the density of water in Table 3.1.

Example 3.13

(a) Calculate the buoyant force on 10,000 metric tons (1.00×10^7 kg) of solid carbon steel completely submerged in water, and compare this with the steel's weight. (b) What is the maximum buoyant force that water could exert on this same steel if it were shaped into a boat that could displace 1.00×10^5 m^3 of water?

Solution: for (a)

To find the buoyant force, we must find the weight of water displaced. We can do this by using the densities of water and steel given in Table 3.1. We note that, since the steel is completely submerged, its volume and the water's volume are the same.

From the definition of density $\rho = \frac{m}{V}$

$$V_{st} = \frac{m_{st}}{\rho_{st}} = \frac{1.00x10^7 kg}{7.84x10^3 kg/m^3} = 1.28x10^3 m^3$$

Because the steel is completely submerged, this is also the volume of water displaced, V_w. We can now find the mass of water displaced from the relationship between its volume and density, both of which are known. This gives

$$m_w = \rho_w V_w = \left(1.000x10^3 kg/m^3\right)\left(1.28x10^3 m^3\right)$$

$$= 1.28x10^6 kg$$

By Archimedes' principle, the weight of water displaced is $m_w g$, so the buoyant force is

$$F_B = W_w = m_w g = (1.28x10^6 kg)(9.80\ m/s^2)$$

$$= 1.3x10^7 N$$

The steel's weight is $m_{st}g = 9.80 \times 10^7\ N$, which is much greater than the buoyant

Exercise 3.7:

Suppose your mass is 70.0 kg and your density is 970 kg/m^3. If you could stand on a scale in a vacuum chamber on Earth's surface, the reading of the scale would be mg = (70.0 kg)(9.80 N/kg) = 686 N. What will the scale read when you are completely submerged in air of density 1.29 kg/m^3? Compare your answer with your weight in the vacuum chamber and decide whether the buoyant force of air is to be considered or to be ignored.

force, so the steel will remain submerged.

Solution for (b)

The mass of water displaced is found from its relationship to density and volume, both of which are known. That is,

$$m_w = \rho_w V_w = (1.000x10^3 kg/m^3)(1.00x10^5 m^3)$$

$$= 1.00x10^8 kg.$$

The maximum buoyant force is the weight of this much water, or

$$F_B = m_w g = (1.00x10^8)(9.80 m/s^2)$$

$$= 9.80x10^8 N$$

The maximum buoyant force is ten times the weight of the steel, meaning the ship can carry a load nine times its own weight without sinking.

Example 3.14

The mass of an ancient Greek coin is determined in air to be 8.630 g. When the coin is submerged in water, its apparent mass is 7.800 g. Calculate its density, given that water has a density of 1.0 g/cm^3 and that effects caused by the wire suspending the coin are negligible.

Solution:

The volume of water displaced V_w can be found by solving the equation for density $\rho = m/V$.

The volume of water is $V_w = m_w/\rho_w$ where m_w is the mass of water displaced. As noted, the mass of the water displaced equals the apparent mass loss, which is $m_w = 8.630\ g - 7.800\ g = 0.830\ g$. Thus the volume of water is $V_w = \frac{0.830\ g}{1.000\ g/cm^3} = 0.830\ cm^3$. This is also the volume of the coin, since it is completely submerged. We can now find the density of the coin using the definition of density:

$$\rho_c = \frac{m_c}{V_c} = \frac{8.630\ g}{0.830\ cm^3} = 10.4\ g/cm^3$$

You can see from Table 3.1 that this density is very close to that of pure silver.

Exercise 3.8:

A crown weighs 25.0 N when it is measured in air and 22.6 N when it is submerged in water. Check whether the crown is made from pure gold or some less valuable metal assuming the density of gold is $19,300 kg/m^3$.

Exercise 3.9:

A rectangular wooden block floats with 75 % of its volume inside a water. What is the density of this block?

3.4 Fluid flow

Fluid flow is caused by differences in pressure. When the pressure in one region of the fluid is lower than in another region, the fluid tends to flow from the higher pressure region toward the lower pressure region. For example, large masses of air in Earth's atmosphere move from regions of high pressure into regions of low pressure creating what we call wind.

Brainstorming question 3.7

i) What mechanism maintains the Blood flows through our circulatory system?
ii) How can a plane fly against gravity?

At the end of this section, you will be able to:

- *Differentiate steady and turbulent fluid flow.*
- *Define flow rate.*
- *Derive equation of continuity from flow rate.*
- *Explain the cause and working principle of some common activities or experiences.*
- *Solve problems on equation of continuity.*

Steady and turbulant fluid flow

When fluid is in motion, its flow can be characterized as being *steady fluid flow* if each particle of the fluid follows a smooth path such that the paths of different particles never cross each other as shown in Figure 3.22. In steady flow, every fluid particle arriving at a given point in space has the same velocity. The laminar flow always occurs when the fluid flow with low velocity and in small diameter pipes.

Above a certain critical speed, *turbulent fluid flow* occurs. Turbulent flow is irregular flow characterized by small whirlpool-like regions as shown in Figure 3.22. The adjacent layers of the fluid cross each other and move randomly in a

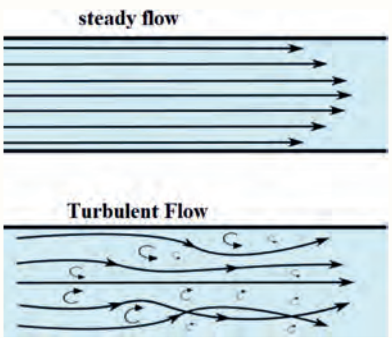


Figure 3.22 Laminar and turbulent flow.

zigzag manner. The turbulent flow occurs when the velocity of the fluid is high and it flows through larger diameter pipes.

As a solid surface is acted by a frictional force when it slides over another solid, there is also an internal frictional force in liquid, called viscosity, when two adjacent layers of fluid try to move relative to each other. Viscosity causes part of the fluid's kinetic energy to be transformed to internal energy. This mechanism is similar to the one by which the kinetic energy of an object sliding over a rough, horizontal surface decreases.

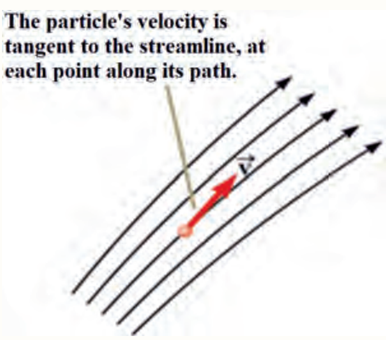


Figure 3.23 A particle in laminar flow follows a streamline.

The path taken by a fluid particle under steady flow is called a *streamline*. The velocity of the particle is always tangent to the streamline as shown in Figure 3.23. A set of streamlines like the ones shown in Figure 3.23 form a tube of flow. In laminar flow, fluid particles cannot flow into or out of the sides of this tube; if they could, the streamlines would cross one another and results in turbulent flow.

Flow rate

Flow rate Q is defined to be the volume of fluid passing by some location through an area during a period of time, as seen in Figure 3.24. In symbols, this can be written as

$$Q = \frac{V}{t} \tag{3.15}$$

where V is the volume and t is the elapsed time.

The SI unit for flow rate is m^3/s , but a number of other units for Q are in common use.

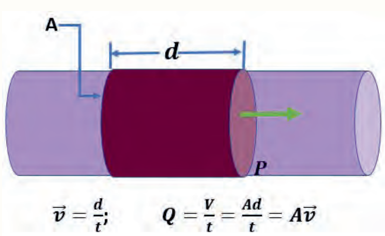


Figure 3.24 Flow rate of fluid.

Example 3.15

How many cubic meters of blood does the heart pump in a 75-year lifetime, assuming the average flow rate is 5.00 L/min?

Solution:
Time and flow rate Q are given, and so the volume V can be calculated from:

Solving $Q = \frac{V}{t}$ for volume gives

$$V = Qt$$

Substituting the known values gives:

$$V = \left(\frac{5.00\ L}{1\ min}\right)(75\ y)\left(\frac{1\ m^3}{10^3 L}\right)\left(5.26\times10^5\frac{min}{y}\right)$$

$$= 2.0\times10^5 m^3$$

Figure 3.25 Flow of incompressible fluid through a pipe of decreasing radius

Equation of continuity

Figure 3.25 shows an incompressible fluid flowing along a pipe of decreasing radius. Because the fluid is incompressible, the same amount of fluid must flow past any point in the tube in a given time to ensure continuity of flow. In this case, because the cross-sectional area of the pipe decreases, the velocity must necessarily increase. This logic can be extended to say that the flow rate must be the same at all points along the pipe. In particular, for points 1 and 2,

$$\left.\begin{aligned} Q_1 &= Q_2 \\ A_1 v_1 &= A_2 v_2 \end{aligned}\right\} \tag{3.16}$$

Discussion question 3.5:

What happens when water flows from a hose into a narrow spray nozzle?

This is called *the equation of continuity* and is valid for any incompressible fluid where v_1 is the average speed of the fluid passing cross section A_1 and v_2 is the average speed of the fluid passing cross section A_2. The *equation of continuity* is used to relate the cross-sectional area and average speed of fluid flow in different parts of a rigid vessel carrying an incompressible fluid. You can visualize effect of cross-sectional area on velocity of fluid flow from the link: https://phet.colorado.edu/en/simulations/fluid-pressure-and-flow.

Since liquids are essentially incompressible, the equation of continuity is valid for all liquids. However, gases are compressible, and so the equation must be applied with caution to gases if they are subjected to compression or expansion.

Example 3.16

A nozzle with a radius of 0.250 cm is attached to a garden hose with a radius of 0.900 cm. The flow rate through hose and nozzle is 0.500 L/s. Calculate the speed of the water (a) in the hose and (b) in the nozzle.

Solution: for (a)

First, we solve $Q = Av$ for v_1 and note that the cross-sectional area is $A = \pi r^2$, yielding

$$v_1 = \frac{Q}{A_1} = \frac{Q}{\pi r_1^2}$$

Substituting known values and making appropriate unit conversions yields

$$v_1 = \frac{(0.500\ L/s(m^{-3}/L)}{\pi(9.00 \times 10^{-3} m)^2} = 1.96 m/s$$

Solution for (b)

We could repeat this calculation to find the speed in the nozzle v_2 , but we will use the equation of continuity to give a somewhat different insight. Using the equation which states

$$A_1 v_1 = A_2 v_2$$

solving for v_2 and substituting πr^2 for the cross-sectional area yields

$v_2 = \frac{A_1}{A_2} v_1 = \frac{\pi r_1^2}{\pi r_2^2} v_1 = \frac{r_1^2}{r_2^2} v_1$ Substituting known values,

$$v_2 = \frac{(0.900)^2}{(0.250\ cm\ )^2}\ 1.96 m/s = 25.5\ m/s$$

Discussion question 3.6

What happens when you blow air hard across the top surface of a piece of paper held at the corners as shown in Figure 3.26. What is the reason for that? Can you relate this to how airplane flies against gravity?

Figure 3.26 A piece of paper held at the corner before air is blown across the top.

As a fluid's speed increases, the pressure that the moving fluid exerts on the surface decreases. This is called Bernoulli's principle and stated as: The pressure that a fluid exerts on a surface decreases as the speed with which the fluid moves across the surface increases.

Fluid flow has important implications in biological systems for example, in the flow of blood through blood vessels. The blood pressure against the wall of a vessel depends on how fast the blood is moving. Pressure is lower when the blood is moving faster. Similarly, a snoring sound occurs when air moving through the narrow opening above the soft palate at the back of the roof of the mouth has lower pressure than nonmoving air below the palate (Figure 3.27). The normal air pressure below the soft palate, where the air is not moving, pushes the palate closed. When airflow stops, the pressures equalize and the passage reopens. The rhythmic opening and closing of the soft palate against the throat leads to the snoring sound. Pressure is also very important in wind musical instruments.

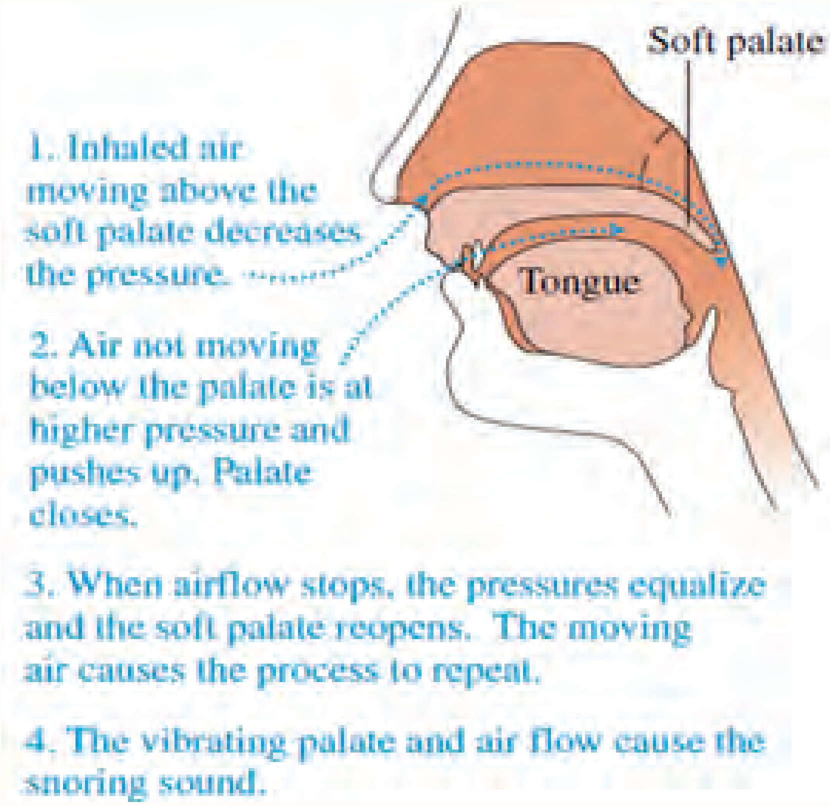


Figure 3.27 Snoring occurs when the soft palate opens and closes due to the starting and stopping of air flow across it.

3.5 Safety and high pressure

At the end of this section, you will be able to:

- *List high- pressure systems.*
- *List application of high-pressure system*
- *Identify the common causes of risk in the high-pressure systems*
- *Familiarized the safety measures related to high pressure systems*

Brainstorming question 3.8

Dear students, have you ever seen while metal and wood technicians spraying ink or varnish on wooden or metallic furniture? How do these spraying machines work? Have you observed other equipment having similar purpose?

High pressure systems

Pressure far greater than 1 atmosphere (most of the time greater than 50 atm) is considered as high pressure. High pressure is used for many applications. High pressure cookers are used in a kitchen to cook food. Gas cylinders containing liquid petroleum gas at high pressure are used as fuel. Gas cylinder are also used to seal different types of gases at high pressure for laboratory or medical use. The bicycle and car tires are inflated by high pressure tire inflator. High pressure is also used in high pressure washers. In physical science (physics and chemistry) high pressure is important to study physical properties of various materials (mainly solids) and to transform their nature.

Many materials undergo fascinating changes in their physical and chemical characteristics when subjected to high pressure. The application of high pressure to biological samples is also of technological relevance because it is known that the microorganism activity is diminished or canceled by application of high pressures, a process called pascalization. Pascalization can be used to increase the shelf lives of perishable foodstuffs: juice, fish, meat, dairy products, etc. High pressure affects many scientific and technological fields, like biology, chemistry, environmental engineering, food technology, material science, pharmacy, and physics.
High pressure equipment may consist of high-pressure compressors (or pumps), high pressure piping (fittings, seals, tubing and valves), high pressure vessels, Steam Generator, Safety Accessories and high-pressure instrumentation (Figure 3.29).

Figure 3.28 A compressor with a storage tank .

High pressure compressors (pumps): A compressor is a mechanical device that increases the pressure of a gas by reducing its volume (Figure 3.28). Compressors are similar to pumps: both increase the pressure on a fluid and both can transport the fluid through a pipe. Heated pressure equipment are intended for generation of steam or super-heated water at temperatures higher than 110°C and having a volume greater than two liters. This includes all pressure cookers. Because of severe stresses, it is essential to design and fabricate high-pressure machines very carefully.

Figure 3.29 Components of high pressure equipments.

High pressure vessels: Pressure vessel means a housing designed and built to contain fluids under pressure including its direct attachments up to the coupling point connecting it to other equipment. A vessel may be composed of more than one chamber.

Safety Accessories: These accessories include safety valves and bursting discs, as well as limiting devices. Limiting devices can either activate the means for correction or shutdown and lock-out, such as pressure switches and temperature switches.

High-pressure instrumentation: To operate high-pressure plants, adequate control- and measuring devices are required. High-pressure instrumentation is available for purposes like pressure, temperature, flow and level measurements.

Safety for high pressure equipment

If pressure systems or equipment fails and bursts violently apart, it can seriously injure or kill people and cause serious damage to property. The main hazards from pressure are: impact from the blast of an explosion, impact from parts of equipment that fail or any flying debris, impact with the released liquid or gas (such as steam), fire resulting from the escape of flammable liquids or gases.

Common causes of pressure system and equipment risks includes

- Damaged equipment or system design
- Poor or no maintenance
- An unsafe system of work
- Operator error due to lack of training/supervision
- Incorrect installation
- Inadequate repairs or modifications

The safety measures to be taken to avoid the risks depends on the nature of the high pressure system. Below the nature and safety measures for high pressure gas cylinders and high pressure washers are briefly explained.

Discussion question 3.7

(i) List at least three applications of high pressure systems.
(ii) What are the cause for high pressure risks?
(iii)What are the basic measures to avoid high pressure risks?

High Pressure Gas Cylinders

Gas cylinders filled with Liquefied Petroleum Gas (LPG) are sealed at high pressure. If the gas is released uncontrollably, there is a considerable hazard to life and health. Thus, to keep you family safe, you have to consider the following safety measures at your home while using LPG:

- keep the gas cylinder in a vertical position, on a flat surface and in a proper ventilated area.
- Gas cylinders should be stored in locations where they are protected from any physical impact or damage, and
- Make sure that there are no inflammable materials and fuels (like kerosene) near the gas cylinder, which can cause an explosion.
- Always turn off the knob on the gas cylinder, after use, to prevent any accidental leakage.
- Keep the gas knob out of reach for children when not using.
- Educate people around you on gas cylinder safety measures and how to use and handle gas cylinders.

- Do not use gas cylinder for long hours while cooking

Dear students,you have to consider similar safety measures when you use compressed gas cylinder in your science laboratory.

High Pressure washers

Pressure washers are high pressure equipment used in industry or our home. Pressure washers can help us clean large areas of all kinds of hard outdoor surfaces quickly. They have made our lives so much easier, in so many ways and so many places (Fig 3.30). They are used for cleaning automobiles, motorcycles, boats and bicycles. They remove grease, tar, gum, wax and grim from concrete, sidewalks and floors. They also remove persistent stains or patches of rust, or strip paint. Despite their useful applications, pressure washer has their own risks if they are not used properly. These risk can be avoided if appropriate safety measures are taken. The following are the common safety measures for high pressure washers:

- Safety glasses or goggles. Proper safety glasses will prevent flying projectiles entering your eye.
- Enclosed shoes. Use work boots while using high pressure washer.
- Gloves. Wear proper safety gloves to avoid the most common point, the hand.
- Wear ear protection while using a gas-powered pressure washer for extended duration.
- Never point your pressure washer at pets or people (this could cut the skin).
- Stand properly when using a pressure washer.
- Turn the machine and water off before taking off the hoses.

Figure 3.30 Application of high pressure washer

Unit summary

- A fluid is a state of matter that yields to sideways or shearing forces. Liquids and gases are both fluids. Fluid statics is the physics of stationary fluids.
- Density is the mass per unit volume of a substance or object.
- Pressure is the force per unit perpendicular area over which the force is applied.
- Pressure due to the weight of a liquid is given by $P = h\rho g$, where P is the pressure, h is the height of the liquid, ρ is the density of the liquid, and g is the acceleration due to gravity.
- Pascal law states that a change in pressure applied to an enclosed fluid is transmitted undiminished to all portions of the fluid and to the walls of its container.
- A hydraulic system is an enclosed fluid system used to exert forces.
- Gauge pressure is the pressure relative to atmospheric pressure.
- Absolute pressure is the sum of gauge pressure and atmospheric pressure.
- Open-tube manometers have U-shaped tubes and one end is always open. It is used to measure pressure.
- A mercury barometer is a device that measures atmospheric pressure.
- Buoyant force is the net upward force on any object in any fluid. If the buoyant force is greater than the object's weight, the object will rise to the surface and float. If the buoyant force is less than the object's weight, the object will sink. If the buoyant force equals the object's weight, the object will remain suspended at any depth. The buoyant force is always present whether the object floats, sinks, or is suspended in a fluid.
- Archimedes' principle states that the buoyant force on an object equals the weight of the fluid it displaces.

- Specific gravity is the ratio of the density of an object to a fluid (usually water).
- Flow rate and velocity are related by $Q = Av$ where A is the cross-sectional area of the flow and v is its average velocity.
- High pressure equipment that we use in our home for various purposes should be used appropriately to keep the family and pets safety.

End of unit questions

1. The distance between air particles is very small—about 3×10^{-7} cm. How can we say that there is considerable empty space in air?
2. How would you determine the density of an irregularly shaped object?
3. Pascal's Principle says that an increase in pressure in one part of an enclosed liquid results in an increase in pressure throughout all parts of that liquid. Why then does the pressure differs at different heights?
4. What does the atmospheric pressure is 760 mm of mercury mean?
5. Why does a fluid exert an upward force on an object submerged in it?
6. What would happen to the level of water in the oceans if all icebergs presently floating in the oceans melted?
7. Describe a method to measure the density of a liquid.
8. Two objects have the same volume, but one is heavier than the other. When they are completely submerged in oil, on which one does the oil exert a greater buoyant force?
9. An iron ball with radius 5.0 cm has a mass of 2.0 kg. Determine the ball's density.
10. Determine the density of the material whose mass-versus volume graph line is shown in Figure 3.31. If you double the mass of this substance, what will happen to its density? What substance might this be?

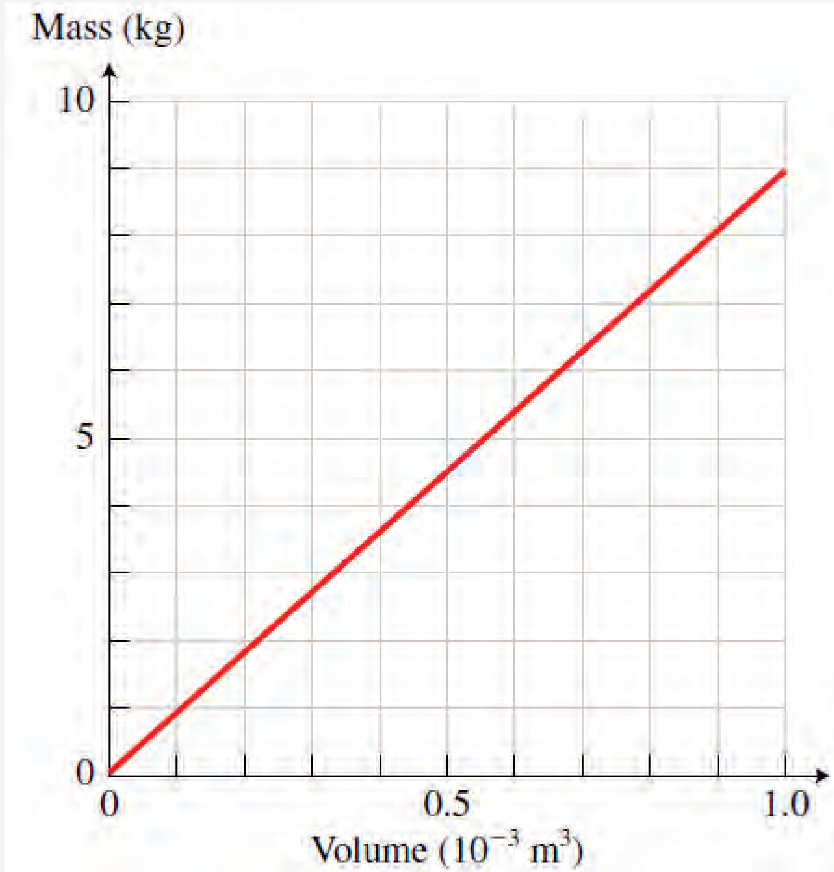


Figure 3.31 Mass versus volume graph of unknown material

11. The pressure in a water line is 1500 kPa. What is the line pressure in (a) torr units and (b) psi units? (c) atm units

12. How tall must a water-filled closed end manometer be to measure blood pressures as high as 300 mm Hg?

13. What fraction of ice is submerged when it floats in freshwater, given the density of water and ice at 0°C respectively are very close to 1000 and 917 kg/m^3 ?

14. A rock with a mass of 540 g in air is found to have an apparent mass of 342 g when submerged in water. (a) What mass of water is displaced? (b) What is the volume of the rock? (c) What is its average density?

15. A manometer is used to measure the air pressure in a tank. The fluid used has a specific gravity of 1.40, and the differential height between

the two arms of the manometer is 50 cm. If the local atmospheric pressure is 0.8 atm, determine the absolute pressure in the tank for the cases of the manometer arm with the (a) higher and (b) lower fluid level being attached to the tank.

16. The gage pressure in a liquid at a depth of 2.5 m is read to be 28 kPa. Determine the gage pressure in the same liquid at a depth of 9 m.

17. Consider a 55-kg woman who has a total foot imprint area of 400 cm^2. She wishes to walk on the snow, but the snow cannot withstand pressures greater than 0.5 kPa. Determine the minimum size of the snowshoes needed (imprint area per shoe) to enable her to walk on the snow without sinking.

18. (a) A 75.0-kg man floats in freshwater with 3.00% of his volume above water when his lungs are empty, and 5.00% of his volume above water when his lungs are full. Calculate the volume of air he inhales called his lung capacityin liters. (b) Does this lung volume seem reasonable?

19. A hydraulic lift has a small piston with surface area 0.0020 m^2 and a larger piston with surface area 0.20 m^2. Assume your mass is 60 kg. If you stand at the smaller piston, how much mass can you lift at the larger piston?

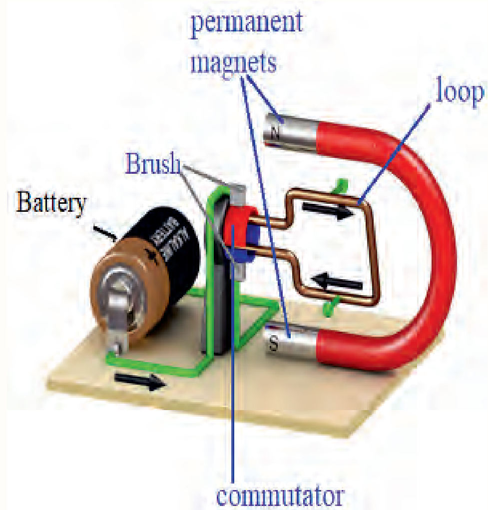
20. A fluid that occupies a volume of 24 L weighs 225 N at a location where the gravitational acceleration is 9.80 m/s^2. Determine the mass of this fluid and its density.

21. Blood flows at an average speed of 0.40 m/s in a horizontal artery of radius 1.0 cm. The average pressure is $1.4 \times 10^4\ N/m^2$ above atmospheric pressure (the gauge pressure). (a) What is the average speed of the blood past a constriction where the radius of the opening is 0.30 cm? (b) What is the gauge pressure of the blood as it moves past the constriction?

22. Suppose your mass is 70.0 kg and your density is 970 $\mathrm{kg/m}^3$. If you could stand on a scale in a vacuum chamber on Earth's surface, the reading of the scale would be $mg = (170.0\ kg)\ (9.80\ \mathrm{N/kg}^2) = 686$ N. What

will the scale read when you are completely submerged in air of density 1.29 kg/m^3? (b) What will the scale read if you weigh yourself in a swimming pool with your body completely submerged?

23. The aorta is the principal blood vessel through which blood leaves the heart in order to circulate around the body. (a) Calculate the average speed of the blood in the aorta if the flow rate is 5.0 L/min. The aorta has a radius of 10 mm. (b) Blood also flows through smaller blood vessels known as capillaries. When the rate of blood flow in the aorta is 5.0 L/min, the speed of blood in the capillaries is about 0.33 mm/s. Given that the average diameter of a capillary is 8.0 μm , calculate the number of capillaries in the blood circulatory system.



Unit 4

Electromagnetism

Introduction

Electromagnetism is one of the fundamental force in nature consisting of the elements electricity and magnetism. It involves the study of electromagnetic force. The electromagnetic force is carried by electromagnetic fields composed of electric fields and magnetic fields. At the subatomic level, electromagnetism is related to the electromagnetic force that causes the attraction and repulsion of electrically charged particles. When electrically charged particles, such as electrons, are put into motion, they create a magnetic field. When these particles are made to oscillate, they create electromagnetic radiation such as radio waves.

Electricity and magnetism have been known to humans for a long time. The relationship between Electricity and magnetism was discovered in 1819 when, during a lecture demonstration, Hans Christian Oersted found that an electric current in a wire deflected a nearby compass needle. His experiment provided the first reproducible observation of a relationship between electricity and magnetism, A current carrying wire produced a magnetic field whose strength and direction depends on the amount of the current flowing and direction of the current. In the 1820s, further connections between electricity and magnetism were demonstrated independently by Faraday and Joseph Henry (1797-1878). They showed that an electric current can be produced in a circuit either by moving a magnet near the circuit or by changing the current in a nearby circuit.

The discovery of electromagnetism marked the birth of modern science and technology. Now, it is known that all magnetic phenomena result from forces arising from electric charges in motion. Without an understanding of electromagnetism, devices such radios, televisions, computers, tape recorders, CD players, electric motors, and generators, could not have been invented.

At the end of this unit, you will be able to:

- *Understand the behaviour of electric and magnetic fields*
- *Demonstrate the principles of electromagnetic induction;*
- *Describe the working principles of transformer;*
- *Understand and implement pertinent safety rules;*

Brainstorming question 4.1

How does a magnetic field originate? What happens if you cut a bar magnet in half ? Do you get one magnet with two south poles and one magnet with two north poles?

4.1 Magnets and Magnetic field

At the end of this section, you will be able to:

- *Describe magnet and magnetic field.*
- *Describe the sources of magnetic field.*
- *Describe the difference between electric field and magnetic field.*

A magnet generates a magnetic field which represents the magnetic force existing in the region around the magnet. A magnetic pole is the part of a magnet that exerts the strongest force on other magnets or magnetic material, such as iron,nickel and cobalt. Every magnet has two poles: a north pole (N) and a south pole (S) (Figure 4.1). Like poles (N-N or S-S) repel each other, and opposite poles (N-S) attract each other.

Figure 4.1 Permanent magnet

Although the force between two magnetic poles is similar to the force between two electric charges, electric charges can be isolated (as a positive and negative charge), whereas it is not possible to separate the north and south poles of a magnet. That is, magnetic poles are always found in pairs. No matter how many times a permanent magnet is cut in to two, each piece always has a north and a south pole.

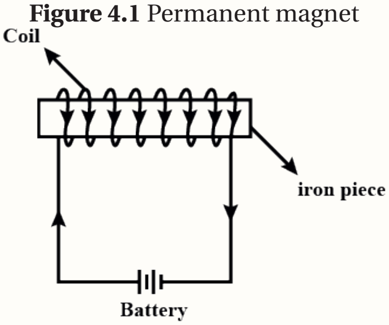


Figure 4.2 Electromagnet

Permanent and electromagnet are the two major types of materials that exhibit magnetic properties. Permanent magnets are materials where the magnetic field is generated by the internal structure of the material itself. Thus, once the permanent magnets are magnetized then they hold their magnetic property for a very long time. The magnet shown in Figure 4.1 is an example of permanent magnet.

An electromagnets usually consist of wire wound into a coil. The electromagnet generates a magnetic field when an electric current is provided to it and it loses its magnetism when the current is off. Figure 4.2 shows a simple electromagnet consisting of a coil of wire wrapped around an iron core. The iron core serves to increase the strength of the magnetic field created.

The Earth has a magnetic field. The magnetic field behaves like a giant bar magnet inside the Earth, with the North magnetic pole corresponding to the South Geographic Pole and vice versa (Figure4.3). A compass needle aligns itself in a north-south direction to line up with Earth's magnetic field.

Magnetic Field is the region around a magnet or a moving electric charge within which the force of magnetism acts. As you have learned in the previous grades, an electric field surrounds an electric charge, like wise a magnetic field also surrounds a magnet. Magnetic field is a vector quantity and the vector points in the direction that a compass would point.

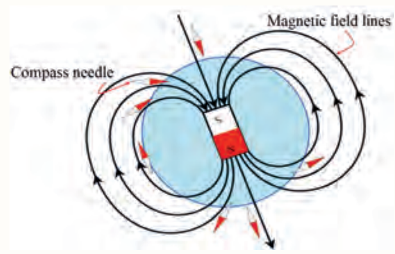


Figure 4.3 Earth's magnetic field is like a bar magnet that resides in the center of the Earth.

Differences Between Electric Field and Magnetic Field

- The SI unit of an electric field is Newton/coulomb, whereas the SI unit of magnetic field is Tesla.
- The region around the electric charge where the electric force exists is called an electric field. The region around the magnet where the pole of the magnet exhibits a force of attraction or repulsion is called a magnetic field.
- The electric field produces by a unit pole charge, i.e., either by a positive or through a negative charge, whereas the magnetic field caused by a dipole of the magnet (i.e., the north and south pole).
- The electric field lines start on a positive charge and end on a negative charge, whereas the magnetic field line do not have starting and ending point.

- The electric field lines do not form a loop whereas the magnetic field lines form a closed loop.

Exercise 4.1:

1. Which one of the following is false about magnets ? A. A magnet generates a magnetic field. B. Every magnet has two poles. C. Like poles attract each other. D. The magnetic field is stronger at the poles.
2. An electromagnet loses its magnetism when the electric current is off. A. True B. False
3. Define magnetic field.
4. Mention some difference between electric field and magnetic field.
5. Explain the difference between permanent magnet and electromagnet.

4.2 Magnetic field lines

Brainstorming question: 4.2

Like elctric field lines, do magnetic field lines have starting and ending point? Explain your answer.

At the end of this section, you will be able to:

- *Describe magnetic field lines around permanent magnets and electromagnet.*
- *Describe the properties of magnetic field lines.*
- *Compare magnetic and electric field lines.*

Magnetic field lines are imaginary lines or a visual tool used to represent magnetic fields. The density of the lines indicates the magnitude of the field. As with electric fields, the pictorial representation of magnetic field lines is very useful for visualizing the strength and direction of the magnetic field. Figure4.4 shows magnetic field pattern surrounding a bar magnet. When we sprinkle iron filings around the magnet, the iron filings will orient themselves along the magnetic field lines, forming magnetic field pattern around the magnet.

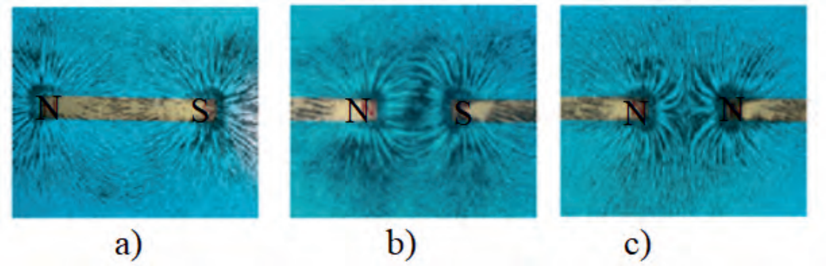


Figure 4.4 a) Magnetic field pattern surrounding a bar magnet b) Magnetic field pattern between opposite poles (N–S) of two bar magnets and c) Magnetic field pattern between like poles (N–N) of two bar magnets.

Properties of Magnetic Field Lines

- Field lines have both direction and magnitude at any point on the field. The direction of the magnetic field is tangent to the field line at any point in space. A small compass placed in a magnetic field will point in the direction of the field line.
- The strength of the field is proportional to the closeness of the lines.
- Magnetic field lines can never cross each other, meaning that the field is unique at any point in space.
- Unlike electric field lines, magnetic field lines are continuous, forming closed loops without beginning or end.
- The field lines emerge from north pole and merge at the south pole (note the arrows marked on the field lines in Figure 4.5). Inside the magnet, the direction of field lines is from its south pole to its north pole. Thus the magnetic field lines are closed curves.

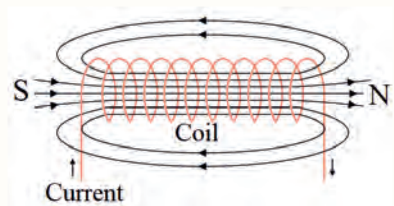


Figure 4.5 Magnetic field lines of electromagnet.

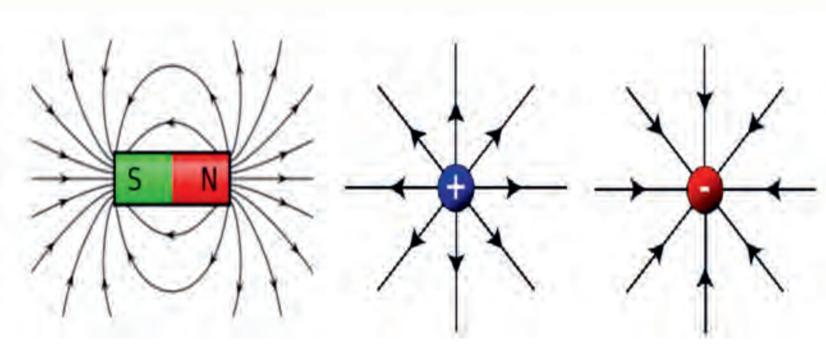


Figure 4.6 Comparison of Magnetic and electric field lines.

Exercise 4.2:

1. Define magnetic field lines.
2. The magnetic field lines are denser where the magnetic field is stronger. A. True B. False
3. Mention som properties of magnetic field lines.
4. Which of the following is true about magnetic field lines ? A. They form closed loops. B. They never intersect each other. C. The magnetic field lines are crowded near the pole. D. All are true

Brainstorming question:4.3

☞ Think about what you have learned about electricity and magnetism. How are they alike? How are they different?

4.3 Current and Magnetism

At the end of this section, you will be able to:

- *Explain the relationship between current and magnetism*
- *Describe Ampere's law.*
- *Describe the magnetic Field Created by a Long Straight Current-Carrying Wire.*

The connection between electricity and magnetism has many important applications in today's world. Whenever a current passes through a conductor, a magnetic field is produced. This is the basis of the electromagnet as shown in Figure 4.7. This could be shown by placing a directional compass near a straight current-carrying wire or conductor (Figure 4.8). A compass placed near a current-carrying conductor will always point in the direction of the magnetic field lines produced. As soon as the current is off there is no magnetic field.This is because the magnetic field is generated by the electric current (moving charges).

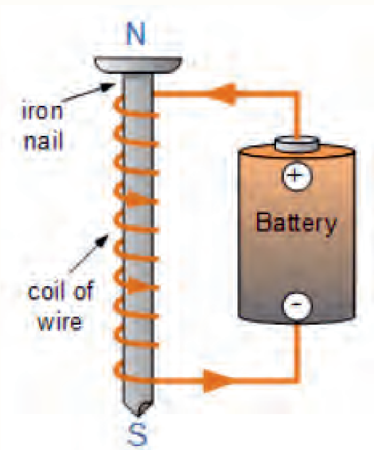


Figure 4.7 A basic configaration of electromagnet.

Ampere's law

Ampere's Law can be stated as: "The magnetic field created by an electric current is proportional to the size of that electric current with a constant of proportionality equal to the permeability of free space."

Magnetic Field Created by a Long Straight Current-Carrying Wire

For our understanding, let us consider a wire through which the current is made to flow by connecting it to a battery. As the current through the conductor increases, the magnetic field increases proportionally. When we move further away from the wire, the magnetic field decreases with the distance.

The magnitude of the magnetic field at a point a distance r from a long straight current carrying wire is given by:

$$\vec{B} = \frac{\mu_0 I}{2\pi r} \quad \text{(for long straight wire)} \tag{4.1}$$

Where μ_0 is permeability of free space, $\mu_0 = 4\pi \times 10^7\, T.m/A$ and r is the distance from the wire where the magnetic field is calculated. I is the current through the wire.

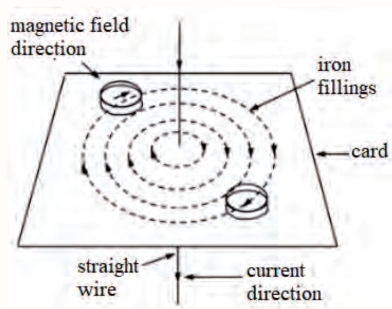


Figure 4.8 The magnetic field around a straight line.

The magnetic field has both magnitude and direction. The SI unit of magnetic field is Tesla(T). The other common unit of magnetic field is *gauss* (G). Gauss is related to the Tesla through the conversion $1T = 10^4$ G.

The circular pattern in Figure 4.8 represents the magnetic field around the wire. A compass needle can also be used to find the direction of the magnetic field.
The magnetic field produced by a current flowing in a straight wire have the following properties.

- The magnetic field lines form a circular pattern.
- The magnetic field strength increases when current increases.
- The magnetic field strength is stronger near the wire and weaker further away.
- When the direction of the current is reversed, the direction of the magnetic field is reversed too.

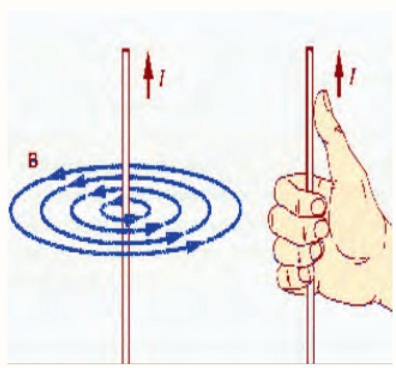


Figure 4.9 Applying the right hand rule to find the direction of the magnetic field around a current carrying wire.

The direction of a magnetic field around a wire carrying a current is given by Fleming's Right Hand Rule. This rule states that, if you grip a straight wire with your right hand in such a way that your extended thumb points in the direction of the current, then your fingers wrapped around the wire will point in the direction of the magnetic field lines as shown in Figure 4.9.

Activities 4.1

Creation of electromagnetism (the model is given in Figure 4.7)

Materials needed

- Dry cell battery
- nail, insulated wire
- paper clips
- Compass needle

Procedure

1. Before you begin to build your electromagnet, check the magnetic property of the nails. Do they attract the paper clips?
2. Connect the insulated wire to the battery. Make sure you complete the circuit by attaching the ends of the wire to opposite ends of battery. Place the compass under the wire. Is there any reaction?
3. Disconnect one end of the wire. Wrap it around a nail 15 times before connecting it back to the battery. What do you see when you bring the compass near to the coiled wire? Is this reaction different from what you saw when you placed the compass under the straight wire? Can you pick up paper clips with the wire? Can you pick up paper clips with the nail?
4. Remove the nail from the wire without unwinding it. Will the wire pick up any paper clips? Will the nail alone pick up any paper clips?
5. Place your compass under the wound wire. Do you get the same reaction as you did when you observed the compass in Step 4? How can you explain this?

Example 4.1

Find the current in a long straight wire that would produce a magnetic field twice the strength of the Earth's magnetic field (The Earth's magnetic field is about $5.0\times10^{-5}\,T$) at a distance of 5.0 cm from the wire.

Solution:

Magnetic field due the earth (B_E) is $5x10^{-5}$ T.
Magnetic field due the current carryng wire B is B=2B_E =2x5x10^{-5} T=1x10^{-4} T.
The equation B = $\mu_0 I/2\pi r$ can be used to find I, since all other quantities are known. Solving for I and entering known values gives

$$I = \frac{2\pi rB}{\mu_0} = \frac{2\pi(5.0x10^{-2}m)(1.0x10^{-4}T)}{4\pi\times 10^{-7}\ T.m/A} = 25A$$

Table 4.1 shows some Approximate magnitudes of magnetic fields

Source of field	**Field Magnitude (T)**
Strong superconducting laboratory magnet	30
Strong conventional laboratory magnet	2
Medical MRI unit	1.5
Bar magnet	10^{-2}
Surface of the sun	10-2
Surface of the Earth	$0.5x10^{-4}$
Inside human brain (due to nerve impulses)	10^{-13}

Exercise 4.3:

1. A long straight wire carrying a current produces a magnetic field of 0.8 T at a distance 0.5 cm from the wire. Find the magnetic field at a distance of 1 cm.

2. Which one of the following does not affect the magnetic field produced by a long straight wire? A. The current in the wire B. the distance from the wire C. the type of the wire D. None

3. The magnetic field B at a distance r from a long straight wire carrying current I is directly proportional to r. A. True B. False

4.4 Electromagnetic Induction

Brainstorming question:4.4

If you have a magnet and a coiled wire, can you produce electricity inside the wire ? Explain your answer.

At the end of this section, you will be able to:

- *Define electromagnetic induction*
- *Define magnetic flux*
- *Calculate magnetic flux*

Electricity and magnetism were considered as separate and unrelated phenomena for a long time. In the early decades of the nineteenth century, experiments on electric current by Oersted, Ampere and a few others established the fact that electricity and magnetism are inter-related. They found that moving electric charges produce magnetic fields. For example, an electric current deflects a magnetic compass needle placed in its vicinity. This naturally raises the questions like: Is the converse effect possible? Can moving magnets produce electric currents? Does the nature permit such a relation between electricity and magnetism? The answer is yes. In 1831, Michael Faraday discovered that magnets could be used to generate electricity. He showed that a changing or variable magnetic field can produce an electromotive force (emf). This e.m.f produces an induced current in a closed circuit. We call this effect electromagnetic induction. This discovery led Faraday to invent the dynamo (generator) through the use of electromagnetic induction. The phenomenon of electromagnetic induction is not only of theoretical or academic interest, but also of practical utility. Imagine a world where there is no electricity, no electric lights, no trains, no telephones, and no personal computers. The pioneering experiments of Faraday and Henry have directly led to the development of modern generators and transformers. The discovery and understanding of electromagnetic induction is based on a long series of experiments by Faraday and Henry.

Activities 4.2: Electromagnetic induction

Materials required

- A coil of N turns

- Bar magnet
- Multimeter (Galvanometer)

Connect the coil to the Galvanometer as shown in Figure 4.10 and examine what happens to the pointer of the galvanometer when the magnet is in motion through the coil. Answer and address the following questions with your observations.
What happens to the pointer of the galvanometer for the following actions of the magnet or coil?

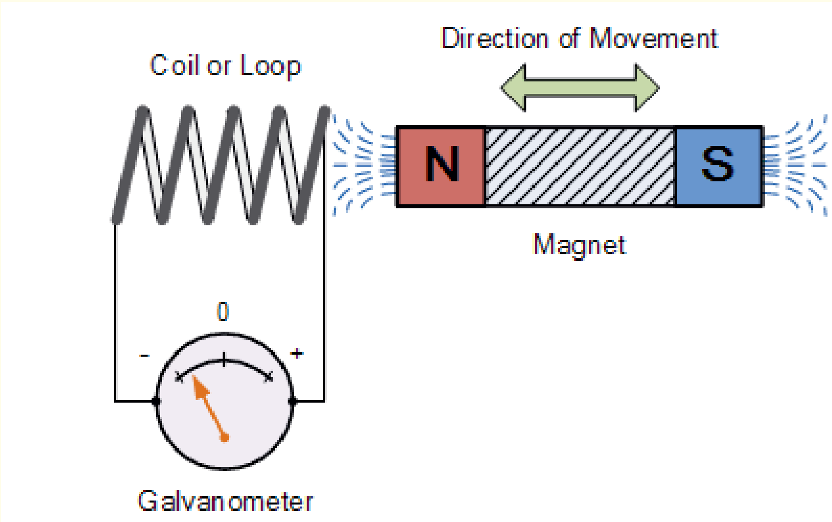


Figure 4.10 Basic principle of electromagnetic induction.

1. When the magnet is moved towards the coil.
2. When the magnet stops moving and is held stationary.
3. When the magnet is moved away from the coil.
4. Moving the magnet back and forth towards the coil.
5. Similarly, if the magnet is now held stationary and only the coil is moved towards or away from the magnet.
6. Increasing the speed of movement of the coil or magnet.
7. What do you conclude from your observation?

Magnetic flux

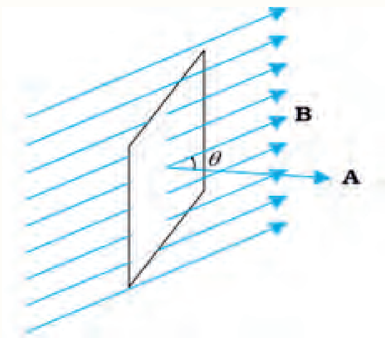


Figure 4.11 A plane of surface area A placed in a uniform magnetic field.

Faraday's great insight lay in discovering a simple mathematical relation to explain the series of experiments he carried out on electromagnetic induction. However, before we state his laws, we must get familiar with the notion of magnetic flux,ϕ . Can you define magnetic flux from your grade 11 physics knowledge?

Magnetic flux is a measurement of the total magnetic lines of force which passes through a given area A as shown in Figure 4.11. For a plane of surface area A placed in a uniform magnetic field B, magnetic flux is mathematically written as:

$$\Phi_B = B.A = BAcos\theta \tag{4.2}$$

where θ is angle between B and A.
The SI unit of magnetic flux is Weber(Wb).

Example 4.2

A square loop of side 3 cm is positioned in a uniform magnetic field of magnitude 0.5 T so that the plane of the loop makes an angle of 60^0 with the magnetic field as shown in Figure 4.11: Find the flux passing through the square loop?

Solution:
Putting the known values into the magnetic flux equation

$$\Phi_B = \text{BA}\cos\theta$$
$$= (0.5)(0.03 \text{ x } 0.03)(\cos 30^0)$$
$$= 0.39 \text{ mWb}$$

Exercise 4.4:

1. Define magnetic flux.
2. A circular loop of area 200 cm^2 sits in the xz plane. If a uniform magnetic field of $\vec{B}$= 0.5 T is applied on it. Determine the magnetic flux through the square loop?
3. The magnetic flux is maximum when the angle between magnetic field lines and the line perpendicular to the plane of the area is:
A. 0^o $B.90^0$ $C.45^0$ $D.30^0$
4. A magnetic field of 2.5T passes perpendicular through a disc of radius 2cm. Find the magnetic flux associated with the disc.

4.5 Faraday's Law of electromagnetic Induction

The discovery and understanding of electromagnetic induction are based on a long series of experiments carried out by Faraday and Henry. From the experimental observations, Faraday concluded that an emf is induced when the magnetic flux across the coil changes with time.

At the end of this section, you will be able to:

- *State Faraday's law of electromgnetic induction*
- *State Lenze's law in the phenomena of electromagnetic induction*

Brainstorming question:4.5

How does a generator produce electricity? What energy conversion takes place in a generator?

Faraday's law of electromagnetic induction and Lenz's Law

Faraday's law considers how the changing magnetic fields can cause current to flow in wires. Lenz's law tells about the direction of the current.

Faraday's law states that the magnitude of the induced electromotive force (emf) is directly proportional to the rate of change of the magnetic flux in a closed coil.

$$\varepsilon = -\frac{\Delta \Phi_B}{\Delta t} \tag{4.3}$$

Where, ε is the induced voltage (also known as electromotive force) $\Delta\phi$ is change in magnetic flux and Δt Change in time.

In the case of a closely wound coil of N turns, change of flux associated with each turn, is the same. Therefore, the expression for the total induced emf is given by:

$$\varepsilon = -\frac{N\Delta \Phi_B}{\Delta t} \tag{4.4}$$

The negative sign is involved according to Lenz's law.
Lenz's law states that the direction of the induced current in the coil is such that it opposes the change that causes the induced emf.
Lenz's law depends on the principle of conservation of energy and Newton's third law. It is the most convenient method to determine the direction of the induced current.

Figure 4.12 illustrates Lenze's law. The change in magnetic flux caused by the approaching magnet induces a current in the loop. When the change in magnetic

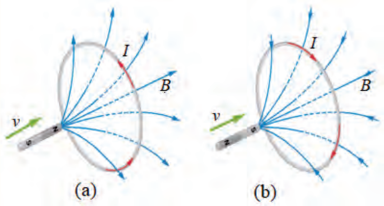


Figure 4.12 (a) An approaching north pole induces a counter-clockwise current with respect to the bar magnet. (b) An approaching south pole induces a clockwise current with respect to the bar magnet.

flux induces a current in a conducting coil, the induced current also generates its own magnetic field that opposes the change in the flux that creates it.

Example 4.3

A square loop of side 10 cm and resistance 0.5 Ω is placed vertically in the east-west plane. A uniform magnetic field of 0.10 T is set up across the plane in the north-east direction. The magnetic field is decreased to zero in 0.70 s at a steady rate. Determine the magnitudes of induced emf and current during this time-interval.

Solution: The angle θ made by the area vector of the coil with the magnetic field is 45° . From the Equation of magnetic flux:

$\Phi = \mathrm{BA}\cos\theta$

the initial magnetic flux is:

$$\Phi_i = B_i A cos\theta$$
$$= \frac{0.1x10^{-2}}{\sqrt{2}}$$
$$\phi_i = 7.1x10^{-4} Wb$$
$$\phi_f = 0$$

The change in flux is brought about in 0.70 s. The magnitude of the induced emf is given by:

$$\varepsilon = -\frac{|\Delta\Phi_B|}{\Delta t} = \frac{|(\Phi_f - \phi_i)|}{\Delta t} = \frac{-7.1x10^{-4} Wb}{0.7s} = 1.01\mathrm{mv}$$

And the magnitude of the current is :

$$I = \frac{\varepsilon}{R} = \frac{1.01\mathrm{mv}}{0.5\Omega} = 2.01\mathrm{mA}$$

https://phet.colorado.edu/en/simulations/faradays-law

Exercise 4.5:

1. The emf induced in a coil can be increased by: A. increasing the number of turns in the coil (N). B. increasing magnetic field strength surrounding the coil. C. increasing the speed of the relative motion between the coil and the magnet. D. All
2. Faraday's Law states that the induced voltage or emf is proportional to: A. the resistance of the coil B. the cross sectional area of the coil. C. the rate of change of the magnetic flux in the coil. D. All
3. Lenz's law is the result of the law of conservation of: A. mass B. charge C. energy D. Momentum

4. In Lenz's law the induced emf opposes the magnetic flux. A. True B. False

5. a) Calculate the induced emf when a coil of 100 turns is subjected to a magnetic flux change at the rate of 0.04Wb/s. b) Calculate the induced current if the resistance of the coil is 0.08Ohm.

Brainstorming question:4.6

1. What is the function of transformer?
2. What household appliances have a transformer?

4.6 Transformers

At the end of this section, you will be able to:

- *Describe the working principle of transformer*
- *Discuss how transformer is used in commonly available devices*

A transformer is an electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction. It is most commonly used to increase ('step up') or decrease ('step down') voltage levels between circuits with out altering the frequency Figure 4.13. A Step-up Transformer converts the low primary voltage to a high secondary voltage and steps up the input voltage. On the other hand, a step-down transformer steps down the input voltage.

A transformer is simply a pair of coils wound on the same core. The core is often shaped as a square loop shown in Figure 4.14 with primary and secondary coils wound on opposite sides. The construction of a transformer allows the magnetic flux generated by a current changing in one coil to induce a current in the neighboring coil.

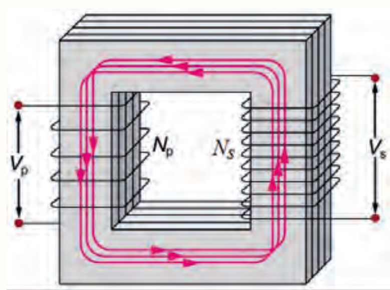


Figure 4.13 Transformer.

The operating principle of a transformer is based on electromagnetic induction. The current from the electrical supply that is connected to the primary coil is an alternating current. An alternating current is a current whose magnitude and direction varies or changes continuously at a certain frequency. The alternating current produces a flux or magnetic field lines which link the primary and the secondary coils. The magnetic flux varies in magnitude and direction.

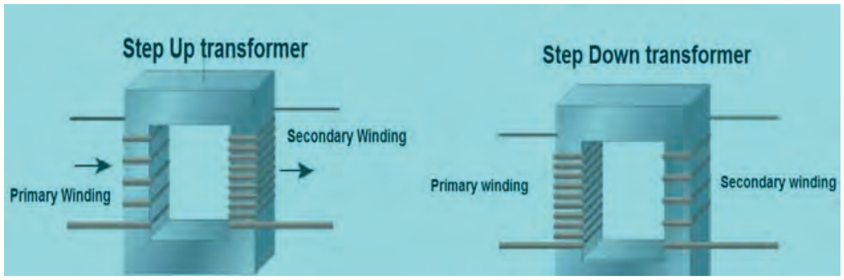


Figure 4.14 step up and step down transformers.

Transformers are used in various fields like power generation grid, distribution sector, transmission and electric energy consumption. The primary and secondary windings are electrically isolated from each other but are magnetically linked through the common core allowing electrical power to be transferred from one coil to the other.

The difference in voltage between the primary and the secondary winding is achieved by changing the number of coil turns in the primary winding (N_P) compared to the number of coil turns on the secondary winding (N_S). The number of turns of the primary coil divided by the number of turns of the secondary coil is called the ratio of transformation, more commonly known as a transformers 'turns ratio'. If the ratio between the number of turns changes the resulting voltages must also change by the same ratio. The relationship between the voltage applied to the primary winding V_P and the voltage produced on the secondary winding V_S is given by

$$\frac{N_p}{N_s} = \frac{V_p}{V_s} = \text{Turns Ratio} \tag{4.5}$$

Where N_p and N_s are number of primary and secondary turns V_p and V_s are primary and secondary volts respectively.

For a transformer operating at a constant AC voltage and frequency its efficiency can be as high as 98%. The efficiency, η of a transformer is given as:

$$\text{efficiency}, \eta = \frac{\text{output power}}{\text{Input power}} \text{x} 100\%$$

Where input and output are all expressed in units of power.

Example 4.4

A transformer has a primary and a secondary coil with the number of loops of 500 and 5000 respectively. If the input voltage is 220 V. What is the output voltage?

Solution:

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$
$$\Rightarrow \frac{Vs}{Ns} = \frac{Vp}{Np}$$
$$\Rightarrow \frac{Vs}{5000} = \frac{220}{500}$$
$$\Rightarrow Vs = 2200\text{Volt}$$

Working principle of transformer in house appliances

An alternating current (AC) changes its direction periodically and typically supplies power to run household appliances and industrial equipment.

Transformer in Chargers: There are many appliances that use transformers in their circuity. Your phone, laptop, computer, tablet power supplies have transformers in them. They step the voltage down to a safe voltage that will not harm you to charge your device battery. Your microwave uses a step up transformer to provide a high voltage to make microwaves to cook food.

Figure 4.15 Mobile Phone charger.

A transformer in real life is a commonly used circuit that can either step up the voltage of incoming current or step down the voltage of incoming current. But why is there a need for a transformer in a mobile phone or laptop charger shown in Figure 4.15 and 4.16? The reason is the current in your wall outlet is at high voltage. So, if this voltage is not stepped down to a lower voltage, it will damage the circuits in your mobile phone or laptop. The electronics in your mobile phone or laptop are designed to work at low voltages compared to the electric current you get in wall outlets.

A mobile phone charger also contains a rectifier. After Stepping down the voltage, AC is converted to DC using the rectifier. You will learn about the working principle of rectifier in unit five.

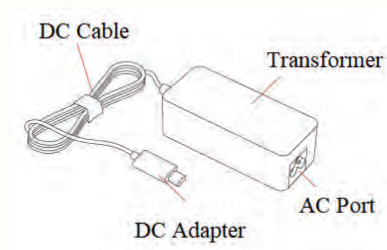


Figure 4.16 Laptop charger.

Exercise 4.6:

1. A transformer has primary coil with 1200 loops and secondary coil with 1000 loops. If the current in the primary coil is 4 Ampere, then what is the current in the secondary coil.
2. Calculate the turn ratio to step 110 V AC down to 20 V AC.
3. Why does a transformer can not raise or lower the voltage of a DC supply? Explain your answer.

4.7 Application and safety

At the end of this section, you will be able to:

- *Describe application of electromagnetism in your daily life.*

Over the last 200 years, physicists have discovered a lot about the natural world. A lot of the time, when that knowledge is first discovered it seems pretty useless, but it almost always leads to applications later.

Now the modern society has numerous applications of electromagnetism. Some computer hard drives apply the principle of electromagnetism to record information. Historically, reading these data was made to work on the principle of electromagnetic induction. However, most input information today is carried in digital rather than analogue form a series of 0s or 1s are written upon the spinning hard drive.

Figure 4.17 A tablet with a specially designed pen to write with is another application of magnetic induction.

Graphics tablets, or tablet computers where a specially designed pen is used to draw digital images, also applies electromagnetic induction principles. This tablets is different than the touch tablets and phones many of us use regularly, but it is still be found when signing your signature at a cash register. Underneath the screen, shown in Figure 4.17, there are tiny wires running across the length and width of the screen. The pen has a tiny magnetic field coming from the tip. As the tip brushes across the screen, a changing magnetic field is felt in the wires which translates into an induced emf that is converted into the line you just drew.

Applications of electromagnetism

Today, there are countless applications for electromagnetism, ranging from large scale industrial machinery, to small-scale electronic components. These machines can be electric motors, generators, transformers or other similar devices. All of these work with the principles related to electromagnetism. The principle of Ampere's law is used in solenoid, straight wire,cylindrical conductor and toroidal solenoid.

Electromagnets at Home or School

Electromagnets are used for various purposes on a day-to-day basis. For example, in electric bells, headphones, loudspeakers, relays, MRI machines, electric fan, electric doorbell, magnetic locks, and others. Most of the electric appliances used in the home use electromagnetism as the basic working principle.

Magnetic Relays

A magnetic relay is a switch or circuit breaker that can be activated into the 'ON' and 'OFF' positions magnetically. One example is the low-power reed relay used in telephone equipment, which consists of two flat nickel–iron blades separated by a small gap as shown in Figure 4.18 . The blades are shaped in such a way that in the absence of an external force, they remain apart and unconnected (OFF position). Electrical contact between the blades (ON position) is realized by applying a magnetic field along their length. The field, induced by a current flowing in the wire coiled around the glass envelope, causes the two blades to assume opposite magnetic polarities, thereby forcing them to attract together and close out the circuit gap.

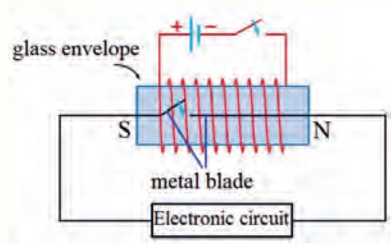


Figure 4.18 A magnetic switch circuit

Electric bell

Electric bell is based on the principle of electromagnetism. When the switch is pressed on, the electromagnet is activated and it attracts the soft iron towards the electromagnet. At this time, the hammer moves and hits the bell. As the hammer moves, the circuit breaks at the screw contact and the electromagnet is disabled. This causes the hammer and the soft iron to go back to initial position due to the spring and then the circuit completes again as shown in Figure 4.19. This process is continuously repeated giving the ringing sound of the bell.

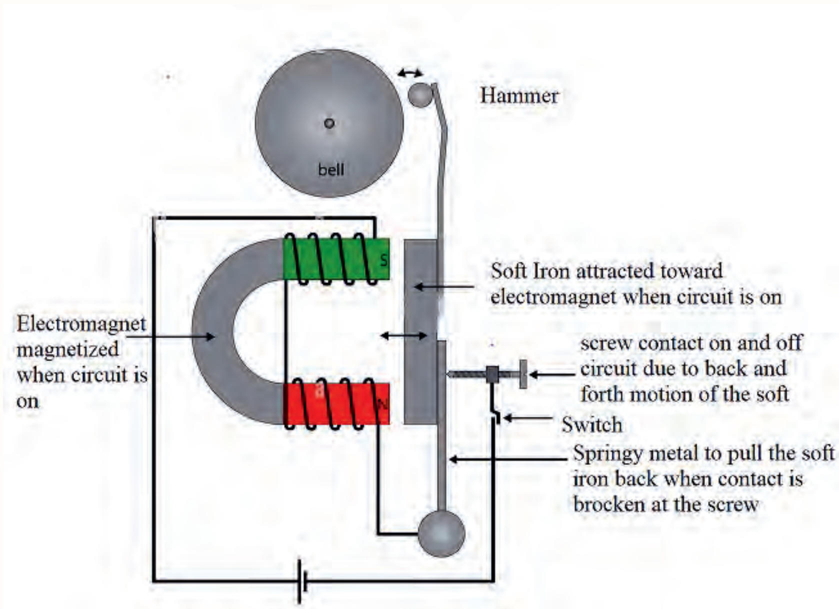


Figure 4.19 Electric bell.

DC Electric Motor

Freely rotating loop is placed between two permanent magnets whose poles facing each other with a sufficient space between them to allow rotation of the loop. Connecting the ends of the loop to battery terminals makes the loop an electromagnet. Since the loop has become a magnet, one side of it will be attracted to the north pole of the magnet and the other to the south pole. This causes the loop to rotate continuously. The components of the DC motor is shown in Figure 4.20.

A DC power source supplies electric power to the motor. The commutator is the rotating interface of the rotating loop (or coil) with a stationary circuit. The permanent magnetic field helps to produce a torque on the rotating coil. The brushes conduct current between stationary wires and moving parts.

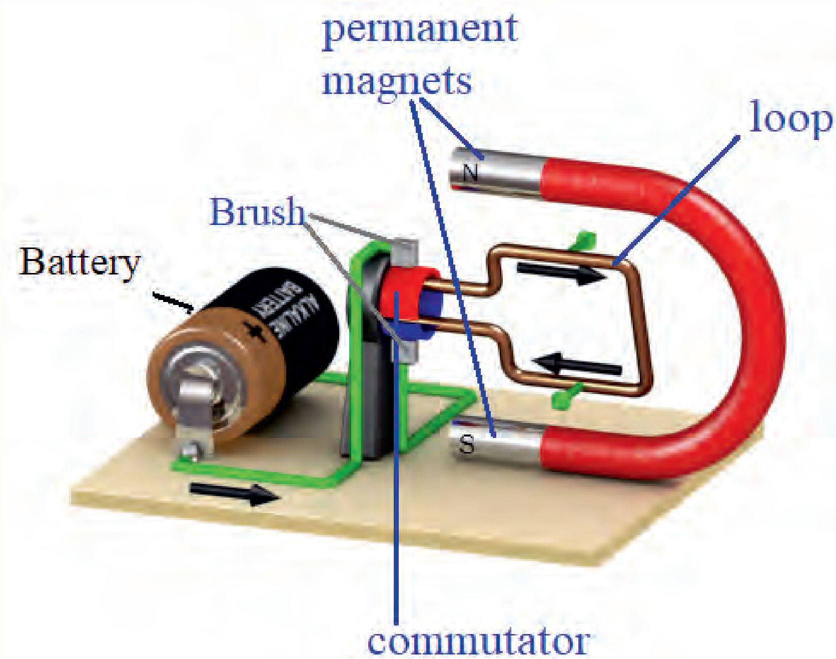


Figure 4.20 DC electric motor.

AC Generator

An AC generator is a mechanical device that converts mechanical energy into electrical energy in the form of alternate electromotive force (emf). For example, the electricity generated at various power plants is produced by the generators installed there. Faraday's Law of electromagnetic induction governs the operation of an AC generator. It consists of a strong permanent magnet and a rectangular coil with a number of wires wounded around an iron core which is used to boost the magnetic flux. When the coil spins in the magnetic field or moves relative to the magnet, it generates an alternating electromotive force.

Electromagnets are generally safe for their various uses, but you need to take precautions depending on the context in which you use them. very powerful electromagnets that come into contact with laptops or computers can damage their hard drives.

An electromagnet can affect monitors for computers or television sets. For classic cathode ray tube (CRT) television sets, powerful magnets can distort the images on the screen when they come close to them. This is because the magnets deflect the beam of electrons that the television sends to produce an image.

Electromagnets help us to lift metal plates and transport them comfortably and quickly. All factors that determine the operation of the electromagnet must be taken into account. The number of plates to be lifted, their weight or the conditions of the surface on which they are located are essential details to be considered. For example, if some of the materials create an air gap between the magnet and the plate, this will have an impact on the lifting.

Unit summary

- Magnetic Field is the region around a magnetic material or a moving electric charge within which the force of magnetism acts.
- A magnetic pole is the part of a magnet that exerts the strongest force on other magnets or magnetic material.
- Like poles (N-N or S-S) repel each other, and unlike poles (N-S) attract each other.
- Magnetic poles are always found in pairs. No matter how many times a permanent magnet is cut in two, each piece always has a north and a south pole.
- Once permanent magnets are magnetized then they hold their magnetic property for a very long time.
- An electromagnet generates a magnetic field when an electric current is provided to it and it loses its magnetism when the current is off.
- The Earth magnetic field behaves like a giant bar magnet inside the Earth.
- Magnetic field lines are imaginary lines used to represent magnetic fields.
- When we sprinkle iron filings around a magnet, the iron filings will orient themselves along the magnetic field lines.
- The strength of the field is proportional to the closeness of the lines.
- Magnetic field lines can never cross, meaning that the field is unique at any point in space.

- Magnetic field lines are continuous, forming closed loops without beginning or end.
- Ampere's law states that the magnetic field around an electric current is proportional to the current.
- The SI unit of magnetic field is Tesla(T):
- The direction of a magnetic field around a wire carrying a current is given by Fleming's Right Hand Rule.
- The principle of Ampere's law is applied in solenoid, straight wire,cylindrical conductor and toroidal solenoid.
- Michael Faraday showed that a changing magnetic field can produce an electromotive force in a closed circuit.
- Electromagnetic induction is a phenomenon in which the relative motion between a conductor and a magnetic field produces an emf across the conductor.
- Magnetic flux is a measurement of the total magnetic lines of force which passes through a given area A.
- For a plane of surface area A placed in a uniform magnetic field B, magnetic flux Φ is mathematically written as:

  $\Phi = B.A = BA\cos\theta$
- The SI unit of magnetic flusx is Weber(Wb).
- Faraday's law of electromagnetic induction states that whenever a conductor is placed in a varying magnetic field, an electromotive force is induced. If the conductor circuit is closed, a current is induced, which is called induced current.
- The time rate of change of magnetic flux through a circuit induces emf in it given by: $\varepsilon = -\frac{\Delta\Phi_B}{\Delta t}$
- The direction of induced current in the coil is such that it opposes the change that causes the induced emf.

- Lenz' s law confirms the general principle of the law conservation of energy.
- A transformer is an electrical device that transfers electrical energy from one circuit to another through the process of electromagnetic induction.
- It is commonly used to increase (step up) or decrease (step down) voltage levels between circuits with out altering the frequency.
- A Step-up Transformer steps up the input voltage. On the other hand, a step-down transformer steps down the input voltage.
- The operating principle of a transformer is based on electromagnetic induction.
- The relationship between the voltage applied to the primary winding V_P and the voltage produced on the secondary winding V_S is given by $\frac{N_p}{N_s}=\frac{V_p}{V_s}$=Turn ratio
- Electromagnets are used in generators, motors, transformers, electric bells, headphones, loudspeakers, relays, MRI machines and others.
- Some electromagnet uses in the home include an electric fan, electric doorbell, induction cooker, magnetic locks, etc

End of unit questions and problems

1. A long straight wire carries a current of 10 A. At what distance from the wire will a magnetic field of 8 x 10^{-4} T be produced?
2. A closed coil of 40 turns and of area 200 cm^2, is rotated in a magnetic field of flux density 2 Wb m^{-2}. It rotates from a position where its plane makes an angle of 30^0 with the field to a position perpendicular to the field in a time 0.2 sec. Find the magnitude of the emf induced in the coil due to its rotation.
3. A portable x-ray unit has a step-up transformer, the 120 V input of which is transformed to the 100 kV output needed by the x-ray tube. The

primary has 50 loops and draws a current of 10.00 A when in use. (a) What is the number of loops in the secondary? (b) Find the current output of the secondary.

4. A 500 turns coil develops an average induced voltage of 60 V. Over what time interval must a flux change of 0.06 Wb occur to produce such a voltage?

5. Calculate the voltage output by the secondary winding of a transformer if the primary voltage is 35 volts, the secondary winding has 4500 turns, and the primary winding has 355 turns.

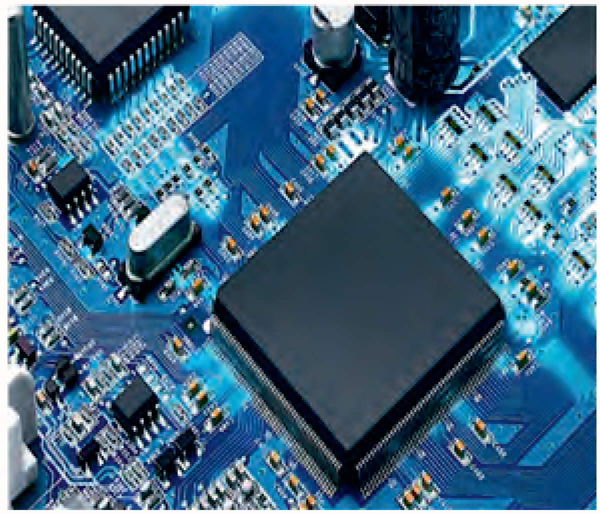
6. A circular loop with a radius of 20 cm is positioned perpendicular to a uniform magnetic field, the magnetic flux that passes through the loop is $1.9x10^{-2}Wb$. What is the magnetic flux density?

7. A uniform magnetic field has a magnitude of 0.1T. What is the flux through a rectangular piece of cardboard of sides 3cm by 2cm perpendicular to the field?

8. A coil of wire 1250 turns is cutting a flux of 5mWb. The flux is reversed in an interval of 0.125 sec. Calculate the average value of the induced emf in the coil.

9. A 150 W transformer has an input voltage of 10V and an output current of 5A. a). is this step-upmor step down transformer? b). what is the ratio of Vout to Vin?

10. Determine the magnetic field strength at a point 5cm from a wire carrying a current of 10A.



Unit 5

Basics of electronics

Introduction

Electronic devices influence our daily lives in such a way that it is almost impossible to spend even a few hours without them. Calculators, digital watches, mobile phones, televisions, and computers are just some of the electronic devices that we use every day. Why have we become so dependent on electronics? The answer is very simple. They simplify our activities and lifestyle. Electronics plays an important role in the aerospace industry and automobile industries. Electronic devices are also necessary in medicine. For example, equipment such as magnetic resonance imaging (MRI), computed tomography (CT) and X-rays rely on electronics in order to do their work quickly and accurately.

Brainstorming question 5.1

Observe the figure above. It shows an electronic circuit board used in electronic devices. List some of the basic electronic components that are used for building electronic circuits.

At the end of this unit, you will be able to:

- *Appreciate the characteristics of the P-N junction diode and its applications in electronics.*
- *Understand the characteristics of the bipolar transistor and its application in electronics.*
- *Appreciate the use of digital electronics in electronic switching and integrate circuits.*
- *Understand the application areas of electronics.*

5.1 Semiconductors

At the end of this section, you will be able to:

- *Describe the difference between conductor, insulator and semiconductor.*
- *Give example of semiconductor elements.*
- *Distinguish between intrinsic and extrinsic semiconductors.*
- *Distingush betwee N- type and P-type semiconductors.*
- *Explain how doping supports current flow in a semiconductor material.*

Brainstorming question 5.2

Why are metals good conductor and insulators poor conductor of electricity? What do you know about semiconductor materials?

Conductors are materials which allow electricity to flow through them. Metals are good conductors of electricity. Conductors have free electrons that allow the easy flow of electric current.

Some materials do not allow electricity to pass through them. These materials are known as insulators. Insulators do not have free electrons every electron in them is tightly bound to the parent atom. Plastic, wood, glass and rubber are good electrical insulators. That is why they are used to cover materials that carry electricity.

Semiconductors are materials which have a conductivity between conductors and insulators. Semiconductors can be pure elements, such as silicon or germanium, or compounds such as gallium arsenide or cadmium selenide. Semiconductors act as insulators at absolute zero temperature (zero kelvin) and conductors at higher temperatures. Conduction occurs at higher temperature because the electrons surrounding the semiconductor atoms can break away from their covalent bond and move freely within the material in order to conduct. In a process called doping, small amounts of impurities are added to pure semiconductors causing large changes in the conductivity of the material.

Lattice structure of semiconductors

Semiconductors, such as silicon (Si) are made up of individual atoms bonded together in a regular and periodic structure to form an arrangement whereby each atom is surrounded by eight electrons. An individual atom consists of a nucleus made up of a core of protons (positively charged particles) and neutrons (particles having no charge) surrounded by electrons (Figure 5.1a). The number of electrons and protons is equal, such that the atom is overall electrically neutral. The electrons in the outer most shell of each atom in a semiconductor are part of a covalent bond. A covalent bond consists of two atoms sharing a pair of electrons. Each atom forms four covalent bonds with the four surrounding atoms (Figure **??**b). Therefore, between each atom and its four surrounding atoms, eight electrons are being shared.

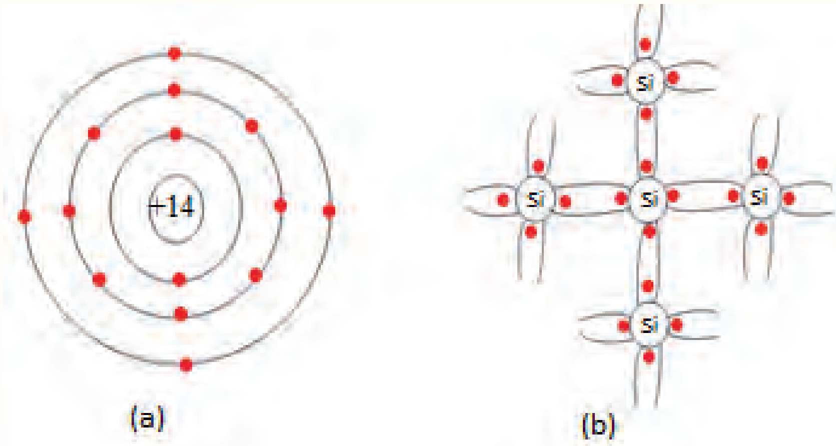


Figure 5.1 a) Electron structure of silicon atom b) covalent bond in silicon.

Hole in a semiconductor means the absence of electron in an atom (Figure 5.2). Hole behaves like a positive charge. In magnitude they are equal to electron but opposite sign. Holes and electrons are two types of charge carriers responsible for current in semiconductor materials.

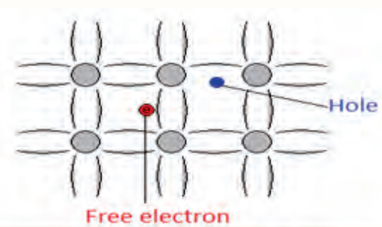


Figure 5.2 Free electron and hole in semiconductor.

Types of Semiconductors

Semiconductors are divided into two categories: Intrinsic semiconductor and extrinsic semiconductor.

Intrinsic semiconductors: are composed of only one kind of material; silicon and germanium are two examples. They are semiconductor materials which has not had impurities added to them in order to change the carrier concentrations. These are also called undoped semiconductors.

Extrinsic semiconductors: have impurities added to their lattice structure. The addition of small amounts of selected impurities to a pure semiconductor considerably improves its conductivity. The process of adding impurity to a pure semiconductor crystal to improve its conductivity is called doping. Sometimes the impurity is called a dopant.

The main aim of doping is to make sure that there are either too many electrons (surplus) or too few electrons (deficiency). Depending on what situation you want to create, you use different elements for the doping. In semiconductor production, doping intentionally introduces impurities into the intrinsic (or pure) semiconductor for the purpose of changing its electrical properties. Lightly or moderately doped semiconductors are called extrinsic semiconductor. The extrinsic semiconductors are further classified as N-type and P-type semiconductors, based on the type of atomic impurity added to the semiconductors.

N-type semiconductor: an extra electron is created by adding an element that has more electrons in the outer shell of the atom (called valence electrons) than the intrinsic semiconductor. These elements usually come from Group V in the periodic table. Elements from Group V have five valence electrons one more than the Group IV elements. Group V elements that serve as impurities include antimony, arsenic, bismuth, and phosphorus. Adding these impurities causes conduction mainly by means of electron flow. The excess electrons are passed from atom to atom when a voltage exists across the material. The electron carries a negative charge, so the material is called an N-type semiconductor and conduction is due to a large number of electrons. Since N-type dopants donate their free electrons to the semiconductor, they are known as donor atoms.

For example, Figure 5.3a shows a silicon (Si) crystal doped with arsenic(As) . When As is added to a Si crystal, the four electrons in As bond with the four Si electrons. The fifth As valence electron is free to move around for conduction. It takes only a few As atoms to create enough free electrons to allow an electric current to flow through the silicon.

P-type semiconductor: when Group III element such as aluminum, boron, gallium, or indium is added to a pure semiconductor. The added impurity atoms establish covalent bonds with the neighboring atoms. For example, boron (B) has three electrons. However, the boron atom is surrounded by four silicon atoms as shown in the Figure 5.3b. So, one of the covalent bonds is not completed. The absence of an electron creates a hole. Boron needs one more electron to complete its covalent bond. So, Boron is an acceptor of electrons. In this type of semiconductor, the holes are majority and the electrons are minority.

Discussion question 5.1:

1. What are the current carriers in semiconductors and conductors?
2. A germanium (Ge) crystal is doped with boron. What type of semiconductor is this?
3. Would the following elements make good P-type dopants or good N-type dopants?
a) Phosphorus b) Gallium c) Arsenic d) Indium

Conduction is due to the majority charge carriers which are holes. Here the holes are behaving like positive charge carriers. This material is therefore called a P-type semiconductor.

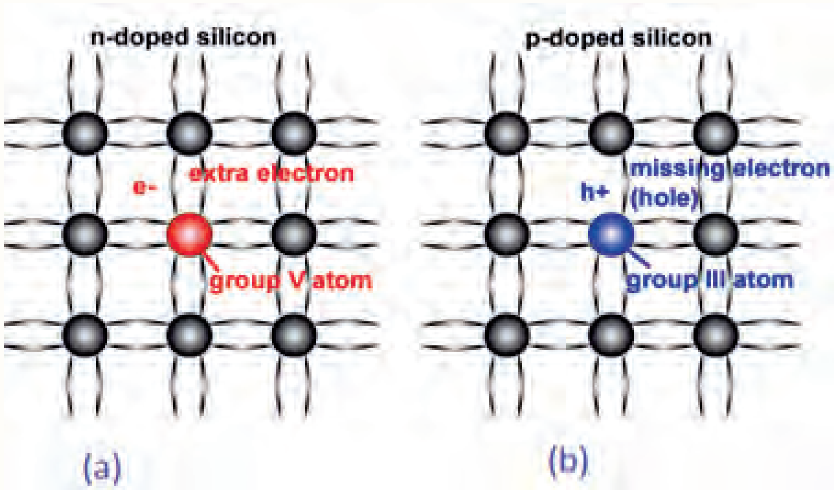


Figure 5.3 (a) Silicon crystal doped with arsenic element. For each arsenic atom present in the Silicon crystal, there is one extra electron. (b) Silicon crystal doped with boron. For each boron atom present in the Silicon crystal, there is one less electron.

Review question 5.1:

1. Why a semiconductor conducts better when it is hot? Explain your answer.
2. Define intrinsic semiconductor and extrinsic semiconductor.
3. What is P-type and N-type semiconductor?
4. Which of the following impurities could be used to convert intrinsic silicon to extrinsic P-type silicon? (A) aluminium. (B) germanium. (C) arsenic. (D) zinc.
5. What type of impurities are chosen for doping to form N-type semiconductor? (A) trivalent (B) tetravalent (C) pentavalent (D) both a and c
6. Electrons are the minority carriers in (A) extrinsic semiconductors (B) P-type semiconductors (C) intrinsic semiconductors (D) N-type semiconductors

5.2 Diodes and their Functions

At the end of this section, you will be able to:

- *Describe what a junction diode is and how it is made.*
- *Draw and label the schematic symbol for a diode.*
- *Explain the difference between forward bias and reverse bias of a diode.*
- *Describe the I-V characteristics of a diode.*
- *Describe the function of diodes, including rectification.*

A diode is a two-terminal electronic component that only conducts current in one direction and blocks current in the reverse direction. Diodes are made from a large variety of materials including silicon, germanium and gallium arsenide,etc.

Brainstorming question 5.3

Do you know a device which allows current to flow in one direction and blocks in the reverse direction?

P-N junction diode

Semiconductor diodes are the most common type of diode. When an N-type semiconductor is joined with the P-type semiconductor, a P-N junction diode is formed as shown in Figure 5.4. When a P-N junction is formed, some of the electrons in the N-region diffuse across the junction and combine with holes to form negative ions on the P-side. In so doing they leave behind positive ions in the N-region.

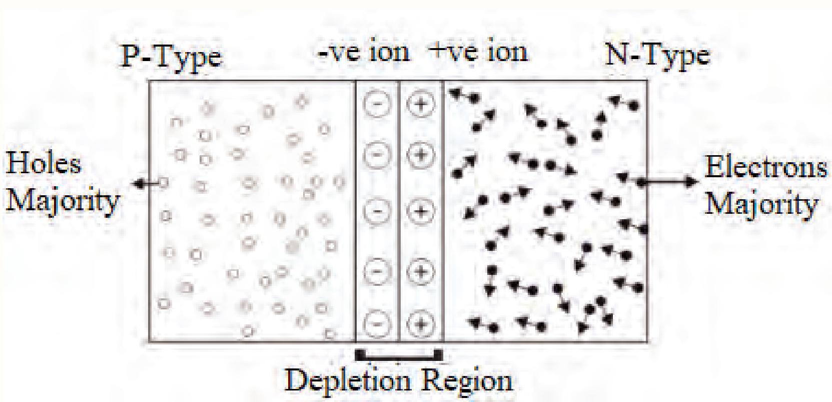


Figure 5.4 The P-N junction diode formed between P-type and N-type semiconductors.

The combination of electrons and holes near the junction creates a narrow region in the vicinity of the junction called the depletion region. Within the depletion region, there are very few mobile electrons and holes.

The electric field created by the ions in the depletion region prevents any further diffusion across the junction by establishing a barrier potential across the junction. The barrier potential is the potential difference required to move the electrons through the electric field. The barrier potential of a P-N junction depends on the type of semiconductor material. This is approximately 0.7V for silicon and 0.3V for germanium.
Figure 5.5 shows symbol of a diode. is shown in Figure . The arrow head points in the direction of conventional current flow. That means the anode is connected to the P side and the cathode is connected to the N side.

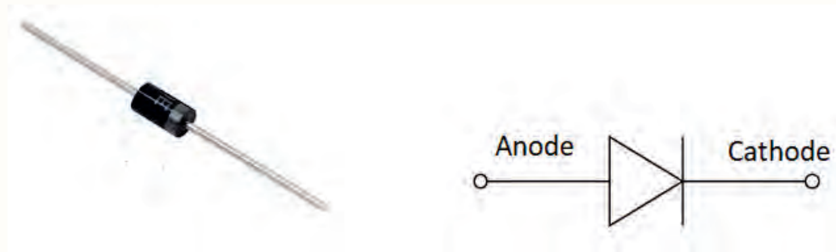


Figure 5.5 a) The P-N junction diode b) P-N junction symbol.

Biasing of P-N junction diode

Applying a suitable DC voltage to a diode is known as biasing. It can be done in two ways: forward and reverse biasing. Diodes in both forward and reverse bias are useful for computer chips, solar cells, and other electronic devices. Zero biasing condition is when no external voltage is applied to the P-N junction diode.

Forward biased

When the positive terminal of the battery is connected to the P-type semiconductor and the negative terminal to the N-type semiconductor, the P-N junction diode is said to be forward biased (Figure **??**).5.6). In forward biasing, the electrons move towards the junction as they are repelled by the negative terminal of the battery. Similarly, the holes move towards the junction because they are repelled by the positive terminal of the battery.
When a forward biasing voltage is applied to a junction diode, the depletion region becomes very thin and narrow. This represents a low resistance path through the junction, allowing high currents to flow.

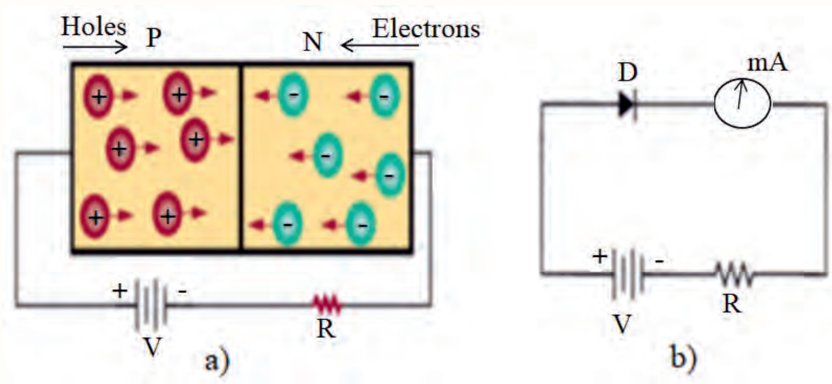


Figure 5.6 (a) Forward biased P-N junction (b) Forward biased circuit diagram.

Reverse biased

When the negative terminal of the battery is connected to the P-type semiconductor and the positive terminal to the N-type semiconductor, the P-N junction diode is said to be reverse biased (Figure 5.7).

When a reverse biasing voltage is applied to a junction diode,the free electrons from the N-type semiconductor and the holes from the P-type semiconductor move away from the P-N junction. This increases the width of the depletion region,which blocks the majority charge carrier current. This condition represents a high resistance path through the P-N junction and almost zero current flows through the junction diode.

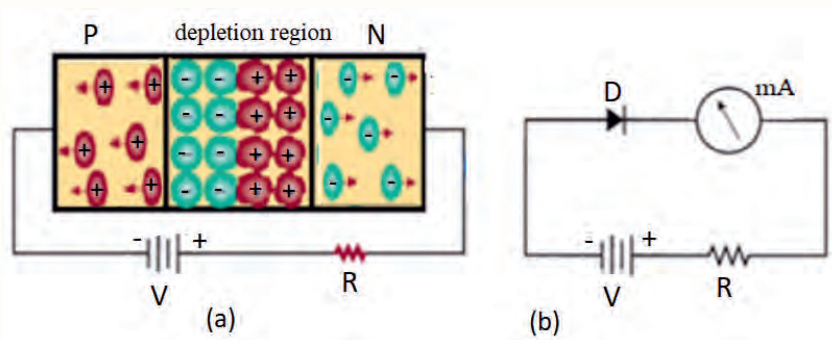


Figure 5.7 (a) Reverse biased P-N junction (b) reverse biased circuit diagram.

Discussion question 5.2:

What is the difference between forward and reverse biasing?
Give examples of the application of diodes in daily life.

Current-voltage (I-V) characteristics of the semiconductor diode

From the I-V curve (Figure 5.8) we can see that the current is very low if the forward voltage is lower than the cut-in voltage. The cut-in voltage is the voltage

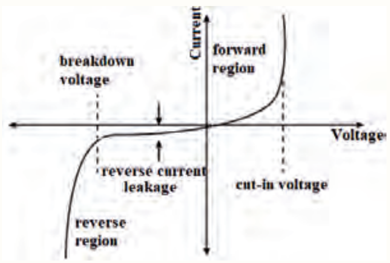


Figure 5.8 I-V characterstics of p-n junction diode.

at which the forward diode current starts increasing rapidly. Once the forward bias exceed the cut-in voltage (0.3 V for germanium diode, 0.7 V for silicon diode), the current will be dramatically increased, in the manner that the diode will function as a short-circuit.Since the diode can conduct very high current above the cut-in voltage, resistors are used in series with the diode to limit its current flow.

In the reverse bias, a very small current called a reverse bias current or leakage current flows through the junction due to the minority charge carriers. If the reverse bias voltage is too high, a sharp change in the reverse bias characteristics occurs. At a certain voltage, called the breakdown voltage, the current in the reverse direction increases rapidly.

https://www.youtube.com/watch?v=IvZv910pM7Am

Review question 5.2:

1. Define diode.
2. Under forward bias, the resistance is low and the current is high. True or False.
3. What are the current carriers in P-N junction diode?
4. What is forward bias? What is reverse bias?
5. The characteristic curve of the diode shows the relation between: (A) Current and voltage. (B) voltage and resistance. (C) voltage and power. (D) resistance and temperature.
6. Depletion layer is caused by (A) doping (B) recombination (C) barrier potential (D) ions

5.3 Rectification

At the end of this section, you will be able to:

- *Describe the working principle of half-wave and full-wave rectification.*
- *Describe the function of capacitor in the case of full-wave rectification.*
- *Describe some practical uses of diode.*

A P-N junction diode conducts electricity when it is forward biased and it does not conduct electricity when it is reverse biased. Hence, it is used to rectify an alternating current (AC) voltage supply. The process in which an AC voltage supply is converted into a unidirectional (DC) voltage is known as rectification and the electric circuit used for the conversion is called a rectifier. When the AC. input is applied to a junction diode, it becomes forward biased during the positive half cycle and reverse biased during negative half-cycle. Rectification is the main function of diodes.

There are two basic types of rectifier circuit used with power supplies: half-wave rectifiers and full-wave rectifiers.

Half wave rectification

A half-wave rectifier only allows one half-cycle of an AC voltage waveform to pass by blocking the other half-cycle. Therefore, the current in the circuit flows in only one direction. A half-wave rectifier consists of a diode and a load resistor connected in series to the cathode end of the diode. Figure 5.9 illustrates the basic principle of a half-wave rectifier.

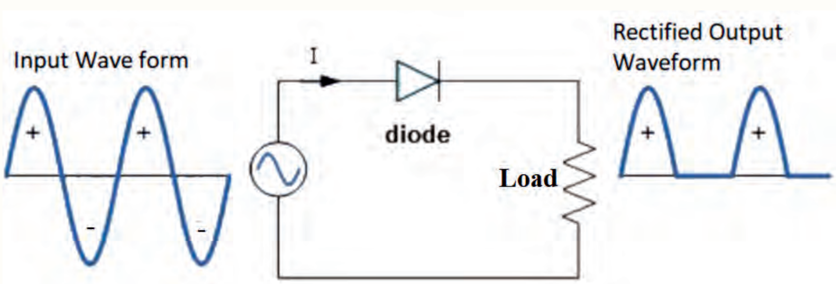


Figure 5.9 Basic half-wave rectifier.

Working principle of Half Wave Rectifier:

In a half-wave rectifier circuit during the positive half-cycle of the input, the diode is forward biased. Current flows through the load resistor and a voltage is developed across it. During the negative half-cycle, the diode is reverse biased and does not conduct. Therefore, in the negative half-cycle of the supply, no current flows in the load resistor as no voltage appears across it. Thus the DC voltage across the load is sinusoidal for the first half-cycle only and a pure AC input signal is converted into a DC pulsating output signal.

Full-wave Rectification

The fact that the current flows only during half of each cycle in a half-wave rectifier is a disadvantage. To overcome this disadvantage, a full-wave rectifier can be used. Figure 5.10 shows a basic full-wave rectifier circuit, which uses four diodes arranged in a particular way.

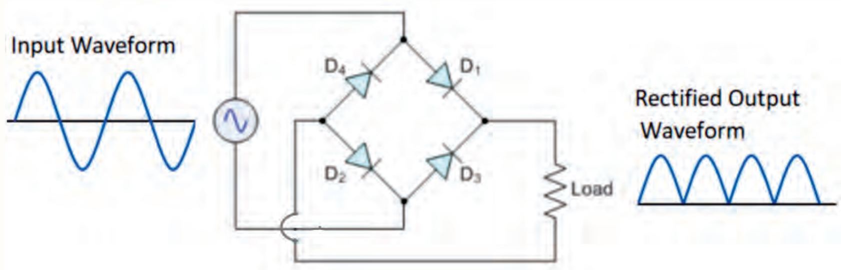


Figure 5.10 Basic full-wave rectifier circuit.

Working principle of full wave bridge rectifier

The four diodes, labeled D1 to D4, are arranged in such a way that only two diodes conduct current during each half-cycle. During the positive half-cycle of the supply, diodes D1 and D2 conduct in series. However, diodes D3 and D4 are reverse biased and so the current flows through the load resistor,as shown in Figure 5.11a. During the negative half-cycle of the supply , diodes D3 and D4 conduct in series, but diodes D1 and D2 switch off as they are now reverse biased. The current flowing through the load is the same direction as before as shown in Figure 5.11.

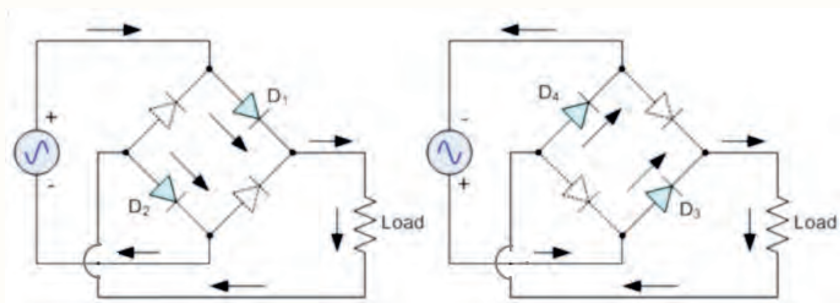


Figure 5.11 *a*) positive half cycle *b*) Negative half cycle.

Diodes and capacitor

Capacitor is used in rectifier circuits to smooth the fluctuations of the output voltage. A capacitor stores charge and releases it later. The capacitor is connected across the terminals as shown in Figure 5.12. During the positive quarter-cycle of the output voltage, the capacitor is charged to the peak voltage. Then, as the rectifier voltage falls, the capacitor discharges and provides the required current to the load resistor from its stored charge.. This charging and discharging process of the capacitor smooths out the waveform.

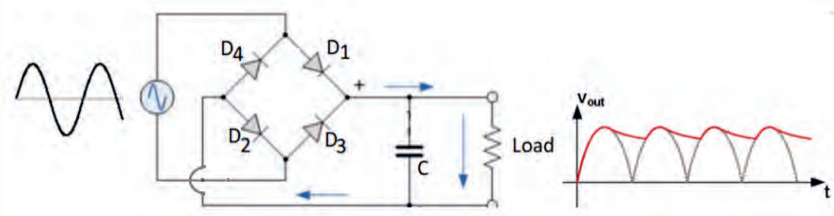


Figure 5.12 Smoothing the output voltage using a capacitor in a full-wave rectifier.

Practical uses of diodes

Light emitting diodes (LED)

A light emiting diode(LED) is a P-N junction diode which can emit light when an electrical current flows through it Figure 5.13. It uses a special kind of doping so that when an electron crosses the P-N junction, a photon is emitted, which creates light. The frequency(color) of the light emitted is determined by the type of semiconductor material used in construction of the diode. LED allows the current to flow in the forward direction and blocks the current in the reverse direction. LEDs are very efficient producers of light.

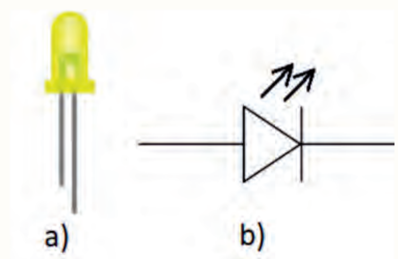


Figure 5.13 a) LED b) LED symbol

Photodiode

A photodiode (Figure 5.14) is a semiconductor device with a P-N junction that converts photons (or light) into electrical current. Photons absorbed in the depletion region (or close to it) will create electron-hole pairs which will move to opposite ends of the diode due to the electric field. Electrons will move toward the positive potential on the cathode, and the holes will move toward the negative potential on the anode. These moving charge carriers form the current (photocurrent) in the photodiode.

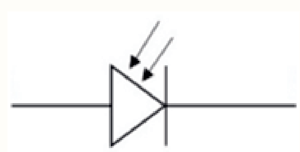


Figure 5.14 Photodiode symbol.

Logic gates

Diodes and resistors can be combined with other components to construct AND and OR logic gates. This is referred to as diode resistor logic.These are discussed in detail in section 5.5.

Over-voltage protection

Excess voltage can damage our electronic devices. Sensitive electronic devices need to be protected from fluctuations in voltage; the diode is perfect for this. Diodes achieve this by shutting down the switch after sensing an over-voltage condition.

Discussion Question 5.3:

If we use half-wave rectifier, what percentage of the input AC power will be converted to DC power ?

Review question 5.3:

1. What is rectification?
2. Describe the function of resistor and capacitor in electronic circuit
3. The dc current through each forward-biased diode in a full-wave rectifier equals: (A) the load current (B) half the dc load current (C) twice the dc load current (D) one-fourth the dc load current.
4. The basic reason why a full-wave rectifier has a twice the efficiency of a half-wave rectifier is that: (A) it makes use of transformer (B) the heating loss is much less (C) it utilizes both half-cycles of the input (D) its output frequency is double the line frequency

5.4 Transistors and their application

At the end of this section, you will be able to:

- *Describe how a transistor is constructed and its two different configurations.*
- *Draw and label the schematic symbol for an NPN and a PNP transistor.*
- *Describe the function of a transistor as an amplifier.*
- *Describe the difference between emitter, base and collector in terms of dopant concentration.*
- *Calculate the gain (amplification) of a transistor.*

A Transistor is a semiconductor device used to amplify or switch electronic signals. It is an essential component in an electronic circuit.

Transistors are classified into two types: bipolar junction transistors (BJT) and field effect transistors (FET). In this section, you will learn about BJTs.
When a third layer is added to a semiconductor diode, a BJT is produced. The term, transistor, will now be used for a BJT. A transistor is a three terminal, two-junction device used to control electron flow. By varying the amount of voltage applied to the three terminals, the amount of current can be controlled. This is how transistors can be used for amplification or switching.

A transistor consists of three alternately doped regions. The three regions are arranged in one of two ways. In the first method, the P-type material is sandwiched between two N-type materials, forming an NPN transistor (Figure 5.15a). In the second method, a layer of N-type material is sandwiched between two layers of P-type material, forming a PNP transistor (Figure 5.15b).
In both types of transistor, the middle region is called the base and the outer regions are called the emitter and collector. The emitter, base, and collector are identified by the letters E, B, and C, respectively.

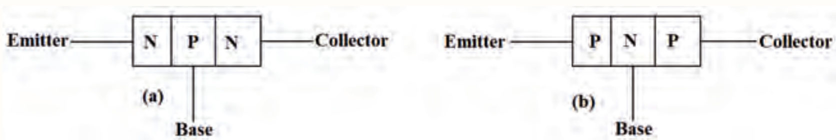


Figure 5.15 Block diagrams of (a) NPN transistor (b) PNP transistor.

Emitter: The section on one side that supplies charge carriers (electrons or holes). The emitter terminal is the heavily doped region as compared to the base and collector.
Collector: The section on the other side that collects the charges carriers. The collector is moderately doped region and slightly larger in size as compared to the base and the emitter.
Base: The middle section between the emitter and the collector. The base is lightly doped and very thin.
In the symbolic representation for a transistor (Figure 5.16), the arrow mark is placed on the emitter in the direction of conventional current flow.

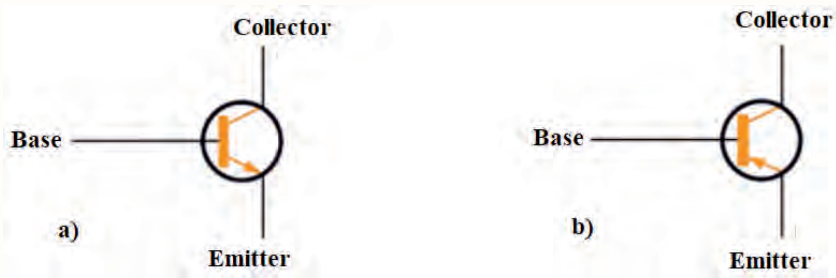


Figure 5.16 Schematic symbols for (a) an NPN transistor (b) a PNP transistor.

Basic transistor operation

NPN transistor

A transistor must be biased by external voltages so that the emitter, base, and collector regions interact in the desired manner. In a properly biased transistor, the emitter junction is forward biased and the collector junction is reverse biased.

The emitter in NPN transistor is connected to the negative terminal of the battery while the base is connected to the positive terminal. Since the second P-N junction is required to be reverse biased for proper transistor operation, the collector must be connected to an opposite polarity voltage (positive), as shown in Figure 5.17a.

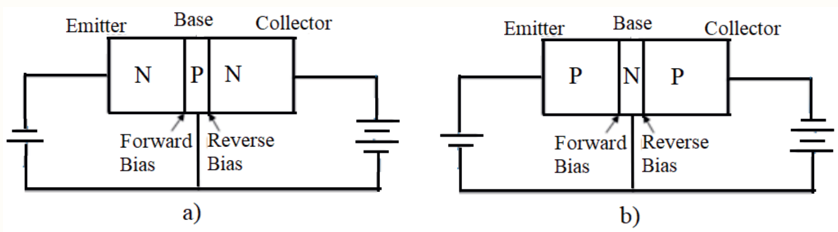


Figure 5.17 a) NPN transistor b) PNP transistor.

In the forward biased circuit:

- Electrons leave the negative terminal of the battery and enter the N material (emitter) as shown in Figure5.18. This constitutes the emitter current I_E.
- Since electrons are majority current carriers in the N material, they pass easily through the emitter, cross over the junction, and combine with holes in the P material (base).

- As the base is lightly doped and very thin, only a few electrons combine with holes and they constitute the base current I_B.
- The electron majorities will diffuse to the collector region and constitutes collector current I_C. These electrons are influenced by the positive potential applied voltage to the collector and are attracted to the positive side of the voltage source of the collector.

It can then be seen that the emitter current is the sum of the base current and collector current.

$$I_E = I_B + I_C \tag{5.1}$$

The arrows in Figure 5.18 show the direction of the electron current which is opposite to the direction of the hole current (conventional current).

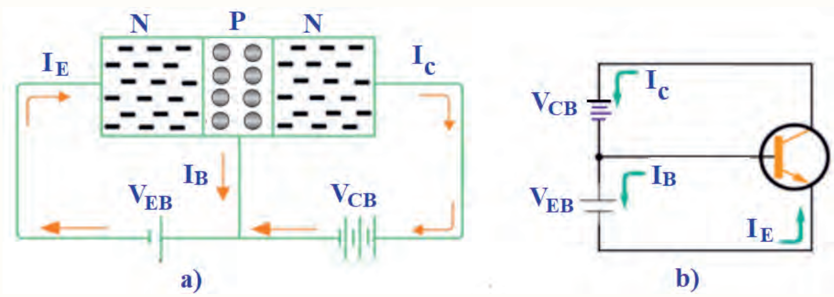


Figure 5.18 Electron current flow in NPN transistor (a) Block diagram NPN transistor (b) Schematic diagram of NPN transistor.

PNP Transistor

The PNP transistor works in essentially the same way as the NPN transistor. The majority current carriers in the PNP transistor are holes. To support this different type of current (hole flow), the bias batteries are reversed that is, the positive terminal of the battery(V_{EB}) is connected with emitter (P-type) and the negative terminal is connected with the base terminal (N-type). Therefore, the emitter-base junction is connected in forward bias as shown in Figure 5.17b.

- Since the base-collector junction is always reverse biased, then the opposite polarity voltage (negative) should be used for the collector (V_{CB}), as shown in Figure 5.19.
- The emitter current is created when the emitter-base junction is forward biased, the emitter pushes the holes towards the base region.

Discussion question 5.4:

1. How does the construction of a transistor differ from the construction of a P-N junction diode?
2. What are the two types of bipolar transistors?
3. What are the three regions of a transistor? Describe their purpose?

- When the holes move into the base, they combine with the electrons.
- The base is lightly doped and is comparatively thin. Hence only a few holes are combined with the electrons and the remaining are moved towards the collector.

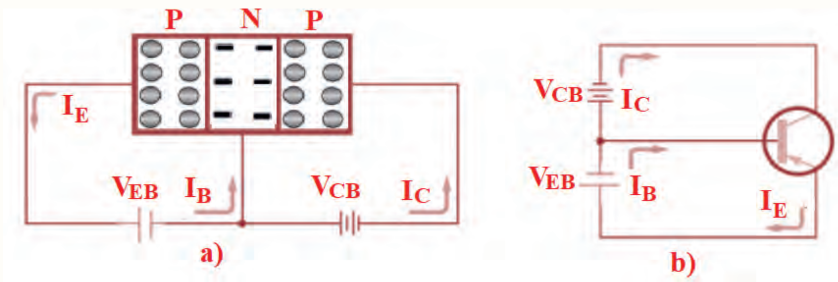


Figure 5.19 Electron current flow in PNP transistor. (a) Block diagram of a biased PNP transistor (b) Schematic diagram of a biased PNP transistor.

Transistor configurations

There are three possible ways to connect a transistor in an electronic circuit with one terminal being common to both the input and output signal. These configurations are common-emmiter,common-collector and common-base (Figure 5.20). Each method of connection responds differently to its input signal in a circuit as the characteristics of the transistor vary with each circuit arrangement.

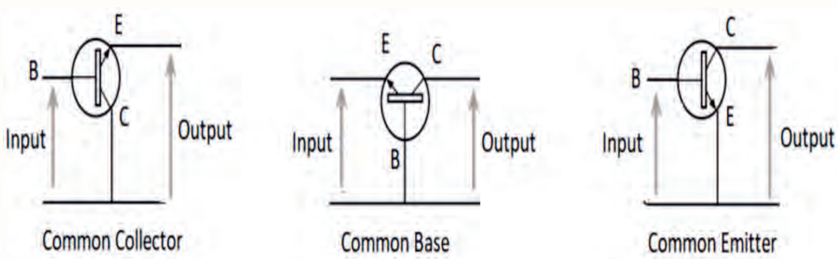


Figure 5.20 NPN Transistor Circuits.

Common-Collector (CC) : In the CC, the input signal is applied between the base and collector terminal and the output is taken between the emitter and collector terminal. It provides good current gain but no voltage gain.

Common-base (CB) : In the CB, the input signal is applied between the emitter and the base terminal and the output signal comes from the collector and base terminal. This leaves the base common to both the emitter and collector. The circuit has voltage gain but no current gain.

Common-emitter (CE) : In the CE, the input signal is applied between the base and emitter terminal , and the output is taken between the collector and emitter terminal. The circuit (Figure 5.22) has both current and voltage gain.

The CE is commonly used because its current and voltage, power gain are quite high.The ratio of collector current to base current is called the amplification factor or current gain β. Amplification is the property of a transistor to raise the strength of a weak signal. It is calculated using the equation:

$$\beta = \frac{I_C}{I_B}$$

Discussion question 5.5

1. Which terminal current in the transistor controls the collector current?
2. What is the most commonly used transistor configuration?
3. What is (are) the high gain(s) in common-base, common-collector and common-emitter transistor circuits?

Example 5.1

A transistor has a current gain of 250 and a base current 20 μA. What is the collector current?

Solution:

From the relation, $\beta = \frac{I_C}{I_B}$

$I_C = \beta I_B = 250 \times 20\ \mu A = 5\ mA$

Output characteristics of common-emitter

The output characteristics for a CE transistor describe the change in collector current I_C when an increasing voltage V_{CE} is placed between the collector and emitter. A greater amount of current flows from the emitter to the collector when there is a small change of current through the base. To determine the output characteristics, the input current or base current I_B is kept constant. However, the graph is usually plotted for more than one base current (Figure 5.21). Notice that the base current is small in micro-Ampere, but the collector current is in milli-Ampere. For example, with the transistor represented by the graph, a change of 10 μA in the base current would produce a change of around 2 mA in the collector current, which is about 200 times more than the base current.

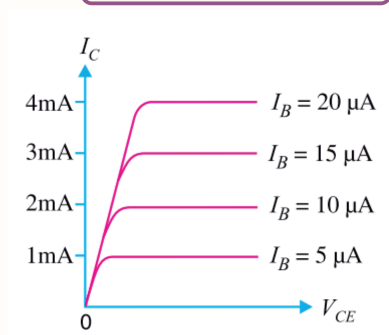


Figure 5.21 Output characteristics

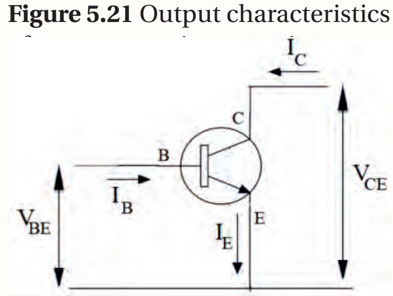


Figure 5.22 common emitter circuit

Transistor applications

The main applications of transistors are amplification of electrical signal and switching. The transistor is a very useful and widely usable electronic component.

- Most of the parts of modern electronic devices like computers, smartphones, tablets, smart watches, etc are made up with transistors where they are acting as switches.
- Transistor can amplify electronic signal. A weak signal applied in the input circuit appears in the amplified form in the output circuit.
- Transistors can be combined to form a logic gate, which compares multiple input currents to provide a different output. Computers with logic gates can make simple decisions using boolean algebra. These techniques are the foundation of computer programs.
- Transistors are used in complex switching circuits that comprise all modern telecommunications systems.
- They are the basic elements in integrated circuits (ICs), which consist of a large number of transistors interconnected in a circuit.
- In large numbers, transistors are used to create microprocessors where millions of transistors are embedded in nearly all ICs, which are part of every electronic device.

Review question 5.4:

1. Describe the function of transistor in electronic circuit
2. Which of the transistor currents is the largest? Which is the smallest?
3. The doping concentration of base in PNP transistor is (A) lightly doped (B) moderately doped (C) heavily doped (D) not doped
4. Which junction in the transistor is forward biassed? Which junction reverse biassed?
5. In transistor, if the current gain is 100 and the collector current is 10 mA, what is the emitter current?

5.5 Integrated Circuits

At the end of this section, you will be able to:

- *Explain the importance of integrated circuits.*
- *Identify the major components of an integrated circuit.*
- *Identify advantages and disadvantages of integrated circuits.*

Brainstorming question 5.4

How diodes, transistors and other electrical elements are connected to perform a certain task?

Transistors and other semiconductor devices have made it possible to reduce the size of electronic circuits because of their small size and low power consumption. It is now possible to extend the principles behind semiconductors to complete circuits as well as individual components.

The importance of integrated circuits

Integrated circuits are used in almost all electronic equipment in use today and have revolutionized the world of electronics. The integrated circuit was invented by Jack Kilby and Robert Noyce. This invention is a boon for digital technologies like computer, mobile phones, MP3, fans, traffic lights, DVDs and many other devices. The goal of the integrated circuit is to develop a single device to perform a specific function, such as amplification or switching, microprocessor, timer, as computer memory, eliminating the separation between components and circuits.

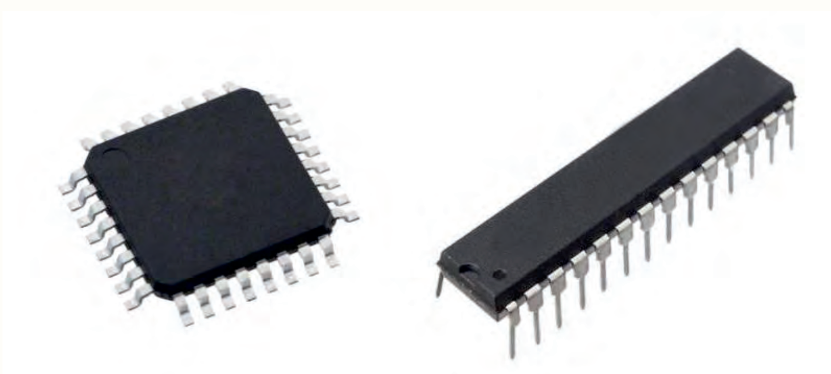


Figure 5.23 Integrated circuits.

The components of an integrated circuit

An integrated circuit (IC) (also referred to as a chip, or a microchip) is a set of electronic circuits on one small flat piece (or "chip") of semiconductor material, usually silicon (Figure 5. 23). It is no larger than that of a conventional low-power transistor. The circuit consists of diodes, transistors, resistors, and capacitors. Integrated circuits are produced with the same technology and materials used in making transistors and other semiconductor devices.

Advantages and disadvantages of integrated components

Among the four types of components included in integrated circuits only a very small amount of the space is occupied by diodes and transistors. The rest is occupied by resistors and capacitors as their size increases with their value. The most obvious advantage of the integrated circuit is its small size. An integrated circuit is constructed of a chip of semiconductor material approximately one-eighth of an inch square. Due to the integrated circuit's small size, it is used extensively in military and aerospace programs. The integrated circuit has also transformed the calculator from a desktop to a handheld instrument. Computer systems are now available in portable models because of integrated circuits. This small, integrated circuit consumes less power and operates at higher speeds than a conventional transistor circuit. The electron travel time is reduced by direct connection of the internal components.

Integrated circuits are more reliable than directly connected transistor circuits. In the integrated circuit, internal components are connected permanently. The components are formed at the same time, reducing the chance for error. After the integrated circuit is formed, it is pretested before final assembly.

Integrated circuits reduce the number of parts needed to construct electronic equipment. This reduces manufacturing cost and further reducing the cost of electronic equipment. Integrated circuits do have some disadvantages. They cannot handle large amounts of current or voltage. High current generates excessive heat, damaging the device. High voltage breaks down the insulation between the various internal components. Furthermore, integrated circuits cannot be repaired. This is because the internal components cannot be separated. Therefore, problems are identified by individual circuit instead of by individual component.

5.6 Logic gates and logic circuits

At the end of this section, you will be able to:

- *Identify digital and analog signals.*
- *Identify and explain the function of the basic logic gates.*
- *Draw the symbols and analog switch circuit for the basic logic gates.*
- *Develop truth tables for the basic logic gates.*

Brainstorming question 5.5

What mechanism is used to record and store video and audio information including musical sounds we often watch or listen?

Digital and analog signals

In electronics and telecommunications, "signal" refers to any time-varying voltage, current, or electromagnetic wave that carries information. Two main types of signals encountered in practice are analog and digital.

An analog signal is any continuous signal representing some time-varying quantity. The voltage signals which vary continuously with time are called continuous or analog voltage signals. Figure 5.24 shows a typical voltage signal, varying as a sinusoidal wave of 0 to 5 v. An analogue signal carries a smooth wave. At any time, the voltage of the signal could take any value.

A digital signal is a signal that is being used to represent data as a sequence of discrete values; at any given time, it can only take on, at most, one of a finite number of values. In most digital circuits, the digital signal can have two possible valid values; this is called a binary signal or logic signal. They are represented by two voltage bands: one near a reference value (typically termed as ground or zero volts), and the other a value near the supply voltage. It is either low or high. It never has any other value. These two special voltages are given symbols. The low voltage level is written as 0, while the high voltage level is written as 1.

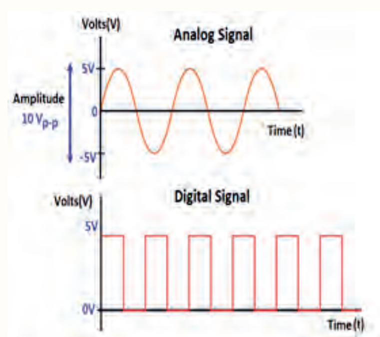


Figure 5.24 Analog and digital signals.

Using a computer, any information can be turned into a pattern of 0s and 1s. Pictures, recorded music, text and motion pictures can all be turned into a string of 0s and 1s and transmitted or stored in the same way. The computer receiving the signal at the other end converts it back again. A compact disc (CD) for example, can store music or text or pictures, and all of them can be read using a computer. You can don all kinds of mathematics using 0s and 1s. That is what computers do.

Positive and negative logic

In computing systems, the binary number symbols ’0’ and ’1’ represent two possible states of a circuit or an electronic device.

Table 5.1 Positive logic

.	Circuit	Switch	Voltage	Sign	Statement
1	on	closed	high	plus	TRUE
0	off	opened	low	minus	FALSE

Table 5.2 Negative logic

.	Circuit	Switch	Voltage	Sign	Statement
1	off	opened	low	minus	false
0	on	closed	high	plus	true

If we say that value 1 stands for 5V and value 0 for 0 V, then we have positive logic system. If on the other hand, we decide that 1 should represent 0 V (low voltage) and 0 should represent 5 V (high voltage), then we have negative logic system.

Logic gates

Digital electronics is a field of electronics involving the study of digital signals and the engineering of devices that use or produce digital signals. This is in contrast to analog electronics and analog signals. The simplest digital circuits are called logic gates. An integrated circuit is a collection of logic gates. The logic gates are building blocks of digital electronics. Each logic gate is made of many microscopic transistors connected together inside a thin slice of silicon. They are used in digital electronics to change one voltage level (input voltage) into another (output voltage) according to some logical statement relating to them. Thus, a logic gate is a digital circuit, which works according to some logical relationship between the input and output voltage. The logic gate may have one or more inputs, but only one output.

The logical statements that logic gates follow are called Boolean expressions.

1. In Boolean algebra, the addition sign (+) is referred to as OR. The Boolean expression for OR is:

$$y = A + B \tag{5.2}$$

This Boolean expression is read as y is equal to A 'OR' B.

2. The multiplication sign (.) is referred to as AND in Boolean algebra. The Boolean expression for this is:

$$y = A.B \tag{5.3}$$

This Boolean expression is read as y is equal to A 'AND' B.

3. The bar sign (-) is referred to as NOT in Boolean algebra. The Boolean expression is:

$$y = \overline{A} \tag{5.4}$$

This expression is read as y is equal to 'NOT' A.

The OR gate, AND gate and NOT gate are called basic logic gates. The NOR gate and NAND gate are called universal logic gates because any logic gate can be made from combinations of NAND gate or NOR gates. Each of these gates performs a different logical operation.

OR gate

Two parallel switches and Lamp is connected as shown in Figure 5.25. Lamp "ON" is equal to 1 and lamp "OFF" is equal to 0.

- If both switches A and B are open, no current will flow through the external wire. So the lamp is OFF i.e. equal to 0.
- If switch A is closed switch B is open, the current passes through switch A and the lamp is ON, i.e. equal to 1; 1 + 0 = 1
- If switch A is open and switch B is closed, the current passes through B and the lamp is ON, i.e. equal to 1; 0 + 1 = 1
- If both switches are closed, tamp is ON, i.e. equal to 1; 1 + 1 = 1

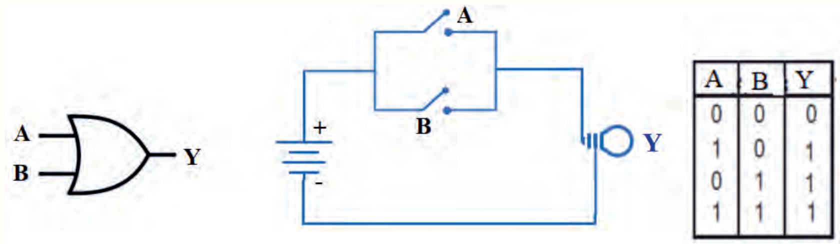


Figure 5.25 The OR gate symbol, switch circuit and truth table.

You can see from the truth table that the Boolean expression $y = A + B$ makes sense. The only case where the OR function differs from normal addition is when A = 1 and B = 1. Here A OR B = 1 in logic, but A+B=2 in arithmetic. However, there is no such thing as '2' in logic, so we define + to mean 'OR', and write 1 + 1=1.

Application of OR gate: An OR gate can be used to fit two light switches for a long, dark corridor which has one switch at each end of the corridor. Each of the switches send an output of 0 to the control unit if no-one has pressed the switch. If someone presses the switch, its output is 1. The lights in the corridor should come on if either witch is pressed.

AND gate

In general, the simple AND gate is also a two inputs and one output logic gate. It combines the inputs A and B to give the output *y*, following the Boolean expression

$$y = A.B \tag{5.5}$$

The AND operation is written as multiplication. A AND B is written AB. If either A or B are 0, then AB will also be 0. For AB to be 1, we need A and B to both be 1.

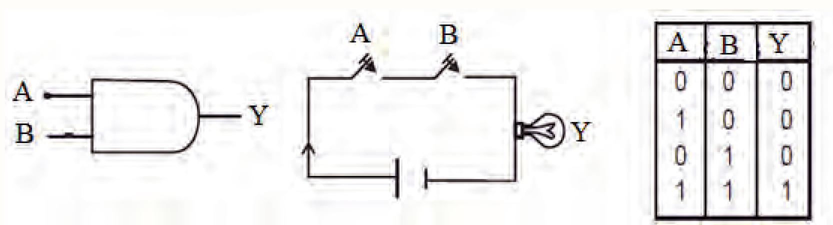


Figure 5.26 The AND gate symbol, switch circuit and truth table.

The symbol, equivalent circuit and truth for an AND gate are shown in Figure 5.26. The function of the AND gate is such that the output is TRUE if and only if all the inputs are in TRUE conditions. In this circuit, the switches and the lamp are in series. All the possible inputs and resulting outputs are tabulated in a truth table.

- If both switches A and B are OPEN (i.e., A = 0, B = 0) then the lamp will not glow, i.e. $y = 0$. The current will not pass through the lamp.
- If switch A is closed and switch B is open, the current will not pass through the lamp. The lamp is OFF, so $y = 0$.
- If switch A is open and switch B is closed, the current will not pass through the lamp. The lamp is OFF, so y = 0.
- If both switches A and B are closed, current will pass through the circuit. Now the lamp is ON and glowing. So $y = 1$.

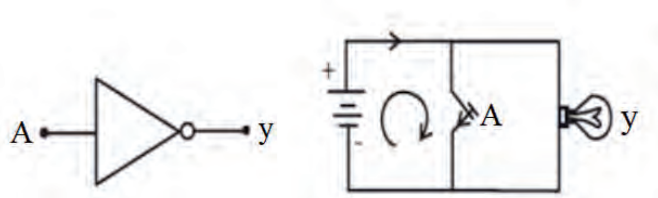
Application of AND gate: An AND gate can be used to fit an automatic circuit to light up a display in an airplane if two toilets are in use. Then passengers know that if the light is off, there is a free toilet for them to use. There is a sensor in each toilet. It gives out a 0 if the toilet is free, and a 1 if it is in use. You can send a 1 to the display unit if both sensors are sending 1. That is, if both toilets are occupied.

NOT gate

The NOT gate is a one input and one output logic gate. It inverts or complements the input A to give output y following the Boolean expression.

$$y = \overline{A} \tag{5.6}$$

This gate is also called an 'inverter'. . The symbol, equivalent circuit and truth table are shown in Figure 5.27.



A	y
0	1
1	0

Figure 5.27 The NOT gate symbol, switch circuit and truth table.

- If switch A is open, the current will pass through the lamp and it will glow. So, $y = 1$ when A = 0

- If switch A is closed, the current will take the shortest path and pass through the switch. Hence the lamp is OFF, so $y = 0$ when A = 1.

Application of NOT gate : Let's assume you want the water pipe in your garden to automatically turn on when it is very dry.. You already have a digital electronic soil moisture sensor. To make the pipe work, you need a circuit which will change a 0 (from the sensor) into a 1 (to send to the pipe). This will make the pipe turn on when the soil is dry. You also want it to change a 1 (from the sensor) into a 0 (to send to the digital pipe). This will close the pipe when the soil is wet.

NOR gate

A NOR logic gate is one in which OR gate is followed by a NOT gate. The symbol, equivalent circuit and truth table are shown in Figure 5.28. The function of this gate is 'inverting' the output of the OR gate.

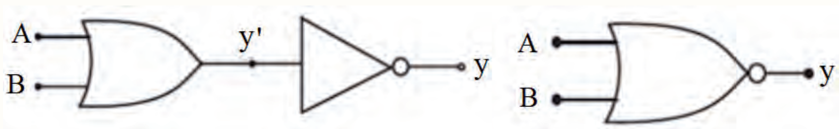
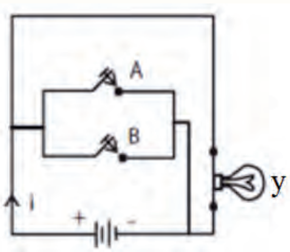


Figure 5.28 The NOR gate symbol.

The NOR gate combines the inputs A and B to give the output y, by the Boolean expression:

$$y = \overline{A + B} \tag{5.7}$$



A	B	y'	y
0	0	0	1
1	0	1	0
0	1	1	0
1	1	1	0

A	B	y
0	0	1
1	0	0
0	1	0
1	1	0

Figure 5.29 The NOR gate switch circuit and truth table.

- switch A and switch B are open, the current will flow through the lamp, and the lamp is ON. So $y = 1$.

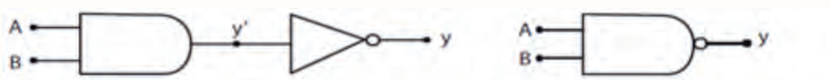
- If switch A is closed and switch B is open, the current will pass through switch A (low resistance path) and reach the cathode of the battery. The lamp is OFF, so $y = 0$.

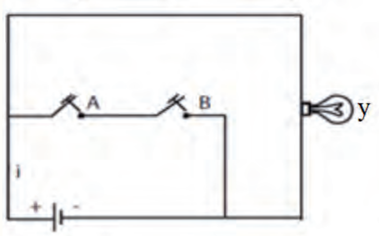
- If switch A is open and switch B is closed, the current will pass through switch B (low resistance path) and reach the cathode of the battery. The lamp is 'OFF', so y = 0.
- If switch A and switch B are closed, the current from the battery will pass through the two parallel switches (the low resistance paths) reach the cathode of the battery. The lamp is OFF, so $y = 0$.

NAND gate

A NAND logic gate is one is logic gate in which an AND gate is followed by a NOT gate. The symbol, equivalent circuit and truth table are shown in Figure 5.30. The function of this gate is to invert the output of the AND gate. It combines the inputs A and B to give the output *y*, by the following Boolean expression:

$$y = \overline{A.B} \tag{5.8}$$





A	B	y'	y
0	0	0	1
1	0	0	1
0	1	0	1
1	1	1	0

A	B	y
0	0	1
1	0	1
0	1	1
1	1	0

Figure 5.30 The NAND gate symbol, switch circuit and truth table.

- If both switches A and B are open, the current will flow through the lamp. The lamp is ON, so y = 1
- If the switch A is closed and B is open, the current will again flow through the lamp. The lamp is ON, so y = 1.
- If the switch A is open and B is closed, the current flows through the lamp. The open switch A act as a inter circuit breaker. The lamp is ON, so y = 1.
- If the switch A and B are in closed position, the current will pass through the switches (low resistance path) and reach the cathode of the battery. Hence, the lamp is OFF, So, y = 0

Exercise 5.1

Figure 5.31 shows a logic circuit and its incomplete truth table. Complete the truth table.

Exercise 5.2

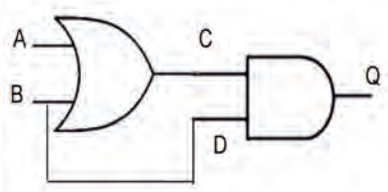
Figure 5.32 shows a logic circuit and its incomplete truth table. Complete the truth table.

Exercise 5.3

The truth table of a logic circuit is given in Figure 5.33 (a) and (b). Name the logic circuit..

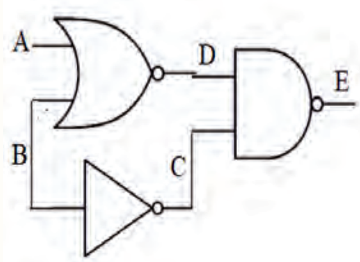
Brainstorming question 5.6

Dear students, think of your living area including your house. List as many devices as you can think of that use electricity. This may be transmitting information, controlling other machine, displaying information, storing information, and many more.



A	B	C	D	Q
0	0			
0	1			
1	0			
1	1			

Figure 5.31 A logic circuit and its incomplete truth table



A	B	C	D	E
0	0			
0	1			
1	0			
1	1			

Figure 5.32 A logic circuit and its incomplete truth table

A	B	C
0	0	1
0	1	1
1	1	1
1	1	0

a)

A	B	C
0	0	1
0	1	1
1	0	1
1	1	0

b)

Figure 5.33 Truth tables of a logic circuit

5.7 Application of electronics

We use a large number of electronic gadgets to simplify our work and to solve our problems. From small alarm watches to complex computers, from mobile phones to camcorders, from leisure items to equipment for work, electronic items can be everywhere. Here are details of a few applications of electronics:

1. **Aerospace industry**

   Electronics is widely used in aerospace such as Space shuttle, Satellite power supplies, aircraft power management. Even in commercial airlines there are hundreds of instruments which are used to measure different physical factors like temperature, pressure, elevation, etc.

2. **Medical**

   The development of electronics, and particularly that of computers, has made it possible for a doctors to examine patients. Many machines like X-ray, MRI and others which are the combination of different physics theorems and electronics. There are tremendous advancement of electronics in the field of medical sciences. There are a few recent innovations which show how important electronics is in medical science - Robotic Check-Ups, Needle-Free Diabetes Care, Electronic Aspirin, etc.

3. **Automobile**

   Electronics are used in road vehicles, such as carputers, telematics, in-car entertainment systems, etc. The first electronic pieces in cars were used to control engine functions; they were referred to as engine control units. Now, electronics are used in engine, transmission, chassis, active safety, driver assistance, passenger comfort and entertainment systems.

4. **Agriculture**

   With an increase in global warming, many devices and systems are being built to monitor a crops. For example, e-Agri Sensors Centre producing sensors to monitor the crop above and below the land. These sensors monitor the crop quality as well as the needs of the crop during growth. There are also several other electronic gadgets which are used for measuring the moisture level, nutrition level and also salinity of the soil.

5. **Communication**

   Electronic devices and systems are used for the acquisition or acceptance, processing, storage, display, analysis, protection, disposition, and transfer of information.

6. **Residential**

   There are also various electronic equipment which make our life easy and better. These include appliances such as air conditioner, cooking appliances, dryer, personal computer etc. These equipment make daily life easy. Nowadays, mobile phones are used by each and every person.

Discussion Question 5.6

Explain how electronics is used in:
1. Agriculture
2. Medicine
3. Military
4. Communication

7. **Military**

Electronics devices and machinery are also widely used in military. Unmanned aerial vehicles (UAVs) and drones are some common aerial electronics machines which are used in the military for aerial attack as well as for monitoring. There are also some electronics equipment used in guns and airplanes which help soldiers to target his enemy during frontline war. Magnetic anomaly detector Night vision device, People sniffer, infrared detector and night vision camera etc. are some gadgets used by military.

Project

1. Dear students, using broken parts of electronic devices, identify and classify different types of diodes. From your collection of broken parts and the school lab, assisted by your teacher, construct functional devices for personal applications.

2. Dear students, using some electronic devices available in the school Lab construct a half-wave rectification circuit. Present your circuit to the class.

Unit summary

- At zero Kelvin, a semiconductor serves as an insulator. As the temperature increases, the conductivity increases, and vice versa.
- Doping is the process of adding impurities to a semiconductor material.
- By adding certain selected impurities to the pure semi-conductor in a very small ratio, the conductivity of a semiconductor crystal can be improved.
- In semiconductors, a hole is an electric charge carrier with a positive charge, equal in magnitude but opposite in polarity to the charge on an electron.
- In N-type materials, electrons are the majority carrier and holes are the minority carrier. In P-type materials, holes are the majority carrier and electrons are the minority carrier.

- A junction diode is created by joining N-type and P-type materials together.
- The depletion region is a region in a P-N junction diode where no mobile charge carriers are present. Depletion layer acts like a barrier that opposes the flow of electrons from N-side and holes from P-side.
- Applying a suitable DC voltage to a diode is known as biasing.
- The *I-V* characteristic curves shows the relationship between the current flowing through a diode and the applied voltage across its terminals.
- The process in which an AC voltage is converted into a unidirectional (DC) voltage is known as rectification.
- A half-wave rectifier only allows one half-cycle of an AC voltage waveform to pass by blocking the other half-cycle.
- A full-wave rectifier is a diode circuit which is used to transform the complete cycle of AC voltage supply to DC.
- A capacitor is used in rectifier circuits to smooth the fluctuations of the output voltage
- A light-emitting diode (LED) is a semiconductor device that emits light when an electricity passes through it.
- A bipolar junction transistor is a three layer (NPN or PNP) semiconductor device.
- The three layers are called the emitter, base and collector.
- A transistor consists of two P-N junction. The junction are formed by positioning either P-type or N-type semiconductor layers between a pair of opposite types.
- The base is lightly doped and sandwiched between the collector and the emitter. The collector is moderately doped and the emitter is heavily doped.
- The base region is much thinner than either the collector or emitter regions.

- The transistor operates when base-emitter junction is forward biased and base-collector is reversed biased.
- Transistors can be used for amplification or switching.
- Transistors are used in digital computers, satellites, mobile phones and other communication systems, control systems,etc.
- The arrowhead in the symbol of a transistor indicates the direction of a conventional current flow.
- In NPN transistors the majority carriers are free electrons, while in PNP transistors these are the holes.
- There are three types of configuration for the operation of a transistor: common-emitter, common-base and common-collector configurations.
- The current gain in the common-emitter circuit is called beta. β is the ratio of collector current to base current.
- Integrated circuits cannot handle large amounts of current or voltage.
- Diodes, transistors, resistors, and capacitors are available as integrated circuits.
- Integrated circuits cannot be repaired, only replaced.
- An AND gate produces a 1 output when all of its inputs are 1s. It performs the basic operation of multiplication.
- An OR gate produces a 1 output if any of its inputs are 1s. It performs the basic operation of addition.
- A NOT gate performs the function called inversion or complementation. It coverts the input state to an opposite output state.
- A NAND gate is a combination of an AND gate and a NOT gate. It produces 1 output when any of the inputs are 0s.
- A NOR gate is a combination of an OR gate and a NOT gate. It produces a 1 output only when both inputs are 0s.

- Electronics is widely used in aerospace such as Space shuttle, Satellite power supplies, aircraft power management. Even in commercial airlines. They are used to measure different physical factors like temperature, pressure,elevation, etc.
- Electronics devices and machinery are widely used in medicine. Today many medical devices and system such as MRI, CT scan x-ray,etc are builds with the combination of different physics theorem and electronics.
- Electronics are used in road vehicles, such as: carputers, telematics, in car entertainment systems,to control engines. etc.
- Electronics has made daily life much easier and better.
- Many devices and system are build with combination of electronics and different other techniques to monitor the activities in agriculture,such as for measuring the moisture level, nutrition level in soil and also salinity of soil,etc.
- Electronic devices and systems are used for the processing, storage, display, analysis, protection, and transfer of information.
- Electronics equipment used in guns and airplanes which help soldiers to target his enemy during frontline war.
- Night vision device, people sniffer, infrared detector and night vision camera, drones, etc. are some electronic gadgets used by military.

End unit questions

1. What determines whether a semiconductor material, when doped, is an N-type or P-type?
2. How does doping support current flow in a semiconductor material?
3. What is a P-N junction?
4. Define a half-wave rectifier and full-wave rectifier.
5. How should collector-base and emitter-base junctions be biased?

6. What are transistors used for?
7. In which direction does the arrow point on an NPN transistor?
8. To properly bias an NPN transistor, what polarity voltage is applied to the collector, and what is its relationship to the base voltage?
9. In the NPN transistor, what section is made very thin compared with the other two sections?
10. What is the name of the device that provides an increase in current, voltage, or power of a signal without appreciably altering the original signal?
11. In the common emitter transistor amplifier, what is the phase relationship between the input and output signals?
12. What is the current gain for a common-base configuration where $I_E = 4.2$ mA and $I_C = 4.0$ mA?

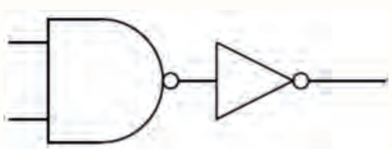


Figure 5.34 A logic gate circuit

13. What two symbols are used in digital electronics, to represent a "high" and a "low"? What is this system known as?
14. What is the difference between a digital signal and an analog signal?
15. What is a logic gate?
16. Write out the truth table for the circuit shown in Figure 5.34. Which single gate is this circuit equivalent to?

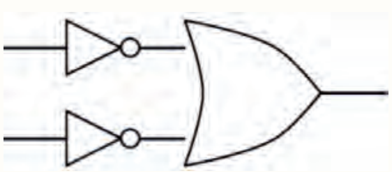


Figure 5.35 A logic gate circuit

17. Write out the truth table for the circuit shown in Figure 5.35. Which single gate is this circuit equivalent to?
18. What logical operations are performed by an AND gate and an OR gate?
19. What *negative logic* and *positive logic* mean?
20. Draw the symbol for a NAND gate and write the Boolean expression for it.

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