MAKKO BILLI SCHOOL

DEPARTEMENT OF NATURAL SCIENCE

GRADE 11 PHYSICS MODULE

PREPARED

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PREFACE

This grade 11 physics module contains seven units, Unit-1 (Physics and Human Society), Unit-2 (Vectors), Unit-3 (Motion in One and Two Dimensions), and Unit-4 (Dynamics), Unit-5 (Heat conduction and Calorimetry), Unit-6 (Electrostatics and Electric circuit), and Unit-7 (Nuclear physics). Each unit begins with a list of learning objectives which allow you to know the results of learning each unit and be aware of what is expected from you. In each unit there are several activities, exercises and self test questions that complement the information in the brief note and encourage your higher level understanding of each unit and will help you assess your understanding of the unit. Whenever you attend the lesson you should use this module.

ACKNOWLEDGEMENTS

First and for most I thank the almighty God, the creator of all, my strength and power. Next,
I would like to express profound gratitude to Makko Billi School for their, motivate, support, encouragement, and useful suggestions throughout this module preparation. Last but not least I do not feel like stopping without expressing my gratitude to all who were support me throughout this work.

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INTRODUCTION

Physics is a major driver of innovation and economic growth in world-wide in sectors ranging from energy, security, advanced manufacturing, data extraction and analysis to healt care and diagnostic , finance and communication for the benefit of society. It is important in providing fundamental knowledge for understanding nature, in providing applied knowledge for the development of technology.

Many physical quantities in nature have both magnitude (size) and direction. To describe the motion of an airplane for instance, we must state its speed and the direction of its motion. To describe a force, we use a number to tell how big the force is and indicate its direction of application.

Motion is one of the significant topics in physics. Everything in the universe moves. If you give a glimpse to your environment, you might see several things in motion: a car on a road, children playing on a playground, an airplane flying in the sky, even an ant crawling on the ground. An object is said to be in motion if its position changes with time. The concept of motion is relative. A body that may be in motion relative to one reference system may be at rest relative to another. For example, if you are sitting in the classroom, you are at rest with respect to the earth; but actually, you are in motion with respect to the sun.

Motion is an important element in studying physics. Naturally, the race of athletes, the flying of a bird, and the jumping of a dolphin out from the water, the trajectory of a soccer ball or a basketball and the like are examples of motion in nature. The motion of a fast driving car, or an airplane or a fast magnetic levitated (Maglev) train, or a supersonic jet, or a satellite orbiting the earth are all fascinating developments of human beings in the advancement of motion. Motions have causes and that cause is a force. The study of motion with its causes is dynamics.

Everywhere you look including yourself, energy transfer taking place in different forms. One of such energy transfer methods is heat transfer. Heat energy is very essential to society. From everyday cooking to some of modern-day luxuries, such as refrigerators and jet engines are using the transfer of heat at the heart of their working principle. Heat is one of the mechanisms to transfer internal energy so that it can be usable. Heat is often misunderstood to be the same as temperature.

Electrostatics is the study of the properties of electric charges at rest and current electricity is the study of properties of charges in motion. The main difference between static and current electricity is that with static electricity, the charges are stationary and build on the surface of an insulator, while in current electricity electron flowing through a conductor form what we call an electric current.

Nuclear physics is the field of physics that studies atomic nuclei and their constituents and interactions that hold them together. Nuclear interactions include radioactive decay, the break-up of a nucleus (fission), and the merging of nuclei (fusion). The main driving strong nuclear force produced by the nucleus of an atom acts within a very short distance-just a few fathometers (10^{-15}) across. The strong nuclear force is the force that is responsible for the binding of protons and neutrons into atomic nuclei. The strong binding energy will help to produce strong radiation up on different reaction processes and radiation decay.

Nuclear physics is the field of physics that studies atomic nuclei and their constituents and interactions that hold them together. A nuclide may be stable or unstable. Unstable nuclides emit radiations spontaneously. These radiations have different forms which are known as alpha, beta and gamma radiations with charges similar to proton, electron and neutron in the atomic system. Through research, nuclear physicists are leading us on a journey of discovery into the nucleus of the atom-the very heart of matter. The goal is a roadmap of matter that will help unlock the secrets of how the universe is put together. Significant efforts have been made from the early 19^{th} century on the observation of different subatomic systems by different scientists. Nowadays, the research reactor (RR) and the power reactor (RR) are widely in use globally.

GENERAL OBJECTIVES

After going through this module, you are expected to:

- Get acquainted with the impact of physics on society.
- Familiarize themselves with physics communities and their roles.
- Develop basic understanding of the making of physics knowledge.
- Familiarize themselves with basic principles and applications of physics in various disciplines.
- Acquire basic knowledge and understandings of nature and appreciate it.
- Update them with the current status of physics.
- Familiarize themselves with basic principles of vector operations.
- Interpret physical phenomena using the concept of vector.
- Develop skills of using the concept of vector in solving various problems.
- Gain an understanding of the fundamental principles of kinematics in one and two dimensions.
- Develop skills in applying equations of motions to solve practical problems.
- Recognize the effect of air resistance and force of gravity on motion of a body.
- Describe technological advances related to motion; and identify the effects of societal influences on transportation and safety issues.
- Demonstrate an understanding of the relationship between net force and the acceleration of an object in linear motion.
- Analyze the effect of a net force in quantitative terms, using graphs, free body diagrams, and vector diagrams.
- Describe the first condition of equilibrium quantitatively.
- Demonstrate an understanding, in qualitative and quantitative terms, of the concepts of work, energy, energy transformations and power.
- Design and carry out experiments and solve problems involving energy transformations and the law of conservation of energy.
- Realize that momentum is an inherent property of moving objects.
- Expresses the relationship between impulse and momentum.
- Gain comprehensive knowledge on basic properties of fluids, thermal properties of matter, phase changes, calorimetry quantitatively and qualitatively.
- Describe about heat capacity, specific heat capacity, and thermal expansions.
- Solve calorimetry problems.
- Use specific heat and heat of transformations in the practical application of calorimetry.
- Calculate the electric field resulting from a point charge.

- Determine the magnitude and direction of the electric force among any point charges.
- Acquire knowledge and understanding in electrostatic phenomenon.
- Demonstrate an understanding of the components and functions of electrical circuits that are commonly found at home and in the workplace.
- Construct, analyze, simple electrical circuits, using schematic diagrams, working with electrical tools and components, and examining small everyday electrical devices and appliances.
- Define a capacitor and explain some of its applications in life.
- Apply Kirchhoff's rules to solve circuit problems.
- Appreciate the basic concept of the atomic nucleus.
- Describe qualitatively the basic nuclear processes (concepts of radioactivity, and nuclear reaction).
- Discuss the types of nuclear forces.
- Explain application of radioactivity and nuclear reaction to society.
- Describe the application of radioactivity and nuclear reaction to explain the energy source of stars.
- Define terms like nuclear fission, nuclear fusion, and isotope.
- Gain the basic knowledge of nuclear medicine.
- Demonstrate high level of awareness to protect themselves and their community from radiation hazard.

UNIT ONE

1. PHYSICS AND HUMAN SOCIETY

Introduction

Physics is a major driver of innovation and economic growth in world-wide in sectors ranging from energy, security, advanced manufacturing, data extraction and analysis to healt care and diagnostic , finance and communication for the benefit of society. In this chapter you will understand the career opportunity of physics, the contribution of physics for every individuals and economic growth of a country. In addition to see you will practice the method of gaining knowledge, it is important in providing fundamental knowledge for understanding nature, in providing applied knowledge for the development of technology.

- **After completing this unit, you will be able to:**
  - Get acquainted with the impact of physics on society.
  - Familiarize themselves with physics communities and their roles.
  - Develop basic understanding of the making of physics knowledge.
  - Familiarize themselves with basic principles and applications of physics in various disciplines.
  - Acquire basic knowledge and understandings of nature and appreciate it.
  - Update them with the current status of physics.

1.1. Importance of Physics to society

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

- Explain the importance of physics to society.

- Physics is one of the sciences that generate fundamental knowledge needed for the future technological advances that will continue to drive the economic engines of the world.
- Physics contributes to the technological infrastructure and provides trained personnel needed to take advantage of scientific advances and discoveries.
- Physics extends and enhances our understanding of other disciplines, such as the earth, agricultural, chemical, biological, and environmental sciences, plus astrophysics and cosmology subjects of substantial importance to all peoples of the world.
- Society's reliance on technology represents the importance of physics in daily life.
- Many aspects of modern society would not have been possible without the important scientific discoveries made in the past.
- These discoveries became the foundation on which current technologies were developed.

- Discoveries such as magnetism, electricity, conductors and others made modern conveniences, such as television, computers, phones and other business and home technologies possible.
- Modern means of transportation, such as aircraft and telecommunications, have drawn people across the world closer together all relying on the concepts of physics.

The influence of physics on society: simple mechanical devices such as pulleys and levers, as well as complex modern machines like quantum computers and nuclear reactors, would be impossible to create without the use of physics.

- Physics lies at the root of many inventions that have an enormous impact on the everyday life of the average person. There are numerous ordinary objects that people use regularly that rely on the science of physics to function, including semiconductors, lasers, X- rays, GPS devices, radio transmitters and bar code scanners.
- Transportation vehicles such as automobiles, airplanes and space shuttles could not be constructed without the help of physics experts.
- Physics is also useful for military purposes, informing the design of weapons.
- Many of scientists responsible for inventing the atomic bomb were physicists, and today physicists are involved in the creation of nuclear weapons.

Activity 1.1

Explain the influence of physics on society in transport, health, economy, technology, etc

1.2. Physics communities and their roles

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

- ❖ Discuss about physics communities and their roles.

- Physics communities are an organized group of persons associated together for scientific purposes.
- This organization is established at the level of national continent as well as worldwide based on their aims.

Ethiopian Physical Society (EPS): In order to help us appreciate the importance of Physics communities, we are going to discuss two professional societies from our country.

- There are two Physical societies in Ethiopia we are interested and going to discuss about them in the following sections. Ethiopian Physical Society (EPS) and Ethiopian Space Science Society (ESSS).
- Ethiopian Physical Society (EPS) was founded on October 10, 1998 by Ethiopian physics professionals to enhance physics research and education, thereby contributing its share to the overall development of the country.

Objectives of EPS:

- To promote physics education and research in the country.
- To organize and coordinate various conferences on physics education and exchange of scientific information.
- To popularize physics in order to make students develop interest in physics.
- To promote active participation of Ethiopian physicists and the general public in the design and implementation of the physics curriculum.
- To create a means for disseminating scientific information; etc…

Ethiopian Physics Society in North America (EPSNA): was established to promoting physics education and research among Ethiopians in Ethiopia and North America.

- The mission of EPSNA was to promote and support the education and training of Ethiopian physics professionals by denoting educational materials, field equipment, computing facilities, provide scholarship, etc…

African Association of Physics students (aaps): is Student-run educational association.

- It comprises students and recent graduates who are interested in physics.
- The purpose of the organization is to encourage physics students in their scientific and professional work between physics students from all over the world.
- The '**aaps'** is committed to supplement physics education with an international scientific experiences and it is affiliated with physics societies and departments.
- **aaps** is open to all persons committed to physics.

Ethiopian Space Science Society (ESSS): is somewhat similar but not exactly physics community.

Activity 1.2

What are the benefits of physics communities?

1.3. Making of Physics Knowledge

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

- Discuss how scientific knowledge is constructed.
- Discuss the roles that the learning of physics plays to the individual intellectual satisfaction.

- One way of understanding the concept of knowledge is to look at different ways in which we acquire knowledge.
- There are two types of knowledge from two entirely different sources. First, there is knowledge through experience: seeing something, hearing about something, feeling something called a posteriori knowledge. Second, there is knowledge that does not come

from experience, but perhaps instead is intuitively from reason itself, such as logical and mathematical truths called a priori knowledge.

1. Experimental knowledge: is the knowledge we get through experiences.

- The four main ways of acquiring though experience are:

Sensory perception: is perhaps the dominant source of experimental knowledge, it immediately raises a critical question.

- We gather knowledge by seeing, touching, hearing, etc.

Introspection: is like a sixth sense that looks into the most intimate parts of our minds, which allows us to inspect how we are feeling and how our thoughts are operating.

- If I go to a doctor complaining of an aching back, she'll ask me to describe my pain. Through introspection I then might report, "well, it's a sharp pain that starts right here and stops right here." The doctor herself cannot directly experience what I do and must rely on my introspective description.

Memory: is like a recording device that captures events that one can experience more or less in the order that they occur.

Testimony: testimonies from written sources are usually more reliable than oral sources, but much depends on the integrity of the author, publisher, and the methods of fact-gathering.

2. **Non-experimental (priori) knowledge:** this source of information is more difficult to describe. We presumably gain access to this knowledge through rational insight.

- Usual examples of non-experimental knowledge are mathematics and logic. Take for example 2+2=4.

Scientific method: is an ordered series of steps to acquire knowledge based on experimental evidences.

1. **Observation**: observing or looking for something.
2. **Questions**: depends on your observation raising some questions.
3. **Research**: reading and refer the back ground of questions
4. **Hypothesis:** formulating hypothesis or guess the answer for the questions.
5. **Experiment**: to design experiments in order to check hypothesis.
6. **Analysis:** analyzing and interpreting results that you get from experiments.
7. **Conclusions:** making conclusions of results.

Activity 1.3: Give some examples in the process of scientific method of knowledge gain.

1.4. The Mission of Physics and Career Awareness

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

- ❖ Explain the job opportunities concerning to physics.

Why do we study physics?

- ➢ Have you ever wondered how big the universe is? How our sun and the stars that you see at night are created? How long have they been there? How small things can be. What is the smallest of all the smallest things? If you want the answer for these types of questions, you must study physics.
- ➢ If you want to understand in depth, the electricity we use, the mechanism how cars move, and the energy we use to cook our food, go study science/physics.
- ➢ For example, people and animals walk, children run around in the playground, cars and trucks move from place to place due to only one simple fact. Friction. To understand and appreciate you must study the physics of friction.
- ➢ The mission of physics is to advance science, engineering, and innovation through the world for the benefit of all and serving society.

What careers can we do with physics?

- ❖ The typical careers in physics are:
  - ➢ Physics careers in space and astronomy
  - ➢ Physics careers in health care
  - ➢ Physics careers in engineering
  - ➢ Physics careers in energy
  - ➢ Physics careers in technology
  - ➢ Physics careers in Geophysics and Metrology
  - ➢ Physics careers in research scientists

1.5. Current Status of Physics

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

- ❖ List at least five recent new developments or discoveries in the fields of physics.

1.5.1. Major recent discoveries in Physics

- ➢ Physics is the study of the physical world from the smallest particles to the gigantic structures known to humans; galaxies, clusters of galaxies, and black holes. Some of the recent discoveries are presented and discussed in the subsequent sections.

Discovery of Exoplanets: An exoplanet or extra solar planet is a planet outside our solar system.

- ➢ As of 1 October 2022, there are 5,197 confirmed exoplanets in 3,833 planetary systems.
- ➢ Michel Mayor and Didier Queloz won the Nobel Prize in Physics in 2019.

Black hole: Black hole is a region of space-time the gravity of it so strong that nothing can escape.

- Not even, light (electromagnetic wave). Roger Penrose, Reinhard Genze. And Andrea M. Ghez has won the Nobel Prize in 2020 for discovery of black hole formation and the discovery of a super massive compact object (Black hole) at the center of our Milky-way Galaxy.

Quantum entanglement: Alain Aspect, John Clauser and Anton Zeilinger have won the The Nobel Prize in Physics 2022 for quantum entanglement:

- The Nobel Prize in Physics is awarded by the Royal Swedish Academy of Sciences, Stockholm, Sweden. It is one of the five Nobel Prizes established by the 1895 will of Alfred Nobel (who died in 1896).
- Quantum entanglement is the phenomenon that if two sub-atomic particles are entangled at the start, they would be entangled forever.
- For example, if the two particles are prepared to have one of them positive property and the other negative property, they would forever linked in this state.
- If one wants to change one of them to positive, the other instantaneously changed to negative no matter how far they are apart. This is the strangest thing to think of if one considers Einstein's theory of relativity which states information cannot travel faster than the speed of light.
- The possible future applications include quantum information science such as quantum computing and quantum cryptography.

Quantum computing: Is a future application of quantum states as an alternative to transistors (we are using now) on and off states called bits.

- With quantum computing the solutions to problems we cannot do at the present, such as in molecular biology, chemistry, and physics would be solvable, it is hopped.

Quantum cryptography: Cryptography is a way of sending information and messages in secret. Think of your bank account number, password, etc. without secret encryption all these are at risk.

- Quantum cryptography is an application of quantum physics that enhances the security of the information exchange at a much higher level.

High energy physics (Particle Accelerators): July 4, 2012, EC, CERN scientists (thousands of them doing collaboratively from almost every corner of the world) discovered a particle called Higgs Boson.

- It is a subatomic particle like photons, protons, and electrons but at the very basic level.

Gravitational waves (Large scale structures): Even more, years have taken to prove Albert Einstein's theory of gravity, which says gravity is a wave that travels with the speed of light 3.00×10^8 m/s.

- The hypothesis was formulated in 1916, it was proved to be right in 2016 by LIGO, it took again thousands of scientists' collaborative work. The first direct observation of gravitational waves was made on 14 September 2015 and was announced by the LIGO and Virgo collaborations on 11 February 2016.
- The gravitational wave was generated due to the collision of two massive Black holes and recorded in two places in the USA by a detector called LIGO
- In the coming decades, gravitational waves could be used as detecting the evolution of the early universe as an additional instrument to radio telescopes and other ground-based telescopes.

Global warming: Global warming is an increase in the earth's temperature and its impact on the earth's climate.

- Climate is a long-term weather variability averaged over many years and decades. Some of the variables are temperature, humidity, atmospheric pressure, and wind.
- According to World Meteorological Organization (WMO), a typical variability average year is 30.
- Syukuro Manabe and Klaus Hasselmann have won the Nobel Prize in Physics in 2021 for modeling the earth's climate and reliability in predicting global warming. The following images from Wikipedia illustrate the effect of global warming.

James Webb Space Telescope (JWST): It is an infrared telescope located between the earth and the sun at a distance of 1,500,000 km beyond the Earth's orbit around the Sun.

- It is operating at the temperature of (-223℃) important for infrared detection of galaxies and other large-scale structures.
- It will tell us about assembly of galaxies, the birth of stars, and the atmospheres of exoplanets and objects in our solar system.

Future perspectives: Physics is still one of the most advanced areas of human knowledge.

- It is also becoming more competitive and very expensive to do research at the forefront.
- As important as physics is some data indicate that students are not that interested to study physics.
- There may be several reasons for this. The goal of these sections is to inform and excite you about what is going on in recent years in areas of science and technology globally and in our country.

- At the forefront -advanced level research-the investigation in physics is a collaboration of many scientists. That includes physicists, engineers, technologists, computer specialists etc. It is no longer the pursuit of individuals.
- Research at the forefront is very expensive (Billions of dollars), it is also needing a collaboration of scientists from many fields. It also involves many countries.
- Rich countries have huge laboratories of their own with many physicists involved. Ethiopia as a developing country must start doing physics at the highest level for its national security and sustainable growth. It is imperative we do that.
- As an example, the Ethiopian Science and Art Museum inaugurated by PM Abiy Ahmed on 4 October 2022 would stimulate and attract young students towards science. It is situated in Addis Ababa.

Activity 1.4

1. What is the importance of learning physics in your opinion?
2. What did you benefit from knowing physics at this level?
3. List at least ten technological benefits that physics has contributed for society.
4. List physics communities in Ethiopia and state their roles.
5. Which physics community founded first?
6. List the objective of Ethiopian Space Science Society (ESSS).
7. What is the benefit of establishing physics communities?
8. Is there a physics community in your high school? If the answer is yes, what is it helpful for?
9. What process skills should you use investigating a phenomenon?
10. What are the process skills you are using in your in investigating a phenomenon?
11. List and explain steps of scientific method.
12. By using steps of scientific method answer the question, why the sky is blue?
13. What are the career opportunities physics have?
14. What are physics careers in space and astronomy?
15. List application of physics in health care.
16. List the recent discoveries in physics.
17. At the forefront in physics research, there are many countries collaborating. Why is that?

Summary of unit

- Physics improves our quality of life by providing the basic understanding necessary for developing new instrumentation and techniques for medical applications, such as computer tomography, magnetic resonance imaging, positron emission tomography, ultrasonic imaging, and laser surgery.
- Transportation vehicles such as automobiles, airplanes and space shuttles could not be constructed without the help of physics experts.
- Physics is also useful for military purposes, informing the design of weapons.
- Many of the scientists responsible for inventing the atomic bomb were physicists, and today physicists are involved in the creation of nuclear weapons.
- Physics communities are an organized group of persons associated together for scientific purposes. This organization is established at the level of national, continent as well as worldwide based on their aims.
- Scientific method is an ordered series of steps to acquire knowledge based on experimental evidence.
- The mission of physics is to advance science, engineering, and innovation throughout the world for the benefit of all and serving Society.
- Physics have a lot of job opportunities in the fields of Astronomy, healthcare, engineering, energy, technology, meteorology, etc
- New discoveries of Exoplanets, Black hole, Quantum cryptography, High energy physics, Gravitational wave, Global warming, James Webb Space Telescope, etc have been seen in recent years.

Key terms: *Black hole, Exoplanet, Experimental knowledge, Non experimental knowledge, Physics communities, Priori, Posteriori, Quantum cryptography, Scientific method.*

Study time: the total study time for this unit is **10 hours**.

SELF TEST-1

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. What is the **mission** of physics?

A. To advance science and innovation throughout the world.

B. To minimize the scientific knowledge of science throughout the world.

C. To minimize the connectivity between science and innovation.

D. To expand non-experimental knowledge throughout the world.

2. The medical application of physics that uses strong magnetic fields and radio pulses in order to identifying disease or damaged tissues of patients is:

A. Computer Tomography Scanning (CTS) C. Laser Surgery

B. Magnetic Resonance Imaging (MRI) D. Ultrasonic Image

3. Which one of the following is source of **experimental (posteriori)** knowledge?

A. Sensory perceptions C. Memory

B. Introspection D. Testimony E. All

4. One of the following is **NOT** the objective of Ethiopian Physical Society (EPS):

A. To promote physics education and research in the country.

B. To popularize physics in order to make students develop interest in physics.

C. To promote active participation of Ethiopian physicist.

D. To minimize a means of scientific information.

5. The knowledge that we get through rational insight is:

A. Experimental knowledge (posteriori) C. non scientific knowledge

B. Non-experimental knowledge (priori) D. All

6. Application of quantum physics that enhances the security of the information exchange at much higher level is:

A. Quantum entanglement C. Quantum cryptography

B. Quantum computing D. Quantum teleportation

7. Which one of the following is **FALSE** about James Webb Space Telescope (JWST)?

A. It is an infrared telescope located between the earth and the sun.

B. It is operating at the temperature of $223℃$

C. It is operating at the temperature of $-223℃$

D. It will tell us about assembly of galaxies, the birth of stars and the atmospheres of exoplanets and objects in our solar system.

UNIT TWO

2. VECTORS

INTRODUCTION

Many physical quantities in nature have both magnitude (size) and direction. To describe the motion of an airplane for instance, we must state its speed and the direction of its motion. To describe a force, we use a number to tell how big the force is and indicate its direction of application.

- **After completing this unit you should be able to:**
  - Familiarize themselves with basic principles of vector operations.
  - Interpret physical phenomena using the concept of vector.
  - Develop skills of using the concept of vector in solving various problems.

2.1. Vectors and types of vectors

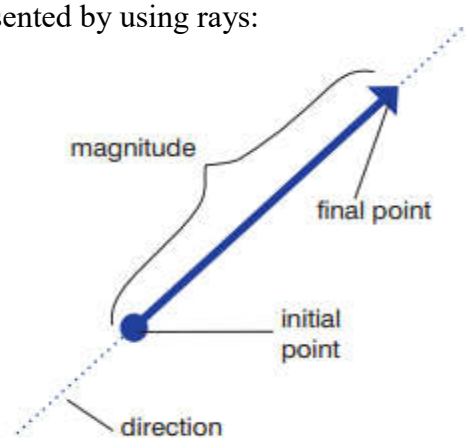
At the end of this section, you will be able to:

- Describe the difference between vector and scalar quantities.
- List down the common vector quantities in our everyday life.
- Discuss geometric representation of vectors.
- Give the definitions of the different types of vectors.

- Physical quantities that are specified or described both by using magnitude and directions are called vector quantities.
- Examples of vector quantities are: displacement, velocity, force, acceleration, momentum, torque, electric field, electric force, magnetic field, magnetic force, current density, impulse and etc.

Representation of vectors: vector quantities can be represented by using graphically and analytically.

- Graphically vectors represented by using rays:



- The length of the ray represents the magnitude and the arrow indicates the directions.

Types of vectors: there are several types of vectors, from that:

Parallel vectors: vectors that are in the same directions are called parallel vectors whereas vectors those are opposite in direction are called anti-parallel vectors.

(a) Parallel vectors

(b) Antiparallel vectors

Equal vectors: if two vectors representing the same quantity have the same magnitude and the same direction they are equal vectors.

(c) Equal vectors

(d) Negative of a vector $\vec{B}$

Collinear vectors: vectors that lies along the same lines or parallel lines.

- Two vectors are collinear if they are parallel to the same line irrespective of their magnitude and direction.

Co-planar vectors: three or more vectors lying in the same plane or parallel to the same plane are known as co-planar vectors.

Zero vector: is when the magnitude of vector is zero and the starting point of vector coincides with the terminal point.

Orthogonal vectors: vectors those are perpendicular to one another.

Unit vector: vector that has a magnitude of unit length.

Negative vector: vector that has the same magnitude as the original vector but in opposite direction.

Example: a) If, S = 60km, toward North, then –S =60km, toward South.

b) If, V = 100km/hr, toward 20^0 South of East, then –V= 100km/hr, toward 20^0 North of west.

Exercise 2.1

1. How do you represent a vector graphically?
2. Why do we use of scale diagram in vector drawing?
3. How does vector **A** differ from vector - **A**?
4. List types of vectors.
5. If, S = 60km, toward North, write this vector by using a unit vectors.
6. What is the magnitude of unit vector?
7. What is the difference between parallel and anti-parallel vectors?
8. Is that collinear vectors are parallel vectors?
9. Can we say coplanar vectors are perpendicular vectors?

2.2. Graphical method of addition of vectors in two dimensions (2-D)

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

- ❖ Define the term resultant vector.
- ❖ Explain the geometric method for addition and subtraction of vectors in a plane.
- ❖ Apply geometric method of addition of vectors to find resultant of vectors in two dimensions.

➢ There are two methods to determine the sum of two or more vectors: graphical and analytical methods.

➢ There three graphical method of vector additions:

Triangle law: the head of the first vector joined with the tail of the second vector and the sum of the two vectors is the vector that drawn from the tail of the first vector to the head of the second vector.

Example: by using triangle method, find the sum of, S_1 and S_2.

Solution:

Parallelogram gram law: the tail of the first vector joined with the tail of the second vector and in order to find the sum of the two vectors we must draw the parallel lines or equal vectors that are parallel to the two vectors and finally, the sum of the two vectors is the diagonal of the resulting parallelogram.

Example: by using parallelogram method, find the sum of, S_1 and S_2.

Solution:

Polygon Law: if we find the sum of above two vectors (many) we use polygon law. Polygon method uses head to tail principle.

Example: Add vectors **A, B, C** and **D** by using polygon method.

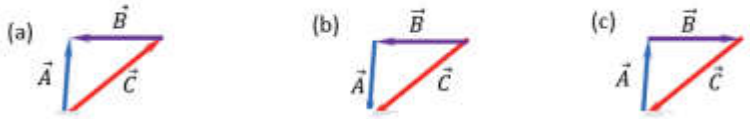
$$\vec{R} = \vec{A} + \vec{B} + \vec{C} + \vec{D}$$

Solution:

SELF TEST-2

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

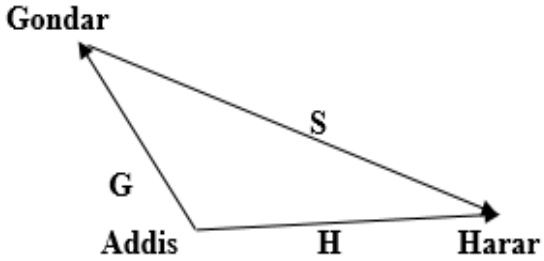
1. Which one of the following vector diagrams satisfies the vector equation: $\vec{C} = \vec{A} + \vec{B}$?



2. What is the minimum number of vectors of equal magnitudes required to produce a zero resultant?

A. 1 B. 4 C. 2 D. 6

3. A pilot of a tourist plane would like to know a real displacement from Gondar to Harar as shown. He can determine this displacement between the two tourist attraction sights by calculating:



A. **H + G**

B. **G + H**

C. **G − H**

D. **H − G**

2.3. Algebraic Method of addition of vectors in Two Dimensions (2-D)

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

- ❖ Apply algebraic method to find the resultant of two collinear vectors, and perpendicular vectors.
- ❖ Apply trigonometry to determine the direction of a resultant vector in terms of the angle it forms with a reference direction.
- ❖ Compare the resultant of two given vectors as determined by way of geometric construction and by analytic method.
- ❖ Resolve a vector into its components.
- ❖ Find the resultant of two or more vectors applying component method.
- ❖ Define unit vector and determine a unit vector in the direction of a given vector.
- ❖ Apply the unit representation of vectors to determine the resultant of two or more vectors.

Resultant of parallel vectors: We can find the resultant of vectors analytically by considering both the magnitude and direction of a given vectors.

Example: find the resultant vectors of the following parallel vectors.

a) 2km North, 5km South, b)100N to the left, 75N to the right, c)20m/s West, 50m/s East

Solution:

a) $\vec{S} = (5\text{km} - 2\text{km})\text{South} = 3\text{km south or } -3\text{km North}$

b) $\vec{F} = (100\text{N} - 75\text{N})\text{Left} = 25\text{N Left or} - 25\text{N Left}$

c) $\vec{v} = (50\text{m/s} - 20\text{m/s})\text{East} = 30\text{m/s East or } -30\text{m/s west}$

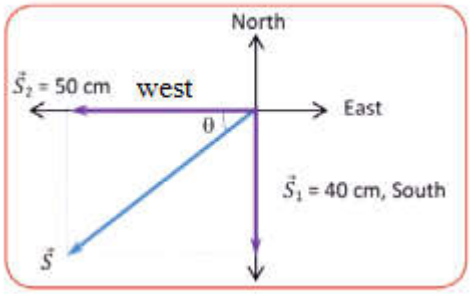
Exercise 2.2

1. The magnitudes of two vectors **A** and **B** are 13 units and 9 units, respectively. What are the largest and smallest possible values for the magnitude of the resultant vector R=A+B?
2. A man rows his boat along the direction of flow of a river (downstream). If the boat can sail in still water at 0.50 m/s, and the river flows at 0.30 m/s, what is the resultant velocity of the boat?

Resultant of perpendicular vectors: for perpendicular vectors the magnitude of resultant can be determined by using Pythagoras theorem.

Example: An ant, starting at a point, walked through a distance of 40 cm due South and then 50 cm due West. What is the resultant displacement of the ant from its starting point?

Solution: Placing the tail of the vectors at the origin of coordinates, the vector diagram of the motion is shown below.



By using Pythagoras theorem, the magnitude of the resultant displacement is:

$$S = \sqrt{S_1^2 + S_1^2} = \sqrt{(40\text{cm})^2 + (50\text{cm})^2} = \sqrt{4100\text{cm}^2} = 64\text{cm}$$

Direction of the resultant displacement is shown by the angle θ, where:

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{40\text{cm}}{30\text{cm}} = 0.8$$

$$\theta = \tan^{-1}(0.8) = 38.6^0$$

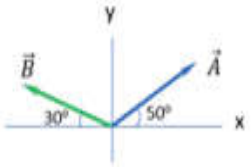
Therefore, the resultant is $64\text{cm}, 38.6^0$ south of west.

Resultant of non-parallel and non-perpendicular (component) vectors: if two vectors are non parallel and non-perpendicular, the resultant vector is determined by using resolving method.

Component of a vector: the projection of a vector on the coordinate axes.

Resolving: splitting vectors into horizontal and vertical components.

Example: Consider two displacement vectors A and B of magnitudes 100m and 200m respectively, as shown below. Find the magnitude and direction of the resultant displacement vector.



Solution: we first resolve the vectors into their x and y components.

$$A_x = A\cos 50^0 = 100 \times 0.643\text{m} = 64.3\text{m}$$

$$A_y = A\sin 50^0 = 100 \times 0.766\text{m} = 76.6\text{m}$$

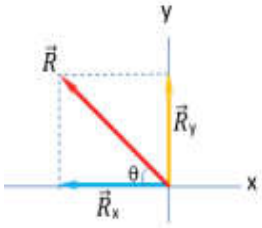
$$B_x = -B\cos 30^0 = -200 \times 0.866\text{m} = -173.2\text{m}$$

$$B_y = B\sin 30^0 = 200 \times 0.50\text{m} = 100\text{m}$$

The vector components of the resultant are:

$$\vec{R}_x = \vec{A}_x + \vec{B}_x = -108.9\text{m}$$

$$\vec{R}_y = \vec{A}_y + \vec{B}_y = 176.6\text{m}$$



The magnitude of resultant is:

$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{(-108.9\text{m})^2 + (176.6\text{m})^2} = 207.5\text{m}$$

$$\theta = \tan^{-1}(1.62) = 58.3^0$$

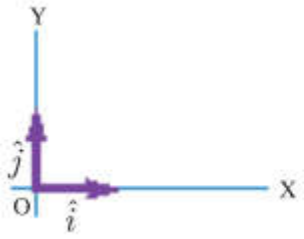
Therefore, $\vec{R} = 207.5\text{m}, \theta = 58.3^0$ above the negative x axis.

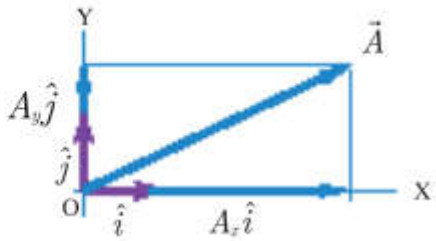
Exercise 2.3

1. A girl walked across a large field through the following distance in the given order: 72m toward 32^0 East of North, 57m toward 37^0 South of West, 18m toward South. Find the magnitude and direction of the resultant displacement of the girl?
2. A car travels 20km due north and then 25km in a direction 60° West of North. Use both graphical and algebraic methods to find the magnitude and direction of a single vector that gives the net effect of the car's trip.

Unit vector: is a vector that has a magnitude of one, but no unit that used to represent the directions of vectors in space.

- The symbol of unit vector is denoted by hat (^) to distinguish it from ordinary vectors.
- In xy- coordinate system we define a unit vector $\hat{\imath}$ that points in the direction of the positive x- axis and a unit vector hat j that points in the direction of the positive y-axis.





- Vector components of vector A is given by:

$$\vec{A}_x = A_x\hat{\imath}$$

$$\vec{A}_y = A_y\hat{\jmath}$$

- Then vector A can be written in vector equation as:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$$

- Using unit vector the resultant of vector A and vector B is given by:

$$\vec{R} = \vec{A} + \vec{B}$$

$$= A_x\hat{\imath} + A_y\hat{\jmath} + B_x\hat{\imath} + B_y\hat{\jmath}$$

$$= (A_x + B_x)\hat{\imath} + (A_y + B_y)\hat{\jmath}$$

- A unit vector along the direction of a non-zero vector is defined as the vector divided by its magnitude.
- If vector A is given by:

$$\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$$

Then a unit vector along the direction of vector A is given by:

$$\vec{U} = \frac{\vec{A}}{A}$$

Example: Given force vector, $\vec{F} = (12i - 16j)$, what is a unit vector along $\vec{F}$?

Solution:

$$\vec{U} = \frac{\vec{F}}{F} = \frac{(12\hat{\imath} - 16\hat{\jmath})}{20} = (0.6\hat{\imath} - 0.8\hat{\jmath})$$

You see that, the magnitude of $\vec{U}$ is 1.

Exercise 2.4

Find a unit vector of the following vectors and its magnitude.

(a) $\vec{A} = 2i + 5j$, along vector $\vec{A}$

(b) $\vec{B} = 3i + 4j$, along vector $\vec{B}$

(c) $\vec{C} = 12i + 5j$, along vector $\vec{C}$

(d) $\vec{D} = 8i + 6j$, along vector $\vec{D}$

SELF TEST-3

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. Vector **A** has x and y components of 4 units and 2 units, respectively and vector **B** has the corresponding components of -9 units and 3 units respectively. Find:

(a) The vector components of their resultant.

(b) The magnitude and direction of their resultant.

2. An unknown vector **D** is added to vector $\vec{C} = (-4i + 5j)$ units and the resultant vector $\vec{R} = \vec{C} + \vec{D}$ has x and y components of each -1 and 1 units, respectively. Find the magnitude of the unknown vector.

3. The vector sum $\vec{P} + \vec{Q}$ is a unit vector along the positive x axis. If $\vec{P} = \hat{i} - \hat{j}$ find $\vec{Q}$

4. If vector, $0.4\hat{i} + b\hat{j}$ is a unit vector, then what is the value of b?

5. Two vectors give a resultant of magnitude 8 units when are parallel and 2 units when they are antiparallel. Determine the possible values of each of the vectors.

6. State the condition where the vector sum of two vectors is a null vector.

7. Suppose you are in a large hall and that you mark a point on the floor and start walking the following distances in the given order: 50 m [forward], 10 m [backward], 10 m [forward], 10 m [backward], 20 m [forward], 10 m [backward], 40 m [forward], and 10 m [backward].

A. What is the total distance you traveled?

B. What is the magnitude and direction of your displacement from the starting point?

8. What vector must be added to vector **C** of 10km, east in order to give a resultant vector of

A. 15 km, east? B. 15 km, West?

9. A sailor boards a paddle boat and heads the boat Westward directly across a river. The river flows South at 50 cm/s and the woman paddles the boat with a speed of 100 cm/s.

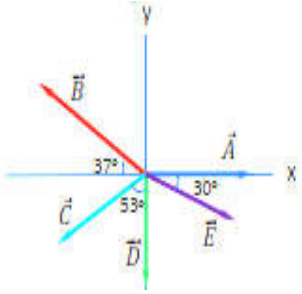
A. Determine the resultant velocity of the boat – both magnitude and direction.

B. How far down stream relative to the straight-across direction will woman be when she reaches the opposite shore?

10. Given three displacement vectors **B, C**, and **D** such that $\vec{B} = (-i + 2j)m$, $\vec{C} = (3i - 2j)m$ and $\vec{D}$ of unknown components, determine the magnitude and direction of $\vec{D}$ for $3\vec{B} - \vec{C} + \vec{D} = 0$

11. Given displacement vectors of $\vec{S}_1$ and $\vec{S}_2$ as $\vec{S}_1 = (3i + 6j)m$ and $\vec{S}_2 = (-2i - 4j)m$ find a unit vector along the direction of $\vec{S}_1 + \vec{S}_2$

12. Five displacement vectors **A, B, C, D** and **E** are placed on the coordinate axes as shown below. Fill the following Table with the correct values of the components of the vectors. (Hint: A vector on either of the coordinate axis has only one component).



	x component	y component
$\vec{A}$		
$\vec{B}$		
$\vec{C}$		
$\vec{D}$		
$\vec{E}$		

2.4. Product of Vectors

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

- ❖ Define dot product of a vector apply the technique of dot product to solve practical problems.

Multiplying or dividing a vector by a number or scalar: multiplying a vector by a number gives a vector.

- ➢ When we multiply a vector $\vec{A}$ by scalar c, the result $c\vec{A}$ has a magnitude equal to $|c|\vec{A}$. If c is positive $\vec{A}$ and $c\vec{A}$ are in the same direction and the magnitude of $c\vec{A}$ is greater than $\vec{A}$. If c is negative, $\vec{A}$ and $c\vec{A}$ are in opposite direction and the magnitude of $c\vec{A}$ is greater than $\vec{A}$.

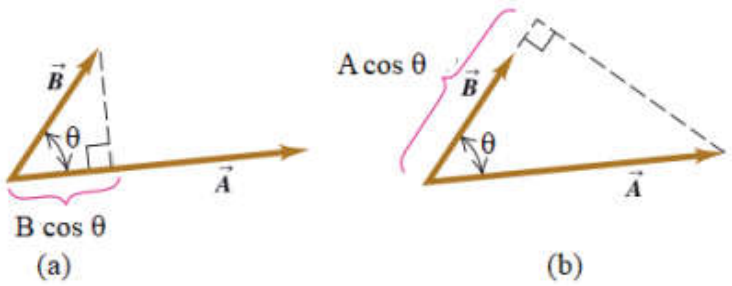
Example: when vector $\vec{A}$ is multiplied by 2 and -2, we have:

- ➢ There are two types of products: scalar and vector products.

<u>Scalar (dot) product:</u> is when the product of two vectors is results scalar.

- ➢ If two vectors, $\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$ and $\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath}$ then the scalar or dot product of the two vectors is given by:

$$\vec{A}\,.\,\vec{B} = |A||B|\cos\theta = A_xB_x + A_yB_y$$



Where, θ is the angle between vectors $\vec{A}$ and $\vec{B}$ and since $\hat{\imath}$ and $\hat{\jmath}$ are orthogonal vectors, their dot product is zero. The dot product of a unit vector itself is one.

Example: find the scalar or dot product of vectors, $\vec{A} = 4\hat{\imath} - 2\hat{\jmath}$ and $\vec{B} = \hat{\imath} + 3\hat{\jmath}$

solution: $A_x = 4,$ $B_x = 1$

$$A_y = -2, \qquad B_y = 3$$

$$\vec{A} \cdot \vec{B} = A_x B_x + A_y B_y = (4 \times 1) + (-2 \times 3) = 4 - 6 = -2$$

Exercise 2.5

1. Displacement vector given as $\vec{S}$ =35km, towards 60^0 North of east. Find the magnitude and direction of:

a) $1.2\vec{S}$

b) $-1.2\vec{S}$

2. Find the angle between each of the pairs of the following vectors:

a) $3\hat{i} - \hat{j}$ and $\hat{i} - 2\hat{j}$

b) $3\hat{i} - 2\hat{j}$ and $\hat{i} - 2\hat{j}$

c) $3\hat{i} - 2\hat{j}$ and $4\hat{i} + 6\hat{j}$

3. What is the result of scalar or dot product of two vectors?

A. Scalar B. Vector

4. Consider a block placed on a horizontal surface and that force $\vec{F}$ is applied on the block to move the block through displacement $\vec{S}$. Find the work done by the force, If $\vec{F} = (5\hat{i} + 3\hat{j})\text{N}$ and $\vec{S} = (-2\hat{i} + 4\hat{j})\text{N}$?

5. Consider force $\vec{F}$ of a certain machine is applied on a body to move the body with an average velocity $\vec{v}$. if $\vec{F} = (50\hat{i} + 30\hat{j})\text{N}$ and $\vec{v} = (3\hat{i} + 4\hat{j})\text{m/s}$, then find the power developed by the machine.

6. What is the dot product of vector $\vec{A}$ with itself?

7. Show that the dot product of two vectors obeys:

a) Commutative property, $\vec{A} \cdot \vec{B} = \vec{B} \cdot \vec{A}$

b) Distributive property, $\vec{A} \cdot (\vec{B} + \vec{C}) = \vec{A} \cdot \vec{B} + \vec{A} \cdot \vec{C}$

8. For what values of the angle between $\vec{A}$ and $\vec{B}$ will the dot product $\vec{A} \cdot \vec{B}$, be positive, negative or zero?

9. If $\vec{D} = (5\hat{i} - 3\hat{j})$ and $\vec{E} = 2\hat{i} + \text{j}$, what is the angle between $\vec{D} + \vec{E}$ and the x axis?

10. If $\vec{P} \cdot \vec{Q} = \text{PQ}$, what is the angle between $\vec{P}$ and $\vec{Q}$?

11. What is the dot product of two orthogonal vectors?

12. If $\text{A} \cdot \vec{B} = \frac{\sqrt{3}}{2}\text{AB}$, what is the angle between $\vec{A}$ and $\vec{B}$?

13. Write the orthogonality condition of two vectors.

14. What is the dot product of two parallel vectors?

Summary of unit

- When a physical quantity is described by a single number, we call it a scalar quantity. In contrast, a quantity described by both a magnitude (the "how much" or "how big" part) and direction in space is a vector.
- Depending on their direction, magnitude and orientation we can categorize vectors as collinear, coplanar, parallel, antiparallel, equal, null, unit vector etc.
- Graphical method of vector addition makes use of translation of vectors.
- Triangle law – Vectors are connected head to tail to form a triangle.
- Parallelogram law – vectors are connected tail to tail and a parallelogram is constructed using the vectors as its sides.
- Polygon law - used to determine the resultant of more than two vectors. The vectors are joined head to tail without regard to the order they are taken. The vector drawn from the tail of the first vector to the head of the final vector represents the resultant.
- Analytic methods of vector addition/subtraction allow us to find resultant of sums or differences of vectors without having to draw them. They are exact, contrary to graphical methods which are approximate.
- The resultant of two vectors in the same direction has a magnitude equal to the sum of the magnitude of each of the vectors and it is directed along the direction of any one of the vectors.
- The resultant of two vectors at right angles has a magnitude equal to the square root of the sum of the squares of the magnitude of each of the vectors and the direction of the resultant is determined by the angle it makes with respect to a reference line (commonly the x axis).
- Using unit vector the sum of vector $\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$ and vector $\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath}$ is given by:

$$\vec{R} = \vec{A} + \vec{B} = (A_x + B_x)\hat{\imath} + (A_y + B_y)\hat{\jmath}$$

- If two vectors, $\vec{A} = A_x\hat{\imath} + A_y\hat{\jmath}$ and $\vec{B} = B_x\hat{\imath} + B_y\hat{\jmath}$ then the scalar or dot product of the two vectors is defined as,

$$\vec{A}.\vec{B} = |A||B|\cos\theta = A_xB_x + A_yB_y$$

- The scalar product of two vectors can be used to determine the angle between the vectors and it can also be used to determine the component of one of the vectors in the direction of the other.
- The angle between two vectors is given by:

$$\theta = \tan^{-1}\left(\frac{\vec{A}.\vec{B}}{|A||B|}\right)$$

- For orthogonal vectors, $\theta = 90^0$, and $\vec{A}.\vec{B} = 0$

Key words: *component of vectors, dot product, parallelogram method of vector addition, polygon method of vector addition, resolution of vectors, triangle rule of vector addition, unit vector, vector addition*,

Study time: total study time for this unit is **13 hours**.

SELF TEST-4

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. When two vectors are in the same direction, their sum has:

A. Minimum possible magnitude C. Zero magnitude

B. Maximum possible magnitude D. Undetermined

2. One of the following is NOT vector quantity?

A. magnetic force B. Momentum C. Torque D. Electric potential

3. Suppose $\vec{A} = 3i - 2j$ and $\vec{B} = -i - aj$ are two vectors in xy-plane. What is the value of a such that, $\vec{A} + \vec{B} = 2i$?

A. 3 B. 2 C. -2 D. -3

4. If the scalar(dot) product of two vectors is zero, then the two vectors are:

A. Orthogonal B. Parallel C. Anti-parallel D. Zero

5. Vector **A** and **B** are perpendicular. Their resultant is 50N, if the value of **B**=40N, then what is the value of **A**?

A. 900N B. 30N C. 70N D. 40N

6. What is the **leas**t number of unequal vectors required to produce a **zero** resultant?

A. 3 B. 5 C. 2 D. 4

7. Given vector $\vec{P} = 4i + 2j + 6k$, if vector $\vec{Q}$ is subtracted from it the result is a unit vector along x-axis. Then what is vector $\vec{Q}$?

A. $5i + 2j + 6k$ C. $3i - j + 6k$

B. $3i + 2j + 6k$ D. $3i + j + 6k$

8. One of the following is not graphical (geometrical) method of vector addition and subtraction

A. Triangle law C. Polygon law

B. Parallelogram law D. Analytical(algebraic law)

9. Vector A is 2cm long and is 60^0 above the x-axis in the first quadrant. Vector B is 2cm long 60^0 below the x-axis in the fourth quadrant. Then, $A - B$ is a vector of magnitude:

A. 2 along +y-axis C. 2 along +x-axis

B. $2\sqrt{3}$ along –y-axis D. $2\sqrt{3}$ along y-axis

10. If the relation of two vectors are given by $\vec{A}+\vec{B}=2i+5j$ and $\vec{A}-\vec{B}=4i+3j$, what is the magnitude of $\vec{A}$?

A. 4 B. 6 C. 5 D. 9

11. Suppose $\vec{C}=xi+yj+k$, which is orthogonal to both vectors $\vec{A}=i+j-k$ and $\vec{B}=-i+j+2k$ then what is vector $\vec{C}$ in components?

A. $\frac{3}{2}i-\frac{1}{3}j-k$ C. $\frac{1}{2}i-\frac{3}{2}j+k$

B. $\frac{3}{2}i-\frac{1}{2}j+k$ D. $-\frac{1}{2}i+\frac{3}{2}j-k$

12. The resultant of P+Q=13unit, if P=5unit and Q=12unit, what is the angle between A and B?

A. 90^0 B. 180^0 C. 60^0 D. 0^0

13. If, $\vec{A}.\vec{B}=\frac{\sqrt{3}}{2}AB$, then what is the angle between vectors **A** and **B**?

A. 0° B. 60° C. 30° D. 90°

14. Which pairs of vectors are **orthogonal**?

A. $\begin{pmatrix}2\\4\\6\end{pmatrix}$ and $\begin{pmatrix}4\\-5\\1\end{pmatrix}$ C. $\begin{pmatrix}-6\\4\\2\end{pmatrix}$ and $\begin{pmatrix}1\\3\\5\end{pmatrix}$

B. $\begin{pmatrix}3\\5\\1\end{pmatrix}$ and $\begin{pmatrix}6\\-4\\2\end{pmatrix}$ D. $\begin{pmatrix}1\\-3\\4\end{pmatrix}$ and $\begin{pmatrix}6\\5\\2\end{pmatrix}$

15. What is the work done, if a force of $(6,-2)$N displaced a particle to a position of $(3,1)$m?

A. 16J B. 18J C. 20J D. 12J

16. If vectors $\vec{A}$, $\vec{B}$ and $\vec{C}$ are non-zero vectors, then which one of the following is **TRUE**?

A. $\vec{A}.\vec{B}=0$, for $\vec{A}\,//\,\vec{B}$ C. $\vec{A}.\vec{B}=-\vec{B}.\vec{A}$

B. $\vec{A}.(\vec{B}+\vec{C})=\vec{A}.\vec{B}-\vec{A}.\vec{C}$ D. $\vec{A}.(\vec{B}+\vec{C})=\vec{A}.\vec{B}+\vec{A}.\vec{C}$

17. Two forces of 50N and 80N act upon a body. What are the maximum and minimum possible values of a resultant respectively?

A. 30N and 40N C. 130N and 30N

B. 30N and 130N D. 40N and 130N

18. If two vectors, $\vec{A}=3i-4j$ and $\vec{B}=-4i+6j$ and vector $\vec{C}$ lies in the xy-plane which is perpendicular to $\vec{A}$. If the dot product of $\vec{C}$ and $\vec{B}$ is 8. Then what is vector, $\vec{C}$?

A. $12i+16j$ C. $16i-12j$

B. $16i+12j$ D. $12i-16j$

19. The magnitude of two vectors $\vec{C}$ and $\vec{D}$ are 12 units and 5 units respectively. Which one of the following is not the possible value for the magnitude of the resultant vector of **C** and **D**?

A. 60 units B. 17 units C. 13 units D. 7 units

20. Two non-zero vectors $\vec{R}$ and $\vec{S}$ are related by $\vec{R} = c\vec{S}$ where c is a scalar. If the two vectors have opposite directions, then one of the following is true about c?

A. c is positive number
C. c is a negative number
B. $c = 1$
D. $c = 0$

21. What is the angle between vectors $\vec{P} = (mi + m\sqrt{3}\,j)$ units and $\vec{Q} = (m\sqrt{3}\,i + mj)$ units?

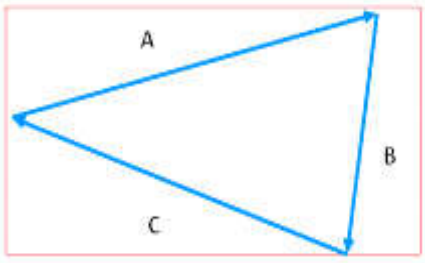
A. 90° B. 60° C. 37° D. 30°

22. Vector **A** has magnitude of 6 units along the positive x-axis. Vector **B** has magnitude of 4 units and lies in xy-plane by making an angle of 30° with the positive x-axis. Then what is the scalar product of **A** and **B**?

A. $6\sqrt{3}$ B. $12\sqrt{3}$ C. $2\sqrt{3}$ D. $8\sqrt{3}$

23. Which one of the following is not true about the three vectors?

A. -A = B + C
B. B = -C – A
C. C = -A – B
D. A + B – C = 0



24. Given $\vec{A} = 3i + 2j + k$ and $\vec{B} = 6i + 4j + 2k$ then which one of the following is **true**?

A. Both vectors are parallel
C. The angle between the two vectors is 30°
B. Both vectors are perpendicular
D. The angle between the two vectors is 60°

25. Suppose, $\vec{P} = (3, -2)$, $\vec{Q} = (-1, -4)$ and $\vec{R}$ is vector in the xy-plane with the property $\vec{P} + \vec{Q} - \vec{R} = 0$, then which of the following is a unit vector along $\vec{R}$?

A. $2i - 6j$
C. $\sqrt{\frac{1}{10}}\,i - \frac{6}{\sqrt{10}}j$
B. $-2i + 6j$
D. $\sqrt{\frac{1}{10}}\,i - \frac{3}{\sqrt{10}}j$

26. Which method of graphical addition of vectors uses **tail to tail** techniques in order to find the resultant of the two vectors?

A. Triangle method
C. Polygon method
B. Parallelogram method
D. All

UNIT THREE

3. MOTION IN ONE AND TWO DIMENSIONS

INTRODUCTION

Motion is one of the significant topics in physics. Everything in the universe moves. If you give a glimpse to your environment, you might see several things in motion: a car on a road, children playing on a playground, an airplane flying in the sky, even an ant crawling on the ground. An object is said to be in motion if its position changes with time. The concept of motion is relative. A body that may be in motion relative to one reference system may be at rest relative to another. For example, if you are sitting in the classroom, you are at rest with respect to the earth; but actually, you are in motion with respect to the sun.

- **After completing this unit, you should be able to:**
  - Gain an understanding of the fundamental principles of kinematics in one and two dimensions.
  - Develop skills in applying equations of motions to solve practical problems.
  - Recognize the effect of air resistance and force of gravity on motion of a body.
  - Describe technological advances related to motion; and identify the effects of societal influences on transportation and safety issues.

3.1. Uniformly accelerated motion in -1D

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

- Explain a uniformly accelerated motion in 1D.
- Explain the difference between average velocity and instantaneous velocity.
- Solve problems involving average velocity, instantaneous velocity and acceleration.

Acceleration: an object is said to be accelerate when its velocity changes in magnitude, in direction or both in magnitude and direction.

- Acceleration is a vector quantity, and defined as the rate of change of velocity or change in velocity per unit time.
- The SI unit of acceleration is,m/s^2.
- Negative acceleration may or may not be deceleration, and deceleration may or may not be considered negative acceleration.
- If the velocity and acceleration have the same sign wether positive or negative it is speeding up.
- If the velocity and acceleration have the same signs, then the object is slowing down.

Average acceleration: is defined as the rate of change of velocity.

$$\vec{a}_{ave} = \frac{\Delta v}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

Example: If the speed of a certain car is increased from rest to 20m/s in 6 seconds, what is the average acceleration of the car?

Solution:

$$\vec{a}_{ave} = \frac{\Delta v}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} = \frac{20m/s}{6sec} = 3.67m/s^2$$

Instantaneous acceleration: is acceleration at specific instant in time, and given by:

$$\vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \frac{dv}{dt}$$

Example: the velocity of a particle moves along straight line varies as a function of time with a velocity equation as: $v(t) = t^2 - 2t$, find the acceleration of the particle at, t = 2s

Solution:

$$\vec{a}(t) = \frac{dv}{dt} = \frac{d}{dt}(t^2 - 2t)$$

$$= \frac{d}{dt}t^2 - \frac{d}{dt}2t = 2t - 2$$

$$a(t = 2) = 2m/s^2$$

Exercise 3.1

1. Define the terms average and instantaneous acceleration.
2. State the conditions in which an object is said to speed up and slow down.
3. What is the relationship between acceleration and deceleration?
4. A car driver accelerates her car by, 1.4m/s^2 starting from rest.
   (a) How long does it take her to reach a speed of 2.0 m/s?
   (b) If she then brakes to a stop in 0.8 seconds, what is her deceleration?
5. A particle is in motion and is accelerating. The velocity of the motion as a function of time is given by: $\vec{v}(t) = 20t - 5t^2 m/s$ Find:
   (a) The functional form of the acceleration,
   (b) The instantaneous velocity at t = 3s,
   (c) The instantaneous acceleration at t = 3 s.
6. If X and Y coordinates of a particle at any time t is given by $x(t) = t^5$ and $y(t) = 5t^2$ what is the magnitude of the acceleration of the particle at, $t = 1sec$?
7. If the motion of a particle is described by the equation $\vec{S}(t) = 2t^2 - 12t - 5$, at what time does the particle become to rest?

3.2. Equations of Uniformly Accelerated Motion in 1D

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

- ❖ Derive and apply the equations of uniformly accelerated motion in 1D.
- ❖ Solve various problems of uniformly accelerated motion in 1D.

Uniformly accelerated motion: is a motion in which acceleration is constant.

- ➢ Any problems related to uniformly accelerated motions can be solved by using equations of uniformly accelerated motion, which are listed below.

Equations of uniformly accelerated motion
$v = u + at$
$S = \left(\frac{v+u}{2}\right)t$
$S = ut + \frac{1}{2}at^2$
$v^2 = u^2 + 2aS$
$S = vt - \frac{1}{2}at^2$

SELF TEST-5

1. A car accelerates uniformly from rest to a speed of 72 km/h in 8.0 s.
   (a) Find the acceleration of the car.
   (b) Find the distance the car travels.
   (c) If the car brakes to a stop over a distance of 50 m, then find its uniform deceleration.
2. Ethiopian Airlines Boeing airplane lands on one of the Bole international airport runways with an initial velocity of 40.0 m/s and then decelerates at 1.50 m/s^2.
   (a) What length of runway will it need?
   (b) For how long will it move on the runway?
3. Derive the five kinematic equations.
4. It is found experimentally that, if a street surface is dry, a good driver can safely decelerate an automobile with reasonably good tires at the rate of about 4.57 m/s^2. So, for a car moving at 60 km/h what should be the minimum distance between two cars so that they won't crash during a sudden stop?
5. A driver of a vehicle traveling at a speed of 30 m/s on a motorway brake sharply to a standstill in a distance of 100m. Calculate the deceleration of the vehicle.
6. The distance covered in n seconds and the distance covered in the nth second are different questions. Derive the equation for the distance covered in the n^{th} second.

7. A motorist travelling at 18 m/s approaches traffic lights. When he is 30 m from the stop line, they turn red. It takes 0.7 s before he can react by applying the brakes. The car slows down at a rate of 4.6 m/s^2. How far from the stop line will he come to rest and on which side of it?
8. The driver of a train travelling at 40 m/s applies the brakes as the train enters a station. The train slows down at a rate of 2m/s. The platform is 400 m long. Will the train stop in time?

Reaction distance, Braking distance and Stopping distance

Distances	Definitions	Formula
Reaction distance	Distance from a point of detecting hazard until you begin braking or swerving	$S_r = vt$
Braking distance		$S_b = \frac{v^2}{2\mu g}$
Stopping distance	When brakes applied to a moving vehicle the distance it travel before stopping	$S = S_r + S_b$

3.3. Graphical Representation of Uniformly accelerated Motion in 1-D

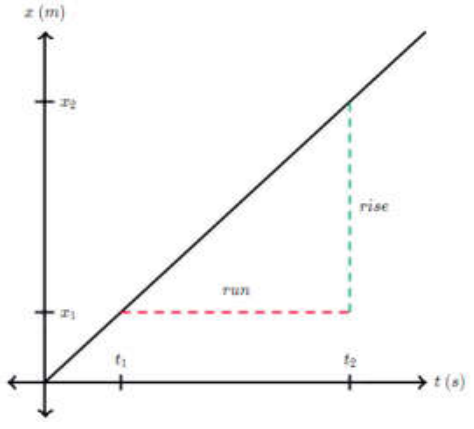
At the end of this section, you will be able to:

- Graphically, represent position versus time graph, displacement time graph.
- Velocity time graph and acceleration time graph of a uniformly accelerated motion in 1D.
- Interpret a graph of velocity vs. time, displacement vs. time and acceleration vs. time.
- Draw graphs from the kinematic equations.
- Determine the velocity of a motion from the slope of displacement-time graph, and acceleration from the slope of velocity – time graph.
- Determine the displacement covered from the area under velocity – time graph.

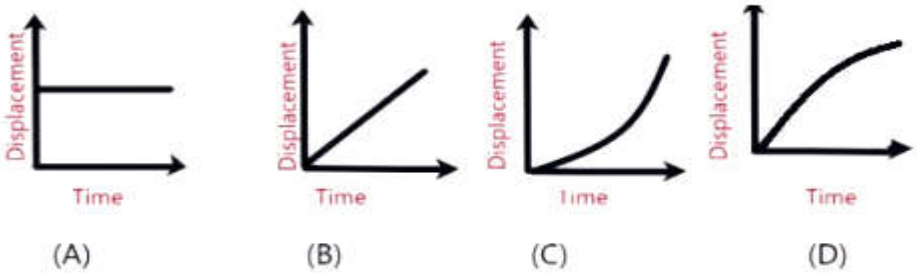
Motion graphs: the graph that shows the motion of an object or particles.

Displacement- time graph: from this graph we get velocity, which is the slope of displacement-time graph.

$$\text{Slope} = \frac{\text{rise}}{\text{run}} = \frac{\Delta x}{\Delta t} = \text{velocity}$$



- Some common displacement- time graph are:

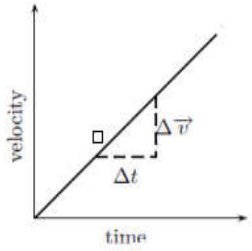


- Graph (A), shows constant displacement mean that velocity is zero.
- Graph (B), shows displacement is increasing constantly within time mean that velocity is constant. Therefore it represents uniform motion.
- Graph (C), shows uniformly accelerated motion.
- Graph (D), shows that uniformly decelerated motion.

Velocity-time graph: from this graph we get acceleration, which is the slope of velocity-time graph.

- The total area covered under velocity-time graph is displacement.

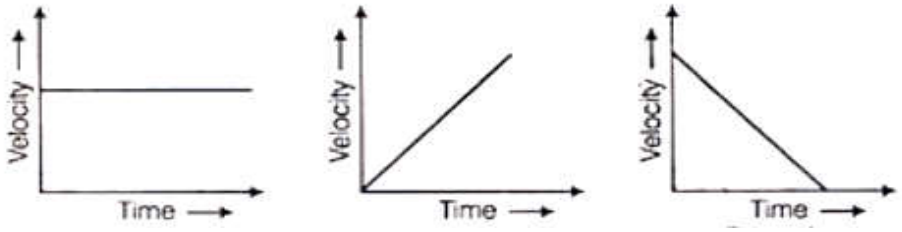
$$\text{Slope} = \frac{\text{vertical increase}}{\text{horizontal increase}} = \frac{\Delta v}{\Delta t} = \text{acceleration}$$



Exercise 3.2

Draw the displacement-time graph of a ball thrown directly upwards and caught when it returns.

- Some common velocity-time graph are:



Constant velocity

uniformly accelerated motion with increasing velocity

uniformly accelerated motion with decreasing velocity

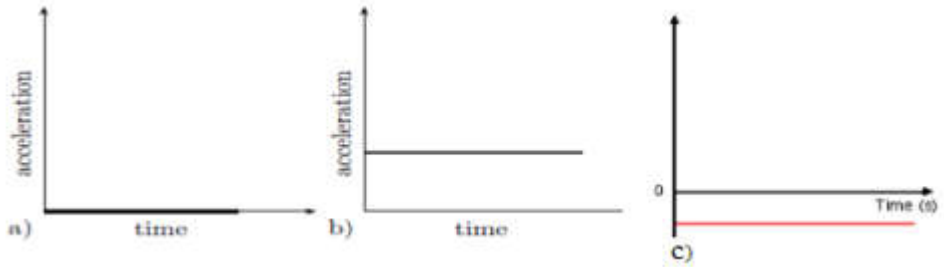
Exercise 3.3

1. Draw the velocity-time graph of a ball thrown directly upwards and caught when it returns
2. Draw velocity-time graph of the following chart.

Velocity (m/s)	0	2	4	6
Time (s)	0	4	6	8

Acceleration-time graph: shows how acceleration changes with time.

- Some acceleration-time graph are:



Uniform motion | uniformly accelerated motion | uniformly decelerated motion

Exercise 3.4

A car starts from rest and accelerates at a rate of 2.0 m/s^2 for 5seconds, then maintains its speed for 4 seconds. It then applied the brakes and stopped within 2 seconds. then it moves at a constant speed of 15m/s in the opposite direction until it reaches the starting point. Determine the position of the car for each interval of time.

a) Draw the displacement versus time, velocity versus time and acceleration

b) Velocity versus time graph of the motion of the car.

C) From the velocity time graph, show that the displacement is zero.

3.4. Vertical Motion

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

- Describe what vertical motion is.
- Solve various problems of vertical motion
- Describe the motion of objects that are in free fall.
- calculate the time, position and velocity of an object given the initial velocity of an object under vertical motion
- Solve problems related to an object thrown vertically upwards, downwards, and freely falling bodies.

Freely falling bodies: when an object thrown upward, downward and dropped from a height, we call it free fall.

- In the absence of air resistance, acceleration of freely falling body is constant and called acceleration due to gravity.
- Free fall is the best example of uniformly accelerated motion.
- Therefore, in order to solve problems related to free fall, we use the five equation of uniformly accelerated motion.

Upward	Downward	Dropped
$v = u - gt$	$v = u + gt$	$v = gt$
$y = ut - \frac{1}{2}gt^2$	$y = ut + \frac{1}{2}gt^2$	$y = \frac{1}{2}gt^2$
$v^2 = u^2 - 2gh$	$v^2 = u^2 + 2gh$	$v^2 = 2gh$

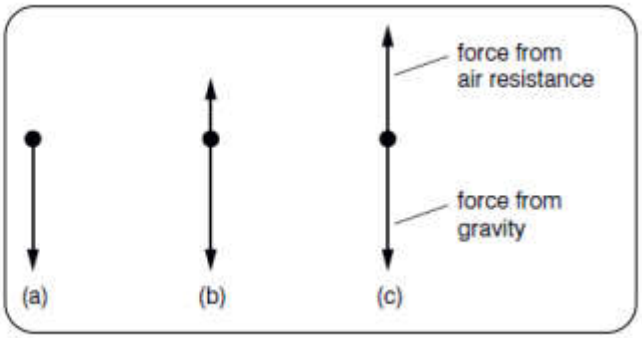
Exercise 3.5

A ball is thrown vertically upwards with a velocity of 10 m/s from the balcony of a tall building. The balcony is 15m above the ground and gravitational acceleration is 10 m/s^2. Find:

(a) The time required for the ball to hit the ground

(b) The velocity with which it hits the ground.

Terminal velocity: is the maximum velocity of a freely falling body where its velocity no more increases or the acceleration of the motion is zero.



SELF TEST-6

1. Describe the motion of freely falling bodies.
2. A ball is thrown vertically upward with a velocity of 20m/s from the top of a building. The height of the point from where the ball is thrown is 25m from the ground.
   (a) How high will the ball rise?
   (b) How long will it take for the ball to hit the ground?
3. A ball is dropped on the floor from a height of 10m. It rebounds to a height of 2.5m. If the ball is in contact with the floor for 0.01sec, what is the average acceleration during contact?
4. If a stone is thrown vertically downward into a well with a speed of 10m/s, how long will it take it to reach the water surface 60m below?
5. Two bodies begin a free fall from rest, from the same height 2sec apart. How long after the first body begins to fall, the two bodies will be 40m apart:
6. A ball rolls off the edge of a horizontal table top 45m high. It strikes the floor at a point 5m horizontally away from edge of the table. How long was the ball in the air in second?

3.5. Uniform Circular Motion

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

- ❖ Define a uniform circular motion.
- ❖ Calculate for angular and tangential displacement, angular and tangential velocity, and centripetal acceleration.
- ❖ Explain uniform circular motion in the horizontal plane.
- ❖ Identify the force required for circular motion to take place.

➢ Uniform circular motion is a circular motion with constant speed but continuously changing direction.

Angular displacement($\boldsymbol{\theta}$): is the angle turned by a rotating objects or particles.

➢ The SI unit of angular displacement is radian (rad).

Angular velocity($\boldsymbol{\omega}$): is the rate of change of angular displacement. $\left(\omega = \frac{\Delta\theta}{\Delta t}\right)$

➢ The SI unit of angular velocity is $\mathrm{rad/s}$.

Angular acceleration($\boldsymbol{\alpha}$): is the rate of change of angular velocity. $\left(\alpha = \frac{\Delta\omega}{\Delta t}\right)$

➢ The SI unit of angular acceleration is $\mathrm{rad/s^2}$.

Tangential displacement: the tangential distance on the circumference of the circle. ($2\pi r$)

Centripetal acceleration: is acceleration in circular motion caused by the change in the direction of velocity. Its direction is always towards the center of the circle.

<u>Relationship between angular motion and translational motion quantities</u>

➢ In this section, we relate 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 in the object.

$$S = r\theta$$
$$V = r\omega$$
$$a = r\alpha$$
$$a_c = \frac{v^2}{r} = r\omega^2$$

Where: S = linear or tangential displacement

V = linear or tangential velocity

ω = angular velocity

a = linear or tangential acceleration

a_c = centripetal acceleration

α = angular acceleration

Note that, angular velocity is the same for all points on the rotating object, while tangential velocity depends on its distance from the axis of rotation.

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

Direction of angular velocity and angular acceleration:

- Angular velocity and angular accelerations can be treated as a vector, 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 angular velocity and angular acceleration are along this axis.
- To illustrate this convention, it is convenient to use the right-hand rule demonstrated in figure below.
- When the four fingers of the right hand are wrapped in the direction of rotation, the extended right thumb points in the direction of angular velocity.
- The direction of angular acceleration follows in the same direction as angular velocity, if the angular speed is increasing in time, and it is antiparallel (parallel but moving in the opposite direction) to angular velocity, if the angular speed is decreasing in time.

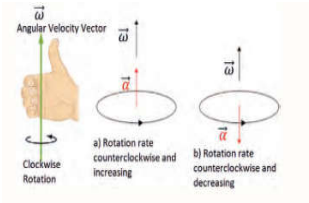


Figure 3.1 The right-hand rule for determining the direction of the angular velocity vector.

Exercise 3.6

1. If the angular velocity of a wheel is 40rad/s, and the wheel diameter is 60cm. determine the tangential velocity of the wheel.
2. An automobile moves with a constant speed of 50.4km/h around a circular track that has a diameter of 40 m.
   (a) What is the angular speed of the automobile?
   (b) What is the period of the motion?
3. By how much would the centripetal acceleration change if the speed of a car changes from 30 km/h to 90km/h?
4. What is the tangential velocity, the angular velocity and the centripetal acceleration, due to the Earth's rotation, of a body on the equator? Radius of Earth = 6,400 km.
5. The wheel of a bicycle has a radius of 40 cm. Calculate its period of revolution if the bicycle moves with a speed of 20 km/h. How much is the angular velocity?

Centripetal Force: is a force that causes centripetal acceleration. It is always perpendicular to the direction of motion of the object.

- Always perpendicular to tangential velocity.
- The direction of centripetal force is toward the center of a circular path, and given by:

$$F_c = m\frac{v^2}{r}$$

Example: A 100g ball is whirled in a horizontal circle of radius 40cm. With what maximum speed can it travel if the breaking strength of the rod is 50N?

Solution:

$$v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{(50 \times 0.4)Nm}{0.1kg}} = 14.14m/s$$

Uniform Circular Motion in a Horizontal Plane: Horizontal circular motion indicates circular motion across a horizontal surface.

Example: the motion of a mass attached to the end of a string and made to rotate in a horizontal circle (figure 3.2). In this case the centripetal force is provided by the tension (T) in string.

$$T = m\frac{v^2}{r}$$

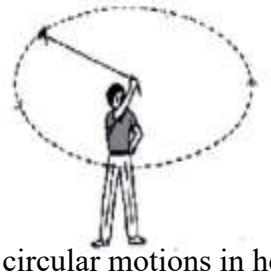


Figure 3.2 circular motions in horizontal plane.

Example: A string cam with stand a tension of 25N. What is the greatest speed at which a body of mass 1kg can be whirled in a horizontal circle using a string of length 1.0m?

Given: T = 25N, m = 1kg, r = 1.0m

Solution:

$$v = \sqrt{\frac{Tr}{m}} = \sqrt{\frac{(25 \times 1)Nm}{1kg}} = 5m/s$$

- When a car moving roundabout, the centripetal force is provided by frictional force between round and the tires of car.

$$\mu F_N = m\frac{v^2}{r}$$

Where $F_{N,}$ is the normal force exerts on the car.

Exercise 3.7: Find the maximum speed of a car with which it can be safely driven along a curve of radius 40m and the coefficient of friction between tires and road is 0.7. (Take g = 10 m/s^2)

Conical pendulum: suppose a particle of mass m is tied to a string of length l and then whirled round in a horizontal circle of radius r, with O fixed directly above the center B of the circle,

as shown figure 3.3. If the circular speed of the particle is constant, the string turns at a constant angle θ to the vertical. This is called a conical pendulum.

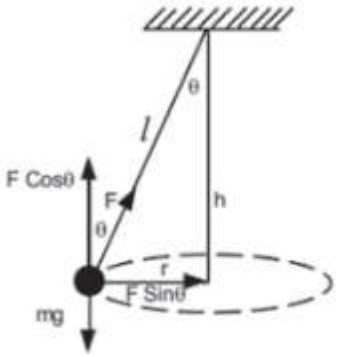


Figure 3.3 Conical pendulum.

- The horizontal component of the tension in the string (T), points towards the center of the circle, hence it provides the centripetal force.

$$T\sin\theta = m\frac{v^2}{r}$$

- The weight (mg) of the particle is balanced by the vertical component of the tension in the string.

$$T\cos\theta = mg$$

- Dividing the above equation by the lower one gives:

$$\tan\theta = \frac{v^2}{rg}$$

Motion of a car Round a Banked Road: suppose a car is moving round a banked road in a horizontal circular path of radius r (figure 3.4). if the only forces at the wheels are the normal reaction forces F_N, that is there is no side-slip or strain at the wheels, the force towards the center of the track is:

$$N\sin\theta = m\frac{v^2}{r}$$

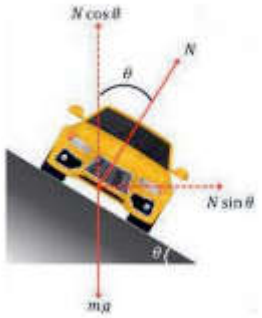


Figure 3.4 Banking of a road

- The angle of banking is given by:

$$\boxed{\theta = \tan^{-1}\left(\frac{v^2}{rg}\right)}$$

Where, $v =$ the speed of the car

$r =$ radius of a curved path

$\theta =$ banking angle

Exercise 3.8

1. Calculate the maximum speed with which a car can be driven safely along a curved road of a radius of 30m and banked at an angle of 30° with the horizontal. (take g = 9.8m/s^2)
2. Find the banking angle of the railway track with a radius of curvature of 1500m. If the train's maximum speed is 15m/s. If the distance between the two tracks is 1.8m, calculate the elevation of the outer track over the inner track.

Summary of unit

- Acceleration is a vector quantity, and is defined as the rate of change of velocity or change in velocity per unit time. The SI unit of acceleration is m/s^2.
- Instantaneous acceleration is acceleration at specific instant in time, and given by:

$$\vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t}$$

- A motion with a constant acceleration refers to a motion where, the velocity of the object is changing by equal amount in equal interval of time.
- The slope of displacement-time graph gives velocity.
- The slope of velocity-time graph gives acceleration.
- Acceleration-time graph shows how acceleration changes with time.
- When things move vertically either up or down under the force of gravity alone, the resulting motion is called free fall.
- The acceleration of a freely falling body is constant and is known as acceleration due to gravity, denoted by the letter g.
- Terminal velocity is defined as the point at which the velocity of a falling object is no longer getting greater.
- An object at terminal velocity has zero acceleration.
- Uniform circular motion is a special type of curvilinear motion in which an object travels in a circle with a constant speed but its direction of motion continuously changes.
- While moving in a circular path, the angle made by the radius 'r' of the circle is known as angular displacement (θ).
- Tangential displacement (s) is the distance covered by the rotating object along the curved path (circumference of a circle).
- A velocity describes the motion of an object along the edge of the circle whose direction at any given point on the circle is always along the tangent to that point.
- Centripetal Acceleration that acceleration an object moving in uniform circular motion the centripetal acceleration. Centripetal means center seeking or towards the center.
- The force which causes centripetal acceleration is called a centripetal force.

Key terms: *acceleration, area under velocity-time graph, angular displacement, centripetal acceleration, terminal velocity, slope of displacement-time graph, slope of velocity-time graph, tangential displacement, uniform circular motion.*

Study time: the total study time for this unit is **15 hours**.

SELF TEST- 7

1. After 2 hours, the displacement of a car is 150 km north. The initial displacement of the car is 0.What is the average velocity of the car?

A. 75km/hr, North
C. 75km/hr, East
B. 150km/hr, North
D. 45km/hr, North

2. A car travels 100 km due east in 2 hours. It then travels 50 km south in 1 hour. What is its average velocity?

A. $37.3\ \text{km/hr}$, at 73^0 south of east
C. 37.3km/hr, at 27^0 east of south
B. $37.3\ \text{km/hr}$, at 27^0 south of east
D. 47.3km/hr, at 73^0 south of east

3. The great Ethiopian athlete Tirunesh Dibaba defended her world $10{,}000\text{m}$ crown in dramatic, historic fashion on August 25, 2007 in Osaka Japan she finished the $10{,}000\text{m}$ in 31min and 55.41seconds. What was her average speed?

A. $10.4\ \text{m/s}$ B. $3.32\ \text{m/s}$ C. $8.44\ \text{m/s}$ D. $5.22\ \text{m/s}$

4. If the motion of a particle is described by the equation $\vec{\mathbf{S}}(\mathbf{t}) = \mathbf{2t^2 - 12t - 5}$, then what is the velocity of this particle at $\text{t} = 4\text{seconds}$?

A. 12m/s B. 16m/s C. 4m/s D. 8m/s

5. Based on question number **4** above, at what time does the particle become to rest?

A. 4 second B. 3 second C. 5 second D. 10 second

6. Under what condition does the average velocity of a body equal to the instantaneous velocity?

A. When the body moves around a circular path.
B. When the body moves at a dynamic velocity.
C. When the body moves with a constant velocity.
D. When a body moves with a negative acceleration.

7. A driver moving at a constant speed of $20\ \text{m/s}$ sees an accident up a head hits the brakes. If the car decelerates at a constant rate of $-5\ \text{m/s}^2$. How far does the car go before it comes to stop?

A. 120 m
C. 100 m
B. 40 m
D. 20 m

8. Albert Einstein cycling in a relating mood in such a way that the distance he travelled is proportional to the time squared. If he travelled 36m in the first 3seconds, what is the acceleration at any time t? A. $4\,m/s^2$ B. $12\,m/s^2$ C. $8\,m/s^2$ D. $9\,m/s^2$

9. If X and Y coordinates of a particle at any time t is given by $x(t) = t^5$ and $y(t) = 5t^2$ what is the magnitude of the acceleration of the particle at, $t = 1sec$?

A. $2\sqrt{20}\,m/s^2$ B. $10\sqrt{2}\,m/s^2$ C. $5\sqrt{10}\,m/s^2$ D. $10\sqrt{5}\,m/s^2$

10. Velocity of a moving particles at instant of time is:

A. Average velocity C. Terminal velocity

B. Instantaneous velocity D. Relative velocity

11. A car travels along straight line at a constant speed of $20m/s$ for a distance **d** and then another distance in the same direction at a constant speed of $36km/hr$. What is the average speed for the entire trip?

A. $23km/hr$ B. $48km/hr$ C. $54km/hr$ D. $60km/hr$

Based on the following table answer questions number (12-13). This chart shows that a student in a laboratory observed an insect moving along a meter stick. He recorded the position of the insect (x) on the stick and the time (t) taken as shown below.

x(m)	5	15	25	35	45	55	65	75	85	95
t(s)	0	5	10	15	20	25	30	35	40	45

12. The student could then describe the motion of the insect by the relation:

A. $x = 3t$ B. $x = 2t + 5$ C. $x = t + 10$ D. $x = 2t$

13. The insect moves along the edge of a table. It is observed that the insect advances equal distance in equal times. What do you refer from this observation?

A. The insect has constant velocity C. The insect changes its position slowly

B. The insect is uniformly accelerating D. The insect is moving faster and faster

14. A ball rolls off the edge of a horizontal table top 45m high. It strikes the floor at a point 5m horizontally away from edge of the table. How long was the ball in the air in second?

A. 2 sec B. 3 sec C. 4 sec D. 5 sec

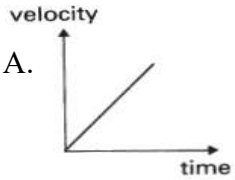
15. Two bodies of masses m_1 and m_2 fall from heights h_1 and h_2 respectively. What is the ratio of their velocities when they hit the ground?

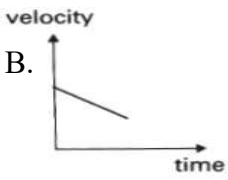
A. $\frac{h_1}{h_2}$ B. $\sqrt{\frac{h_1}{h_2}}$ C. $\frac{m_1 h_1}{m_2 h_2}$ D. $\frac{h_1^2}{h_2^2}$

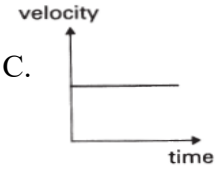
16. An object has a constant acceleration of $3.2\,m/s^2$. At a certain instant, its velocity is $9.6\,m/s$. What is the ratio of its velocities at 2.5 second later to 2.5 second earlier?

A. 111 B. 11 C. 11.1 D. 1.1

17. One of the following graph shows an object moving with zero acceleration:

A. 

B. 

C. 

D. All

18. A stone is dropped from the top of a tower 50m high. At the same time, another stone is thrown upwards from the foot of the tower with a velocity of $25\ \mathrm{m/s}$. When and where the stones cross each other?

A. From the top of the tower at 30m and after 2sec.

B. From the top of the tower at 20m and after 2sec.

C. From the bottom of the tower at 20m and after 2sec.

D. From the bottom of the tower at 30m and after 2sec.

19. A cart on air track is moving at 0.5m/s when the air is suddenly turned off. The cart comes to rest after travelling 1m. The experiment is repeated, but now the cart is moving at 1m/s when the air is turned off. How far does the cart travel before coming to rest?

A. 1m B. 2m C. 3m D. 4m

20. An object moving with uniform acceleration has a velocity of 12m/s in the x-direction when its x-coordinate is 3cm. if its x-coordinate 2 second later is -5cm. what is its acceleration?

A. $-12\ \mathrm{m/s^2}$ B. $-13\ \mathrm{m/s^2}$ C. $-16\ \mathrm{m/s^2}$ D. $12\ \mathrm{m/s^2}$

21. A train is at rest at a station. The train then move away from the station and after 20 seconds, its velocity is 15 m/s and moves at this velocity for 60 seconds. Its velocity increases to 20 m/s over 5 seconds. It moves at a velocity of 20 m/s for 120 seconds and then slows down to come to a stop after a further 30 seconds. What is the total displacement travelled by the train? A. 3738.5m B. 3837.5m C. 2850m D. 4750m

22. An object starts from rest and moved with a constant acceleration of $4\ \mathrm{m/s^2}$ along straight line. What is the distance moved by this object in the 5^{th} second?

A. 10m B. 12m C. 18m D. 24m

23. An airplane come for landing at speed of 100 m/s. if it decelerates at $5m/s^2$ on the run way, what is the minimum time it needs before coming to rest?

A. 20sec B. 30sec C. 15sec D. 35sec

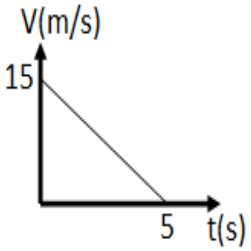
24. A body moving with constant acceleration covers the distance between two points 60m apart in 5sec. its velocity as it passes the second point is 15m/s. what is the acceleration?

A. $3\ \mathrm{m/s^2}$ B. $1.8\ \mathrm{m/s^2}$ C. $2.4\ \mathrm{m/s^2}$ D. $1.2\ \mathrm{m/s^2}$

25. What is the slope of velocity-time graph?

A. Displacement B. Speed C. Acceleration D. Distance

26. The velocity-time graph of a moving object is shown below. How far does the object move in the first two seconds?



A. 13m
B. 26m
C. -26m
D. -13m

27. Bolt, the world class athlete can reach his maximum speed in 4sec, and maintain this speed for the remained of a 100m race, finishing with a total time of 9.1sec. What is his acceleration during the first 4sec? A. $3.5\,m/s^2$ B. $1.5\,m/s^2$ C. $4.5\,m/s^2$ D. $5.5\,m/s^2$

28. A ball is thrown downward from the top of a tower. After being released, its downward:

A. Velocity will be uniform
B. Acceleration will be equal to g
C. Acceleration will be greater than g
D. Acceleration will be smaller than g

29. A particle starts with initial velocity **u** and retardation **a**. it will reach the point of start in time: A. $\frac{u}{a}$ B. $\frac{u}{a^2}$ C. $\frac{u^2}{a}$ D. $\frac{2u}{a}$

30. A ball rolls off the edge of a horizontal table top 4m high. It strikes the floor at a point 5m horizontally away from the edge of the table. How long was the ball in the air in second?

A. $\frac{3}{\sqrt{5}}$sec B. $\frac{1}{\sqrt{5}}$sec C. $\frac{2}{\sqrt{3}}$sec D. $\frac{2}{\sqrt{5}}$sec

31. If a ball is thrown vertically upward with a speed **u** the distance covered during the last **t** seconds of its ascent is: A. ut B. $\frac{1}{2}gt^2$ C. $ut-\frac{1}{2}gt^2$ D. $ut+\frac{1}{2}gt^2$

32. Two balls are projected simultaneously with the same speed from the top of a tower. One upward and the other downward. If they reach the ground in 9sec and 4sec respectively, the height of the tower is:

A. 100m B. 120m C. 180m D. 200m

33. Which one of the following statement is **CORRECT**?

A. An object moving toward east cannot have acceleration towards west.
B. If the average velocity of an object is zero in some time interval, the average speed of the object for that time interval is also zero.
C. The $\vec{V}-t$ graph of the object is parallel to the time axis.
D. An object having zero velocity can have acceleration different from zero.

34. The velocity of a particle with displacement varies with $\mathbf{V=\sqrt{3x+16}}$ what are the acceleration and initial velocity of the particle respectively?

A. 1.5 units and 4 units
B. 3 units and 4 units
C. 16 units and 1.6 units
D. 16 units and 3 units

35. One body is dropped, while a second body is thrown downward with an initial velocity of 1m/s simultaneously. The separation between them is 18m after a time of:

A. 4.5 sec B. 9 sec C. 18sec D. 36sec

36. Three particles of masses 1g, 2g and 3g are dropped from different heights 1m, 2m and 3m respectively. Now, which one of the following is correct?

A. A particle of mass 1g has maximum acceleration.

B. A particle of mass 2g has maximum acceleration.

C. A particle of mass 3g has maximum acceleration.

D. All particles have equal acceleration.

37. A body of weight 200N is dropped from a certain height and it attains a maximum velocity before it hit the ground. With this velocity it moves at a constant of proportionality 5kg/s. then what are its terminal velocity and height it moved?

A. 40m/s and 40m C. 80m/s and 40m

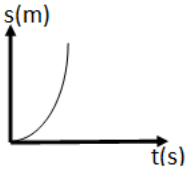
B. 40m/s and 80m D. 80m/s and 80m

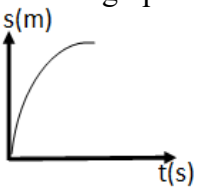
38. Galileo's experiment showed that if two bodies of unequal masses are dropped from the same height, they reach the ground at the same time. But if they are thrown up with equal velocity, the ratio of time they take to reach the ground is equal to:

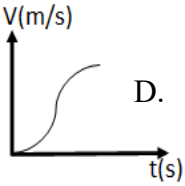
A. One C. the ratio of their masses

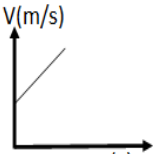
B. Mass one times mass two D. the inverse ratio of their masses

39. Which one of the following motion graphs describe uniformly **decelerated** motion?

A. 

B. 

C. 

D. 

40. **P, Q** and **R** are three balloons ascending with velocities **u, 4u** and **8u** respectively. if stones of the same mass are dropped from each, when they are at the same height, then:

A. Stone from **P** reaches the ground first C. Stone from **R** reaches the ground first

B. Stone from **Q** reaches the ground first D. All reach at the same time

UNIT FOUR

4. DYNAMICS

INTRODUCTION

Motion is an important element in studying physics. Naturally, the race of athletes, the flying of a bird, and the jumping of a dolphin out from the water, the trajectory of a soccer ball or a basketball and the like are examples of motion in nature. The motion of a fast driving car, or an airplane or a fast magnetic levitated (Maglev) train, or a supersonic jet, or a satellite orbiting the earth are all fascinating developments of human beings in the advancement of motion. Motions have causes and that cause is a force. The study of motion with its causes is dynamics.

- **After completing this unit, you will be able to:**
  - Demonstrate an understanding of the relationship between net force and the acceleration of an object in linear motion.
  - Analyze the effect of a net force in quantitative terms, using graphs, free body diagrams, and vector diagrams.
  - Describe the first condition of equilibrium quantitatively.
  - Demonstrate an understanding, in qualitative and quantitative terms, of the concepts of work, energy, energy transformations and power.
  - Design and carry out experiments and solve problems involving energy transformations and the law of conservation of energy.
  - Realize that momentum is an inherent property of moving objects.
  - Expresses the relationship between impulse and momentum

4.1. The Concept of Force and Newton's Laws of motion

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

- Discuss what the concept of force means in physics, and why forces are vectors.
- Define force and discuss its effects on a body.
- Distinguish between contact forces and field forces.
- Discuss the four fundamental forces in nature and their real life application.
- State Newton's laws of motion.
- Demonstrate the cause effect relationship of force and acceleration.
- Apply Newton's second law to determine the weight of an object.
- Demonstrate the relationship between weight and normal force.

Dynamics: The subdivision of mechanics that deals with the motion of objects in relation to the physical factor that causes the motion, the force.

Force: An external agent of a body that changes state of rest or state of motion of that body.

- The known fundamental forces in nature are all field forces. These are, in order to decreasing strength:
  1. The strong nuclear force between subatomic particles.
  2. The electromagnetic forces between electric charges.
  3. The weak nuclear force which arises in certain radioactive decay processes.
  4. The gravitational force between objects

4.1.1. Laws of Motion

Newton's First Law of Motion: state that, "an object at rest remains in a state of rest and an object in motion continues in motion along a straight line with constant speed unless an external force acts up on it.''

- Newton's first law motion is also called the law of inertia.

Inertia: The tendency of a body to oppose any change in its state of rest or its state of uniform motion.

Some examples of applications of Newton's first law: you have heard about the importance of safety belts to protect passengers in a car or in an airplane or in a bus from severe damage during accidents. The probability of severe injury to the extent of death when an accident occurs is very high on people who do not fasten seat belts.

Newton's Second Law of Motion: state that, "when an unbalanced forces acts on an object of mass m, the object accelerates in the direction of the applied force with the magnitude of acceleration directly proportional to the net force and inversely proportional to the mass of the object."

- Mathematically given by:

$$\vec{F}_{net} = m\vec{a}$$

- The SI unit of Force is called Newton (N).
- Newton's second law also states that, the net force is directly proportional to the rate of change of momentum.

$$\vec{F}_{net} = \frac{\Delta\vec{P}}{\Delta t}$$

Newton's third Law of Motion: state that, "for every action there is always an equal and opposite reaction."

- Action and reaction: During an interaction between two objects the force one exerts on the other is action and the force it is acted upon by the other is reaction.

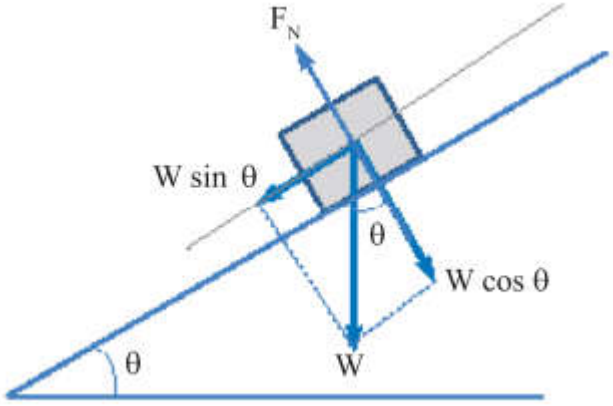
$$F_{12} = -F_{21}$$

- In Newton's third law, the pair of forces are satisfy the following conditions:
  1. Must equal in magnitude and opposite in direction.
  2. Must acts on the different bodies.
  3. Must the same type of forces.

Weight: The gravitational pull on an object (W = mg)

Normal forces: A force with which to objects push one another and acting perpendicularly at the surface of contact.

Example: If in figure 4.1, the mass of the block is 6 kg resting on top of a 37^0 inclined plane, determine the weight and the normal force.



Solution: $W = mg = 6kg \times 9.8m/s^2 = 58.8N$

$$F_N = mg\cos\theta = 58.8\cos 37^0 = 47N$$

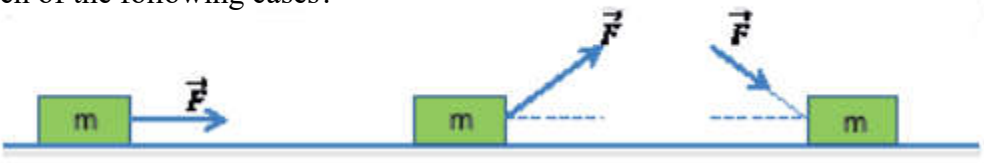
Exercise 4.1

1. What are contact forces and field forces? Give examples of each.
2. List down the four fundamental forces in nature and arrange them in the order of increasing strength.
3. State the three Newton's laws of motion.
4. How are inertia and mass related?
5. Discuss the advantages of wearing seat belt in a car?
6. What is the advantage of having airbag in a car?
7. Discuss the dependence of acceleration of a body with its mass and net force applied on it.
8. What is the relationship between weight and mass? Which is an intrinsic, unchanging property of a body?
9. Identify the action and reaction forces in the following situations:
   (a) Earth attracts the Moon
   (b) a boy kicks a football
   (c) a rocket accelerates upward
   (d) a car accelerates forward

(e) a high jumper leaps

(f) a bullet is shot from a gun.

10. A block of mass m is placed on a horizontal surface as shown below. What is the normal force in each of the following cases?



4.2. Frictional Force

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

- ❖ Describe the general characteristics of friction.
- ❖ List the various types of friction.
- ❖ Calculate the magnitude of static and kinetic friction, and use these in problems involving Newton's laws of motion.
- ❖ Solve more complex acceleration problems involving Newton's laws of motion.
- ❖ Use free-body diagrams to solve problems on Newton's Laws of motion.

- ➢ Friction is a force that opposes the motion of one surface over another.
- ➢ There are two types of frictional forces:

Static friction: Friction between two contacting surfaces at rest.

Kinetic friction: Friction between two surfaces while one slides over the other.

- ➢ Frictional force is directly related to the normal force and its value depends upon the property of the surfaces in contact.
- ➢ This property of material that resist motion is called the coefficient of friction (μ), which is defined as the ratio between the friction force and the normal force.
- ➢ Mathematically given by:

$$\mu = \frac{\text{frictional force}}{\text{normal force}} = \frac{F_f}{F_N}$$

- ➢ The maximum value of static friction is known as limiting friction and it is the frictional force between the surfaces when the body just begins to slide.
- ➢ Static friction is less than or equal to the product of coefficient of static friction and the normal force.

$$F_S \leq \mu_s F_N$$

- ➢ Kinetic friction is less than static friction.

$$F_k < F_s$$

Example: An 8 kg block is placed on a horizontal surface. The coefficient of static friction and that of kinetic friction between the block and surface are 0.4, and 0.35, respectively.

A) What is the horizontal force just enough to start moving the block?

B) What horizontal force must be applied on the block to keep it uniformly accelerating at 4 m/s^2?

Given: $\mu_s = 0.4, \quad \mu_k = 0.35, \ m = 8kg$

Solution: A) $F_s = \mu_s F_N = \mu_s mg = 0.4 \times 8kg \times 9.8m/s^2 = 31.4N$

B) $F_{app} = F_{net} + F_k = F_{net} + \mu_k F_N = 32N + 23.5N = 55N$

Exercise 4.2

A 6 kg block is placed on a ramp that makes an angle of 30^0 above the horizontal, if the block remains at rest,

A) What is the static friction that supports the block from sliding down the ramp?

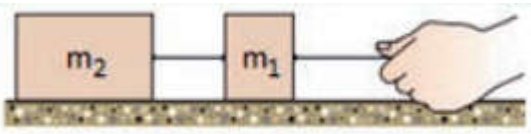
B) What is the coefficient of static friction between the block and the ramp?

Some applications of Newton's Laws of motion

A free-body diagram: The most important step in solving a problem by means of Newton's second law. It is a drawing that includes only those forces that act directly on the object of interest.

- By using the concept of Newton's second law, ($F_{net} = ma$) we solve several problems.

Example: Two blocks of identical materials are connected by a light string on a level surface as shown below. Assuming no friction between the blocks and the level surface, find the acceleration of the masses and the tension in the connecting string when the string attached to m_1 is pulled to the right by a 36 N force. Use m_1 = 4 kg and m_2 = 8 kg.



Given: m_1= 4 kg, m_2 = 8 kg, F = 36 N

The blocks move together to the right under the action of force F. Writing Newton's second law for each block we have:

For, m_1: $F - T = m_1 a$

For, m_2: $T = m_2 a$

Adding the above two equations we get:

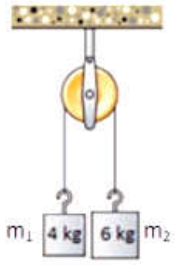
$$F = (m_1 + m_2)a$$

$$a = \frac{F}{m_1 + m_2} = \frac{36N}{8kg + 4kg} = 3m/s^2$$

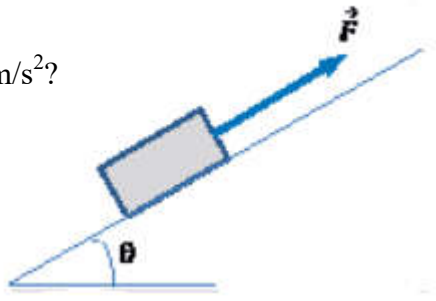
Therefore, by inserting the value of acceleration into the above formula we get, T = 24N.

SELF TEST-8

1. For the system of masses in Example above, find the acceleration of the masses if the coefficient of kinetic friction between each of the blocks and the level surface is 0.25.
2. Two masses (m_1 = 4kg and m_2 = 6kg), are connected by a light cord that passes over a massless, frictionless pulley as shown in Figure below. This arrangement is called Atwood's machine and sometimes is used to measure the acceleration due to gravity. Find the magnitude of acceleration of the two masses and the tension in the cord.

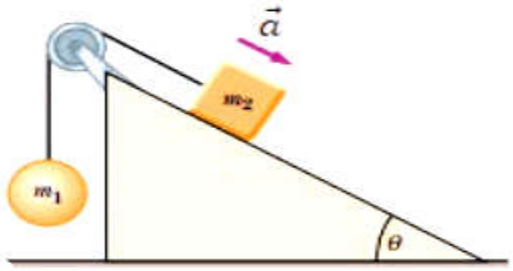


3. A 25 kg block is initially at rest on a horizontal surface. A horizontal force of 75N is required to set the block in motion. After it is in motion, a horizontal force of 60N is required to keep the block moving with constant speed. Find the coefficients of static and kinetic friction from this information.
4. If a car is traveling westward with a constant speed of 20 m/s, what is the resultant force acting on it?
5. A person weighs a fish of mass m on a spring scale attached to the ceiling of an elevator. What can you say about the motion of the elevator if the reading of the scale is:
   (a) Equal to mg?
   (b) Greater that mg?
   (c) Less than mg?
6. A block is placed on a smooth inclined plane shown in Figure shown below. What force parallel to the surface of the inclined plane is require to move the block up the plane at:
   (a) A constant speed?
   (b) A constant acceleration of 0.5 m/s^2?



7. Repeat question 6 if the coefficient of kinetic friction between the block and the inclined surface is 0.25.
8. A ball of mass m_1 and a block of mass m_2 are attached by a lightweight cord that passes over a frictionless pulley of negligible mass, as shown in Figure below. The block lies on a

frictionless incline of angle θ. Find the magnitude of the acceleration of the two objects in terms of m_1, m_2, g and θ



4.3. The First Condition of Equilibrium

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

- ❖ Define the term equilibrium.
- ❖ Explain the first condition of equilibrium apply the first condition of equilibrium to solve practical problems.

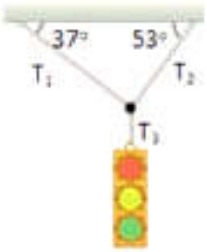
Equilibrium: a word that describes a state of rest or uniform motion along a fixed direction of a body.

- ➢ If an object is in equilibrium, its acceleration is zero and according to Newton's second law of motion, the vector sum of all the forces acting on it must be zero.

$$\sum \vec{F} = 0 \qquad \text{(The first condition of equilibrium)}$$

Exercise 4.3

1. A traffic light weighing 100 N hangs from a vertical cable tied to two other cables that are fastened to a support, as shown in Figure below. The upper cables make angles of 37° and 53° with the horizontal. Find the tension in each of the three cables.



2. If only one force acts on an object, can it be in equilibrium? Explain.

3. If an object is in equilibrium, which of the following statements is not true?

(a) The speed of the object remains constant

(b) The acceleration of the object is zero.

(c) The net force acting on the object is zero.

(d) The object must be at rest.

(e) The velocity is constant.

(f) All

4.4. Work, Energy and Power

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

- Define work in terms of the applied force and the displacement.
- Calculate the work done by a constant force, by a varying force.
- Demonstrate by examples that maximum work is done when the applied force is parallel to the displacement vector.
- Apply work-energy theorem to solve problems.
- Calculate kinetic energy and potential energy of a body.
- Differentiate between conservative and non-conservative forces.
- Explain the law of the conservation of energy.
- Solve problems by applying the law of conservation of energy.
- Define power and solve problems involving power.

Work: defined as the transferring of energy from one body to another or transforming of energy from one type to another.

Energy: is the capacity to do work.

- Both work done and energy are scalar quantity and its SI unit is called Joule (J)

$$1\text{J} = \text{Nm} = 10^7\text{erg}$$

- Mechanical work done by a constant force is given by:

$$\boxed{W = \vec{F}.\vec{S} = FS\cos\theta}$$

Where, W = work done

F = applied force

S = displacement

θ = the angle between force and displacement

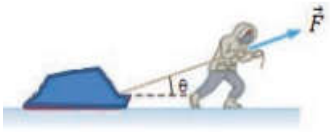
Example: What is the work done on a block of mass 10kg, when a force of 20N, 30^0 above the horizontal displaces the block by 5m?

Given: m = 10kg, F = 20N, $\theta = 30^0$, $S = 5\text{m}$

Solution: $W = FS\cos\theta = 20\text{N} \times 5\text{m} \times \cos 30^0 = 86.6\text{N}$

Exercise 4.4

1. A man pulls a package along a horizontal floor with a force of 400 N at an angle of 30^0 as shown in Figure below. A constant frictional force of 100 N acts between the package and the floor. Find the work done by each force acting on the sled and the total work done by all the forces.



2. Can work done be positive, negative or zero? Specify the conditions in which work can be positive, negative or zero.
3. A man pushes a stalled vehicle with a steady force $(150\mathrm{i} - 40\mathrm{j})\mathrm{N}$ and the displacement of the car is,$(14\mathrm{i} + 11\mathrm{j})\mathrm{m}$. How much work does the man do on the car?

Work done by gravitational force: is given by:

$$W_g = mgd\cos\theta$$

Example: A 5kg bag is raised to a height of 2.5 m above the ground. What is the work done by the applied force and by the gravitational force?

Given: m = 5kg, h = 2.5m

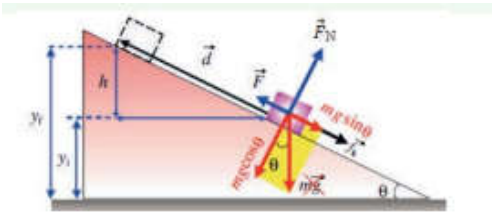
Solution:

$$W_g = mgd\cos\theta = 5\mathrm{kg} \times 9.8\mathrm{m/s^2} \times 2.5\mathrm{m} \times \cos 180^0 = -122.5\mathrm{J}$$

Exercise 4.5

Consider a block of mass m is pushed up a rough inclined plane of angle θ by a constant Force F parallel to the incline, as shown in Figure below. e displacement of the block up the incline is d.

a. by the applied force
b. by the force of gravity
c. by the normal force
d. by the kinetic friction



Work done by a variable force: the work done due to variable force is determined by calculating the total area under force versus time graph.

Work- energy theorem: the total work done on a body by external forces is related to body's displacement that is, to change in its position. But the total work is also related to change in the speed of the body. Therefore, the total work done is equal to the change in its kinetic energy.

$$W = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_i^2 = K_{Ef} - K_{Ei} = \Delta K_E \qquad (\mathrm{Work - energy\ theorem})$$

Kinetic energy: Energy due to motion. $\left(K_E = \frac{1}{2}mv^2\right)$

Potential energy: Energy due to position or shape. $\left(\mathrm{GPE} = mgh \text{ and } \mathrm{EPE} = \frac{1}{2}kx^2\right)$

Mechanical energy: the total energy (the sum of kinetic and potential energy).

Conservative and non-conservative Forces: there are generally two kinds of forces, namely conservative force and non-conservative forces.

Conservative force: A force in which work done is independent of the path followed.

- The work done by a conservative force on a particle moving between any two points is independent of the path taken by the particle.

- The work done by a conservative force on a particle moving through any closed path is zero. (a closed path is one in which the beginning and end points are identical).
- Gravitational force is an example of a conservative force, and the force that a spring exerts on any object attached to the spring is also conservative.

Non- conservative force: A force in which work done is path dependent.

- Non-conservative forces acting within a system cause a change in the mechanical energy of the system.
- Work done on a system by a non-conservative force is equal to the change in mechanical energy of the system.
- Typical example of non-conservative force (also known as dissipative force) is frictional force.

$$f_k d = (K_{Ef} - K_{Ei}) + (P_{Ef} - P_{Ei})$$

Power: is the rate of conversion of energy or the rate of doing work.

- Mathematically given by:

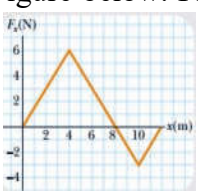
$$P = \frac{W}{t} = \vec{F}.\vec{v}$$

- The SI unit of power is called Watt (W).

$$1 \text{ horse power} = 746 \text{Watts}$$

Exercise 4.6

1. A 1000 kg elevator car carries a maximum load of 800 kg. As the elevator moves upward a constant frictional fore of 4000 N retards its motion. What minimum power must the motor deliver to li the loaded elevator car at a constant speed of 2.5 m/s?
2. Write down two examples in which a force is exerted on an object without doing any work on the object.
3. A bullet has twice the mass of a second bullet. If both are fired so that they have the same speed, which has more kinetic energy? What is the ratio of the kinetic energies of the two bullets?
4. (a) If the speed of a particle is doubled, what happens to its kinetic energy?
   b) What can be said about the speed of a particle if the net work done on it is zero?
5. Can kinetic energy be negative? Explain.
6. The force acting on a particle varies as in Figure below. Find the work done by the force on the particle as it moves,
   (a) From x = 0 to x = 8 m
   (b) From x = 0 to x = 10 m



7. Elastic potential energy depends on the spring constant and the distance the spring is stretched or compressed. By what factor does the elastic potential energy change if the spring's stretch is:
   (a) Doubled
   (b) Tripled?
8. Calculate the elastic potential energy of a spring with spring constant k = 225 N/m that is:
   (a) Compressed
   (b) Stretched by 1cm.
9. A diver drops from a board 15 m above the surface of water. Neglecting air resistance,
   (a) Use conservation of mechanical energy to find his speed as he is 5 m above the water's surface, and
   (b) Find his speed as he hits the water.
10. What average power must be supplied to push a 10 kg block from rest to 20 m/s in 5 s when the coefficient of kinetic friction between the block and surface is 0.2? Assume the acceleration is uniform.
11. An advertisement claims that a certain 1200 kg car can accelerate from rest to a speed of 25 m/s in a time of 8s. What average power must the motor develop to produce this acceleration?

4.5. Conservation of mechanical energy

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

- ❖ Define mechanical energy.
- ❖ State the law of conservation of mechanical energy.
- ❖ Apply the law of conservation of mechanical energy to solve problems.

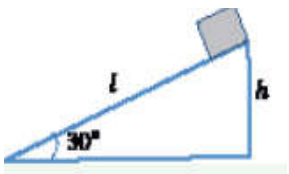
➢ The law of conservation of mechanical energy states that in the absence of dissipative forces like air resistance and friction, the total mechanical energy of an object or system of objects remains unchanged.

$$\Delta M_E = 0$$

$$K_{Ei} + P_{Ei} = K_{Ef} + P_{Ef}$$

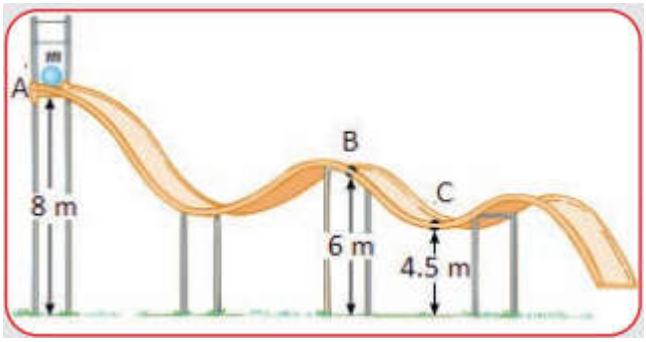
Exercise 4.7

1. A 10 kg block is released from rest at the top of a smooth inclined plane 10m in length, as shown in Figure below. Find the speed of the block as it reaches the bottom of the inclined plane.



2. Repeat the question (1) if the inclined plane is rough and the coefficient of kinetic friction between the block and the surface is 0.2.
3. A 2kg block sliding over a smooth horizontal surface with a constant speed of 8m/s hits a horizontal spring whose one end is fixed as shown in Figure below. If the maximum compression of the spring just before the block comes to rest is 20cm, what is the spring constant of the spring?

4. A ball is thrown straight up into the air. Where will it attain its minimum kinetic energy? At what position is the gravitational potential energy of the ball–Earth system a maximum?
5. A 1 kg ball is released from the top of an 18 m high tower. Neglecting air resistance, where above the ground will the ball have its kinetic energy twice its potential energy at that location?
6. A particle of mass m = 8 kg is released from point A and slides on the frictionless track shown in Figure below. Determine:
   (a) The particle's speed at points B and C and
   (b) The work done by the gravitational force in moving the particle from A to B.
   (c) The net work done by the gravitational force in moving the particle from A to C.
   (d) The net work done by the gravitational force in moving the particle from A to ground.



7. A 0.50kg block slides across a tabletop with an initial velocity of 20cm/s and comes to rest in a distance of 50 cm. Find the average friction force that retarded its motion.
8. Suppose a car traveling at a speed v skids a distance d after its brakes lock. Estimate how far it would skid if it were traveling at speed 2v when its brakes locked.
9. A spring has a spring constant of 150N/m and a mass of 100g is attached to it. The spring sits on a horizontal frictionless surface and the other end of the spring is attached to a solid block. The mass is pulled by 10cm to stretch the spring and then let go. What is the highest velocity of the mass?

4.6. Impulse and Linear Momentum

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

- ❖ Discuss impulse and linear momentum.
- ❖ Relate impulses to collisions apply the impulse-momentum theorem to solve problems.
- ❖ Differentiate elastic and inelastic collisions.
- ❖ State the law of conservation of linear momentum.
- ❖ Explain the meaning and usefulness of the concept of center of mass.
- ❖ Calculate the center of mass of a given system
- ❖ Calculate the velocity of the center of mass
- ❖ Apply the law of conservation of linear momentum to solve problems involving collision in one dimension.

Momentum: describe the effort require to get a body moving or to stop it.

Impulse: is change of momentum.

- ➢ Linear momentum is mathematically given by:

$$p = mv$$

- ➢ Impulse is also given by:

$$J = \Delta p = m\Delta v = F\Delta t$$

- ➢ The SI unit of linear momentum is **Kgm/s**.

Example 1: What is the linear momentum of a 0.5 kg match box that is moving at a constant speed of 6m/s toward the positive x direction?

Given: m = 0.5kg, v = 6m/s

Solution:

$$p = mv = 0.5\text{kg} \times 6\text{m/s} = 3\text{kgm/s}, \text{along positive x axis}$$

Example 2: If the box in the above example is acted by an external force and its velocity is increased from 6m/s to 15m/s along the same direction, what is the change in momentum?

Given: m = 0.5kg, V = 15m/s, u=6m/s

Solution: $\text{Impulse} = \Delta p = m\Delta v = 0.5\text{kg}(15\text{m/s} - 6\text{m/s}) = 4.5\text{kgm/s}$, toward positive x axis.

Exercise 4.8

1. A 2 kg ball that was moving along a smooth horizontal floor at 2.5m/s toward East hits a hard surface and rebounds with a speed of 2.3m/s along the same line. If the time of interaction between the ball and the wall is 0.20 s,

(a) What is the change in momentum of the ball?

(b) What is the impulse imparted to the ball?

(c) What is the net force exerted on the ball by the surface?

2. How would the momentum of an object change if:

A. the mass is doubled but the velocity remains the same?

B. the velocity is reduced to one-third of its original magnitude?

C. the direction of the velocity changes from South to East?

Law of Conservation of Linear Momentum: if two bodies collide or push each other apart and no forces act except for each one pushing the other, the total momentum of the two bodies does not change. That is the initial total momentum is equal to the final total momentum.

Collision: is an event during which two particles come close to each other and interact by means of forces.

- Depending on wether the kinetic energy is conserved or not, collision is categorized into two:

Elastic collision: collision in which both momentum and kinetic energy are conserved.

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 \quad \text{(conservation of momentum)}$$
$$u_1 - u_2 = -(v_1 - v_2) \quad \text{(from conservation of kinetic energy)}$$

Where, u_1 , u_2 are velocity of the first and the second bodies before collision respectively.

v_1 , v_2 are velocity of the first and the second bodies after collision respectively.

Exercise 4.8

1. Consider two masses m_1 of 4 kg and m_2 of 6 kg moving along the same line in opposite direction, with velocities of 2 m/s and 1 m/s respectively. If the masses make an elastic collision, what are the velocities of each of the masses after collision?

2. Two gliders A and B with masses of 0.5 kg and 0.3 kg, respectively, move toward each other on a frictionless air track. After they glider B has a final velocity of 2 m/s toward the positive x direction.

a) What is the final velocity of glider A?

(b) How do the changes in momentum and in velocity compare?

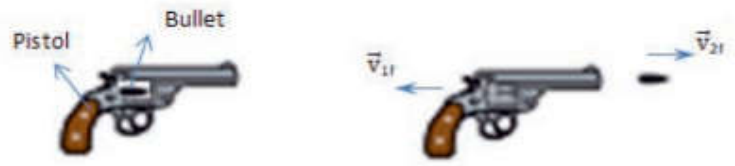
Inelastic collision: inelastic collisions are of two types. When the colliding objects stick together after the collision is called perfectly inelastic. When the colliding objects do not stick together, but some kinetic energy is lost the collision is called inelastic.

- In general, in inelastic collision only linear momentum is conserved but not kinetic energy is conserved.
- Therefore we use equation of conservation of momentum:

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2 \quad \text{(conservation of momentum)}$$

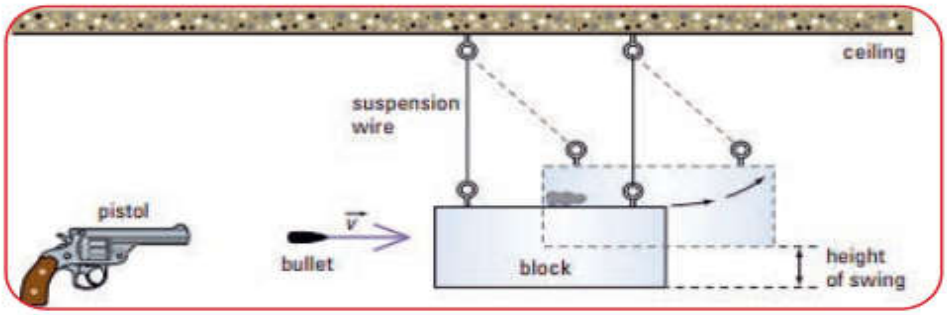
Exercise 4.9

1. A 700 g pistol loaded with a 180g bullet rests on a smooth table, as shown below. If the bullet suddenly goes o with a speed of 300 m/s, with what speed will the pistol recoil?



2. A fully loaded dump truck with a mass of 25000 kg is moving at 72 km/h on a level paved road. On its way, it suddenly collides head on with a 150 kg Bajaj which was moving at 54 km/h in the opposite direction. What will be the final velocity of the truck-Bajaj system after collision?

Ballistic pendulum: Consider a ballistic pendulum, a type of pendulum used to determine the speed of bullets before electronic timing devices were invented (Figure shown below).



- A stationary block of wood is suspended from the ceiling by light ropes. When a bullet is red at the block, the bullet becomes embedded in the wood upon impact. Just after interaction the pendulum-bullet system starting from rest, rises up to a certain height of swing before stopping. Derive an expression for the velocity of the bullet in terms of mass of its own mass, mass of the block, g and swing height.

Solution

On impact some of the kinetic energy of the bullet is transferred to the pendulum-bullet system so that the system will have speed v_f just after interaction. As the pendulum-bullet system swings upward, its kinetic energy is converted to gravitational potential energy.

Taking mass of bullet = m_1

Mass of the block = m_2

Velocity of bullet before impact $v_{1i} = v$

Initial velocity of the block = 0

Swing height = h

- By using conservation of linear momentum we have:

$$\text{The speed of the bullet before impact(v)} = \frac{m_1 + m_2}{m_1}\left(\sqrt{2gh}\right)$$

Exercise 4.10:

1. A 14.9g bullet from a pistol strikes a 2kg ballistic pendulum. Upon impact, the pendulum swings forward and rises to a height of 21.9cm. What was the velocity of the bullet immediately before impact?

Center of Mass: is a point where the total mass of a body or system of objects is assumed to be concentrated.

- Is a point where the net torque of a system will be zero.
- Is a point where an object becomes balanced.
- Suppose we have several particles with masses m_1, m_2 and so on. Let the coordinates of m_1 be (x_1, y_1) , be those of m_2 be (x_2, y_2) and so on. We define the center of mass of the system as the point that has coordinates (x_{cm}, y_{cm}) is given by:

$$x_{cm} = \frac{m_1x_1 + m_2x_2 + m_3x_3 + \cdots + m_nx_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

$$y_{cm} = \frac{m_1y_1 + m_2y_2 + m_3y_3 + \cdots + m_ny_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

Example: Three masses on m_1 = 300 g, m_2 = 500 g and m_3 = 200 g are place on the xy plane at coordinates (-2, 2), (2, 3) and (3,-1), respectively. If distances are in centimeters, find the coordinates of the center of mass of the system.

Given: m_1 = 0.3 kg at (-2, 2), m_2 = 0.5 kg at (2, 3), m_3 = 0.2 kg at (3, -1)

Solution:

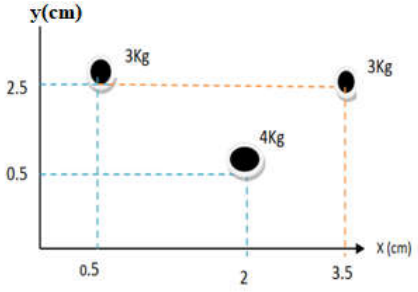
$$x_{cm} = \frac{m_1x_1 + m_2x_2 + m_3x_3}{m_1 + m_2 + m_3} = 1$$

$$y_{cm} = \frac{m_1y_1 + m_2y_2 + m_3y_3}{m_1 + m_2 + m_3} = 1.9$$

Therefore, the coordinates of center of mass is given by: $CM = (1, 1.9)cm$

Exercise: 4.11

Suppose that there are three point masses arranged as shown in the figure below. Where is the center of mass of this three- object- system with respect to the origin?



Summary of unit

- Newton's laws of motion can be applied in numerous situations to solve problems related to motion.
- Newton's first law also known as the law of inertia tells us that in the absence of unbalanced force a body at rest remains at rest and a body in motion keeps on moving with the same velocity.
- Newton's second law describes what happens to a body if it is acted upon by an unbalanced force. The acceleration of a body is directly proportional to the net force and inversely proportional to the mass of the body. A body accelerates in the direction of the net force on it.
- Newton's third law tells us the fact that forces are in pairs and that action and reaction are equal and opposite.
- Friction is an example of contact type of force. It arises when a body moves or attempts to move on another body.
- Friction depends on the nature of the surfaces in contact and the normal force.
- Static friction is greater than sliding (kinetic friction).
- The normal force on an object is not always equal in magnitude to the weight of the object. It depends on the orientation of the surface on which an object is placed.
- A body is in equilibrium is the net force acting on it is zero.
- When a body is in equilibrium, it is either at rest or moves at a constant speed in a fixed direction. Its acceleration will be zero.
- For problems involving two or more forces, draw free-body diagrams, resolve the forces into their components and apply Newton's laws the net work done Wnet, is the work done by the net force acting on an object.
- Work done on object transfers energy to the object.
- The work-energy theorem states that the network Wnet on a system changes its kinetic energy.
- Gravitational potential energy of a mass m placed at height h above a reference is PE = mgh.
- One of the common examples of work done by a varying force is work done on a spring.
- Linear momentum is defined as the product of a system's mass and its velocity.
- Center of mass of a body is a point where the total mass of the body is assumed to be concentrated.
- Power is the rate of doing work or the rate of transfer of energy.
- Positive power means energy is transferred to the object by the force.
- Negative power means energy is transferred from the object by the force

Key terms: *action and reaction, center of mass, conservative force, dynamics, elastic collision, equilibrium, force, free body diagram, friction, impulse, inelastic collision, inertia, kinetic energy, kinetic friction, momentum, net force, Newton's second law, non-conservative force, normal force, potential energy, power, static friction, system, weight.*

Study time: the total study time for this unit is **18 hours**.

SELF TEST-9

1. Identify the **incorrect** statement about **'Second law of dynamics'**?

A. The direction of acceleration produced by net force acting on the object is the same to the net force.

B. The magnitude of net force acting on the object is directly proportional to the acceleration produced by net force.

C. The magnitude of net force acting on the object is inversely proportional to the change of momentum.

D. The magnitude of net force acting on the object is directly proportional to the change of momentum.

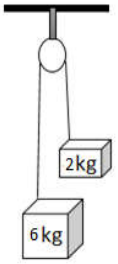
2. Two masses 6kg and 2kg are attached to the end of a light string passing over a pulley. What are the tension and acceleration in terms of g respectively?

A. $\frac{1}{2}g,\ 2g$

B. $3g,\ \frac{5}{3}g$

C. $\frac{1}{2}g, 3g$

D. $3g,\ \frac{1}{2}g$



3. A collision occurs between a 2kg body moving with $(-4i-5j)m/s$ and a 4kg body moving with $(6i-2j)m/s$. After the collision the bodies stick together. What is their common velocity?

A. $(3i-2.7j)m/s$

B. $(2.7i-3j)m/s$

C. $(2.7i+3j)m/s$

D. $(-2.7i-3j)m/s$

4. The tendency of an object, if it is displaced to neither return to its original position nor to move further from it is:

A. Stable equilibrium

B. Un stable equilibrium

C. Neutral equilibrium

D. All are correct

5. **Translational** equilibrium is:

A. Linear equilibrium

B. Rotational equilibrium

C. Equilibrium in which linear momentum is not conserved

D. Equilibrium in which angular momentum is conserved

6. The energy possessed by an object because of its ***configuration*** is:

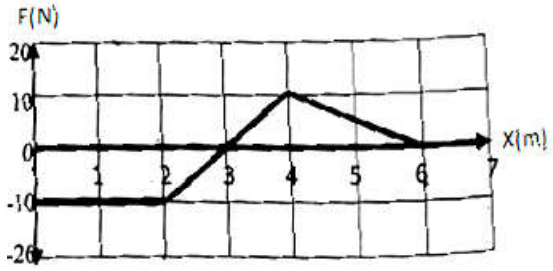
A. Elastic Potential Energy(EPE)
B. Gravitational Potential Energy (GPE)
C. Linear Kinetic Energy
D. Rotational kinetic energy

7. Identify the **CORRECT** statement

A. Work done by a conservative force along any closed path is zero, whereas the work done by non-conservative force along a closed path is not zero.
B. Work done by conservative force is path dependent, whereas work done by non-conservative force does not depend on the path followed.
C. Friction is an example of conservative force, whereas spring force and gravitational force are typical examples of non- conservative force.
D. A conservative force dissipates energy, whereas a non-conservative force does not.

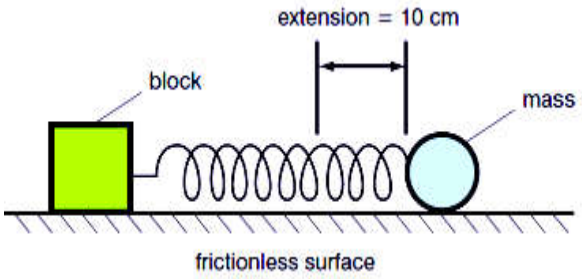
8. The force acting on a particle varies with position as shown in figure below. What is the work done as the particle move from x=0 to x=6m?

A. 10J
B. -10J
C. 40J
D. -15J



9. A spring has a spring constant of 150N/m and a mass of 100g is attached to it. The spring sits on a horizontal frictionless surface and the other end of the spring is attached to a solid block. The mass is pulled by 10cm to stretch the spring and then let go. What is the highest velocity of the mass?

A. $3.9\ \text{m/s}$
B. $4.8\ \text{m/s}$
C. $5.8\ \text{m/s}$
D. $15\ \text{m/s}$



10. A force $\vec{F} = (2i + 4j)\text{N}$ displaces a particle through $\vec{S} = (2i + 6k)\text{m}$, in 16 seconds. Then what is the power developed by this force?

A. 0.25W B. 25W C. 225W D. 450W

11. A sport car of mass 50kg is moving on a banked road of radius 40 meters at a safe speed of $20m/s$. the angle that the cycle makes with the vertical so that it may not fall is:

A. 60^0 B. 90^0 C. 30^0 D. 45^0

12. Identify the **CORRECT** statement about **energy, work,** and **force**

A. Work is said to be done by a force whenever the force is exerted on an object.

B. Machine can multiply energy but not force.

C. Energy cannot possessed by an object at rest.

D. Force is a vector quantity, whereas work and energy are scalars.

13. The force acting on a body varies with the displacement and given by:

$$\mathbf{F(x) = (8 - 2x)}$$

Then what is work done by this force as the body displaces 4m?

A. 20 J C. 16J

B. 18 J D. 40J

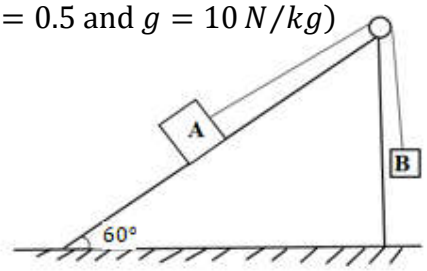
14. Two blocks are connected over a pulley. If mass of block A is$5kg$, $\mu_k = 0.4$, $\theta = 60°$and that block A slides down the incline at a constant speed, then what is the mass of block B? (Use: $\sin 60° = 0.866$, $\cos 60° = 0.5$ and $g = 10\,N/kg$)

A. 13kg

B. 1.3kg

C. 2.5kg

D. 3.3kg

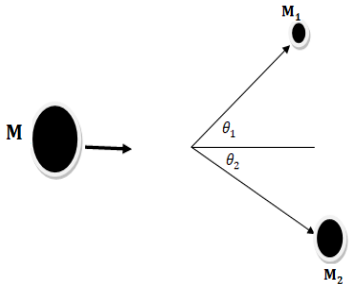


15. When a bus starts suddenly, the passengers are pushed back. This phenomenon is best example of one of the following laws of motion, which one is it?

A. Newton's second law C. Newton's third law

B. Newton's first law D. Newton's law of universal gravitation

16. A ball of mass M moves with speed V in the +x direction. It explodes into two pieces that go off at angles θ_1 and θ_2 as shown below.



What are the magnitudes of the momenta of the two pieces?

A. $P_1 = \frac{MV\sin\theta_2}{\sin(\theta_1+\theta_2)}$, and $P_2 = \frac{MV\sin\theta_1}{\sin(\theta_1+\theta_2)}$

B. $P_1 = \frac{MV\cos\theta_2}{\sin(\theta_1+\theta_2)}$, and $P_2 = \frac{MV\cos\theta_1}{\sin(\theta_1+\theta_2)}$

C. $P_1 = MV\tan\theta_2$, and $P_2 = MV\tan\theta_1$

D. $P_1 = \frac{MV\cos\theta_2}{\cos(\theta_1+\theta_2)}$, and $P_2 = \frac{MV\cos\theta_1}{\cos(\theta_1+\theta_2)}$

17. According to the **work-energy theorem**,

A. Work done by gravity on an object thrown down ward is negative.

B. Work done by tension on an object tied to string and moving in a horizontal circle is negative.

C. Work done by gravitational force on a satellite moving around the earth in a circular orbit is positive.

D. Work done by gravity on an object thrown upward and moving upward is negative.

18. A 1kg roller coaster is acted on by a 4N force over a displacement of 2m in the direction of force and then set free. The roller is moving on smooth and horizontal surface towards a free end of a spring of spring constant K, whose other end is fixed on the wall. If the spring is compressed by 20cm to bring the roller coaster to rest, then what is the value of the spring constant?

A. 400N/m C. 200N/m

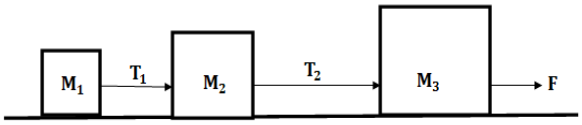
B. 100N/m D. 800N/m

19. A block slides on a rough 45^0 incline. The coefficient of friction is μ_k. What is the ratio of acceleration when the block accelerates down the incline to the acceleration when the block is projected up the incline?

A. $\frac{\mu_k-1}{\mu_k+1}$ C. $\frac{1-\mu_k}{1+\mu_k}$

B. $\frac{\frac{\mu_k}{\sqrt{2}}-1}{\mu_k+1}$ D. $\frac{1+\mu_k}{1-\mu_k}$

20. Three blocks of mass $M_1 = 1\text{kg}$, $M_2 = 2\text{kg}$ and $M_3 = 3\text{kg}$, placed on a horizontal frictionless table, are connected with strings and pulled to the right by a force F=9N, as shown below. The acceleration(a), tension ,T_1 and T_2, are respectively:



A. $a = \frac{2}{3}\text{m/s}^2$, $T_1 = \frac{2}{3}\text{N}$ and $T_2 = 2\text{N}$ C. $a = \frac{3}{2}\text{m/s}^2$, $T_1 = 3\text{N}$ and $T_2 = \frac{9}{2}\text{N}$

B. $a = \frac{3}{2}\text{m/s}^2$, $T_1 = \frac{3}{2}\text{N}$ and $T_2 = \frac{9}{2}\text{N}$ D. $a = 3\text{m/s}^2$, $T_1 = 3\text{N}$ and $T_2 = 9\text{N}$

21. Suppose that you are given a mass attached to a spring and oscillates up and down. This mass-spring system has maximum gravitational potential energy (GPE), Elastic potential energy (EPE) and Kinetic energy (KE) at the;

A. Top, bottom and middle respectively. C. Middle, bottom and top respectively.

B. Bottom, middle and top respectively. D. Middle, top and bottom respectively.

22. Consider two collisions, that occurred between two trollies having the same mass; moving with the same speed, and in opposite directions,

Collision 1: After collision the two trollies bounce back with the same speed.

Collision 2: After collision the two trollies stick together due to magnetic coupler.

Which one of the following statement is **CORRECT** about the two collisions?

A. Collision 1 is inelastic and collision 2 is elastic.

B. Both collisions are inelastic.

C. Collision 1 is elastic and Collision 2 is inelastic. D. Both collisions are elastic.

51. Which one of the following is the fundamental natural force between electric charges?

A. Strong nuclear force C. Gravitational force

B. Electromagnetic force D. Weak nuclear force

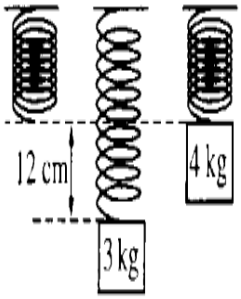
52. A block of mass 3.0kg is hung from a spring, causing it to stretch 12cm at equilibrium, as shown. The 3.0kg block is then replaced by a 4.0kg block, and the new block is released from the position shown, at which the spring is unstretched. How far will the 4.0kg block fall before its direction is reversed?

A. 18 cm

B. 16cm

C. 32 cm

D. 48 cm



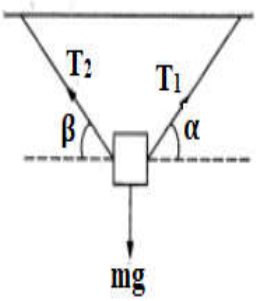
53. A body of mass m is suspended by two strings making angles $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ with the horizontal. What are the tensions in the string? (Assume the system is in equilibrium)

A. $T_1 = \frac{mg\cos\beta}{\sin(\alpha+\beta)}$, $T_2 = \frac{mg\cos\alpha}{\sin(\alpha+\beta)}$

B. $T_1 = \frac{mg\cos\alpha}{\sin(\alpha+\beta)}$, $T_2 = \frac{mg\cos\beta}{\sin(\alpha+\beta)}$

C. $T_1 = \frac{mg\cos\alpha}{\sin(\alpha+\beta)}$, $T_2 = \frac{mg\sin\beta}{\cos(\alpha+\beta)}$

D. $T_1 = \frac{mg\cos\beta}{\sin(\alpha+\beta)}$, $T_2 = \frac{mg\sin\alpha}{\sin(\alpha+\beta)}$



54. Which one of the following is **INCORRECT** statement about frictional force?

A. Friction depends on the nature of the surfaces in contact that is their roughness or smoothness and the normal force.

B. Friction doesn't depend on the area of the surfaces in contact.

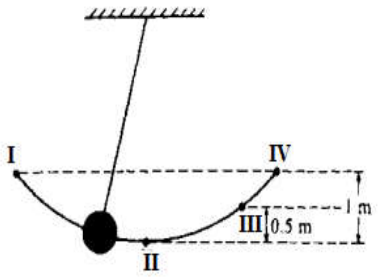
C. Kinetic friction is usually less than static friction.

D. Coefficient of friction is the ratio of normal force to frictional force.

55. An advertisement claims that a certain 1200 kg car can accelerate from rest to a speed of 30 m/s in a time of 10 s. What average power must the motor develop to produce acceleration?

A. 540KW
C. 54KW
B. 5.4KW
D. 5400KW

56. A ball swings freely back and forth in an arc from point I to point IV, as shown. Point II is the lowest point in the path, III is located 0.5 meter above II, and IV is 1 meter above II. Air resistance is negligible. If the potential energy is zero at point II, where will the kinetic and potential energies of the ball be equal?



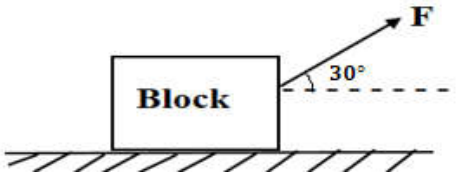
A. At point II
B. At some point between II and III
C. At point III
D. At some point between III and IV

57. **Equilibrium** is best described by:

A. Newton's first law
C. Newton's third law
B. Newton's second law
D. Newton's law of universal gravitation

58. A force **F** of magnitude 10N applied to a block of mass 4kg that lies on a rough horizontal surface as shown below, the coefficient of kinetic friction between the block and surface is 0.2, then what is the magnitude of the acceleration of the block? (Use: $\sin 30° = 0.5$, $\cos 30° = 0.866$ and $g = 10\ N/kg$)

A. $0.8\ m/s^2$
B. B. $0.6\ m/s^2$
C. C. $0.4\ m/s^2$
D. $0.9\ m/s^2$



59. Which one of the following is **TRUE** about pairs of forces in Newton's third law?

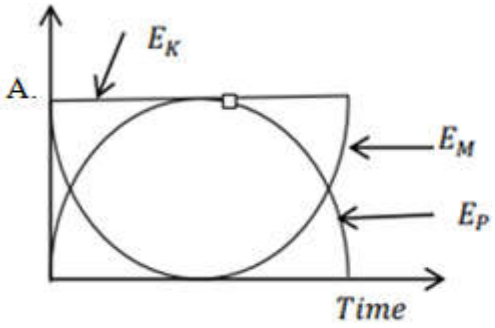
A. Pairs of forces are different type and acts on different bodies.
B. Pairs of forces are the same type and acts on the same bodies.
C. Pairs of forces are different type and acts on the same bodies.
D. Pairs of forces are the same type and acts on different bodies.

60. A 15g bullet from a pistol strikes a 2kg ballistic pendulum. Up on impact the pendulum swings forward and rises to a height of 20cm. what was the velocity of the bullet immediately before impact? (given; $g = 10m/s^2$)

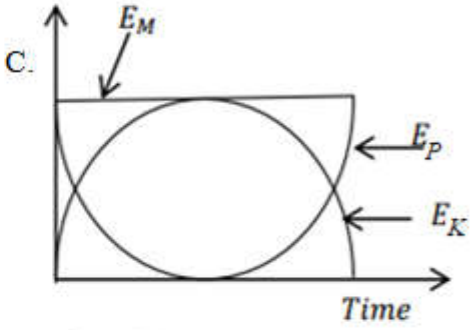
A. 280m/s
C. 268.6m/s
B. 258.6m/s
D. 286m/s

61. A pendulum is pulled to one side and released. It swings freely to the opposite side and stops. Which of the following might best represent graphs of kinetic energy (E_K), potential energy (E_P) and total mechanical energy (E_M)

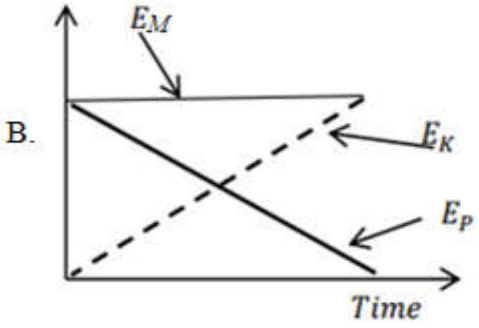
A.



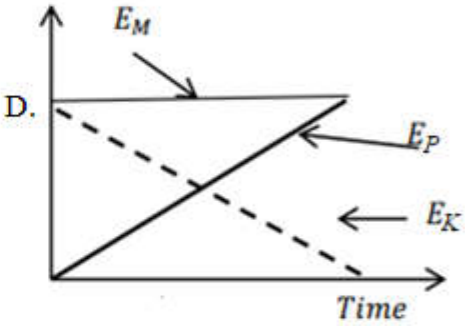
C.



B.



D.



62. Consider two masses 2kg and 5kg moving along the same line in opposite direction with velocities of 4m/s and 2m/s respectively. If the masses make an elastic collision, what are the velocities of each of the masses after collision?

A. $\frac{10}{7}\text{m/s}$, $\frac{32}{7}\text{m/s}$

B. $\frac{10}{7}\text{m/s}, -\frac{32}{7}\text{m/s}$

C. $\frac{7}{10}\text{m/s}$, $\frac{7}{32}\text{m/s}$

D. $\frac{7}{10}\text{m/s}, -\frac{7}{32}\text{m/s}$

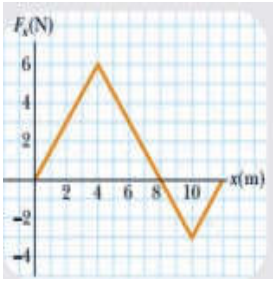
63. The force acting on a particle varies as shown below. What is the work done by the force on the particle as it moves from, $\text{x} = 0$ to $\text{x} = 10\text{m}$?

A. 21J

B. 24J

C. 12J

D. 27J



64. A block of mass 10kg is pulled up a rough inclined plane with a force of 100N parallel to the inclined plane. The inclined plane makes an angle of 37^0 with the horizontal. At the instant when the force is applied, the block has a speed of 1.5 m/s. if the coefficient of kinetic friction is 0.4 and the block is pulled up 5m, what is the change in kinetic energy of the block?(use: $\sin 37^0 = 0.6018, \cos 37^0 = 0.7986$)

A. 20J B. 40J C. 30J D. 45.5J

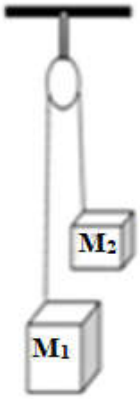
65. Two particles are make collision when they are moving along straight path. Before and after collision the velocities of particles are given according to the following table.

Particles	**Masses of particles in (kg)**	**Velocities of particles in (m/s)**	
		Before collision	After collision
X	4.5	6.8	4.8
Y	8.5	-12.5	-11.44

Which type of collision is occurred between the particles?

A. Elastic collision
B. Inelastic collision
C. Perfectly inelastic collision
D. Perfectly elastic collision

66. Two masses $\mathbf{M_1}$ and $\mathbf{M_2}$ are attached to the end of a light string passing over a pulley. What is the acceleration of the system?



A. $g\left(\frac{M_1 - M_2}{M_1 + M_2}\right)$
B. $g\left(\frac{M_2 - M_1}{M_1 + M_2}\right)$
C. $g\left(\frac{M_1 + M_2}{M_1 - M_2}\right)$
D. $g\left(\frac{M_1 + M_2}{M_2 - M_1}\right)$

67. Pick the **CORRECT** statement about center of mass:

A. The position of the Center of mass is not fixed in a rigid body.
B. If the masses of the particles were equal, we could find the Center of mass by calculating the quarter of the line.
C. The position of the Centre of mass of a rigid body is at its geometric center.
D. It is impossible to determine the location of Centre of mass for 3D objects.
E. The center of mass of the object cannot be out of its parts.

UNIT FIVE

5. HEAT CONDUCTION AND CALORIMETRY

INTRODUCTION

Everywhere you look including yourself, energy transfer taking place in different forms. One of such energy transfer methods is heat transfer. Heat energy is very essential to society. From everyday cooking to some of modern-day luxuries, such as refrigerators and jet engines are using the transfer of heat at the heart of their working principle. Heat is one of the mechanisms to transfer internal energy so that it can be usable. Heat is often misunderstood to be the same as temperature.

- **At the end of this unit, you will be able to:**
  - Gain comprehensive knowledge on basic properties of fluids, thermal properties of matter, phase changes, calorimetry quantitatively and qualitatively.
  - Describe about heat capacity, specific heat capacity, and thermal expansions.
  - Solve calorimetry problems.
  - Use specific heat and heat of transformations in the practical application of calorimetry.

5.1. The Concept of Heat

- **At the end of this section, you will be able to:**
  - Explain the concept of heat.
- Heat is the energy which is in transit from one body to another as the result of a difference in temperature.
- Heat and work are two different ways of transferring energy from one system to another.
- Heat is the transfer of thermal energy between systems, while work is the transfer of mechanical energy between two systems.

5.2. Heat transfer mechanisms

- **At the end of this section, you will be able to:**
  - Explain the concept of heat transfer
- Heat transfer mechanism is the mechanisms in which heat transfer from one system to another.
- Heat always transfers from a system of high temperature to low temperature, until the temperature of the two systems becomes equal.
- If the temperature of the two systems is equal, heat cannot transfer from one system to another.
- There are **three** heat transfer mechanisms:

Conduction: is the process by which heat energy is transmitted through collisions between neighboring atoms or molecules.

Convection: is the transfer of heat from one place to another due to the movement of fluid.

Radiation: heat transfer occurs via electromagnetic waves. Unlike conduction and convection, radiation does not need a medium for transmission.

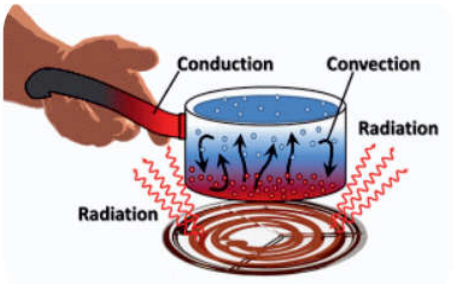


Figure 5.1. The three heat transmission mechanism

5.3. Heat Capacity and Specific Heat Capacity

- **After completing this section, you should be able to:**
  - Differentiate between heat capacity and specific heat capacity
  - List the specific heat capacity of various materials

Heat capacity: is the amount of heat required to raise the temperature of an object by 1℃ or 1K.

- Mathematically, given by:

$$C = \frac{Q}{\Delta T}$$

Where, C = heat capacity

Q = amount of heat transferred to the object

ΔT = change in temperature

- The SI unit of heat capacity is J/ ℃ or J/K

Specific heat capacity: is the amount of energy required to raise the temperature of 1kg of the substances by **1℃ or 1K.**

$$c = \frac{Q}{m\Delta T}$$

Where, c = specific heat capacity

- The SI unit of specific heat capacity is J/kg ℃ or J/kg. K

Example: Calculate the heat energy transferred if the temperature of 600g of lead is raised from 20℃ to 100℃ .

Given: $c_{pb} = 128\ J/kg.K$

$m = 600g = 0.6kg$

$\Delta T = 80K$

Solution: $Q = mC\Delta T = 0.6kg \times 128J/kg.K \times 80K = 6144.0J$

SELF TEST-10

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. Which one of the following is **FALSE** about **heat?**

A. Heat is the transfer of energy between the systems due to temperature differences.

B. Heat is the transfer of thermal energy between systems.

C. Heat is not something you get it sitting down or at stationary point.

D. There is a heat transfer between systems of equal temperature.

2. Pick the **invalid** statement

A. Conduction is the process by which heat energy is transmitted through collisions.

B. Convection is the transfer of heat from one place to another due to the movement of fluid.

C. Radiation is heat transfer occurs via electromagnetic waves.

D. Like conduction and convection, radiation does not need a medium for transmission.

3. The **SI** unit of specific heat capacity is:

A. J/kg. ℃ B. J/kg. °F C. J/kg. K D. All except B

4. What is the heat transferred if the temperature of 500g of gold is raised from, 20℃ to 80℃ ? (Given that, the specific heat capacity of gold ($\mathbf{c_{Au} = 129\ J/kg}$. ℃)

A. 3870J C. 1290J

B. 5160J D. 1356J

5. What is the temperature increase of **50kg** of steel falling from a height of **50m** if **50%** of its kinetic energy is converted into heat and assume no heat flow to the surrounding? ($\mathbf{c_{steel} = 448\ J/kg.℃}$

A. 5.6℃ C. 1.56℃

B. 0.56℃ D. 2.56℃

6. Which one of the following quantity should **NOT** be necessary known in order to determine the specific heat capacity of substance?

A. The mass of substance C. The change in temperature

B. The amount of heat energy supplied D. The weight of substance

5.4. Thermal expansion

- **After completing this section, you should be able to:**
  - Solve problems associated with thermal expansion.

Thermal expansion: is the change in size of matter in response to a change in temperature.

- Thereby, the particles start to vibrate and move and usually maintain a greater average separation.
- Except in some cases, most substances expand when heated and contact when cooled.
- Thermal expansion is also affected by the properties of the substance.

- Solids expand very less as compared to liquids and gases.
- This happens because intermolecular force of attraction is very strong in solids, intermediate in liquids and very weak in gases.
- All factors that affect thermal expansion will be treated below.
- Thermal expansion can be classified in to three:

Linear expansion: if the change in length is along one dimension (length) over the volume due to a change in temperature, it is called linear expansion.

- Suppose an object has an initial length of L_0 at some initial temperature T_0. Let the length be changed to L when the temperature is changed to T. experiments show that if the change in temperature is not too large, the changes in length is directly proportional to change in temperature and change in length. Then the change in length is defined as:

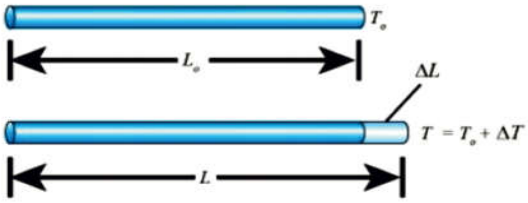
$$\Delta L = L_0 \alpha \Delta T$$

Where, $\Delta L = \text{change in length} = L - L_0$

$\Delta T = \text{change in temperature} = T - T_0$

$L_0 = \text{original length}$

$\alpha = \text{Linear coefficient of expansion}$



Example: A steel bridge is built in several segments, each 20m long. The bridge was constructed when the temperature was 20°C. If a gap of 4cm is left between neighboring segments what would be the maximum temperature that the bridge can manage before buckling?

Given: $\Delta L = 4\text{cm} = 0.04\text{m}$

$\Delta T = 20°\text{C}$

$L_0 = 20\text{m}$

$\alpha = 1.1 \times 10^{-5}\text{K}^{-1}$

Solution:

$$\Delta T = \frac{\Delta L}{\alpha L_0} = \frac{0.04\text{m}}{1.1 \times 10^{-5}\text{K} \times 20\text{m}} = 180\text{K}$$

Therefore,

$$T = \Delta T + T_0 = 180\text{K} + 20\text{K} = 200\text{K}$$

Such big change in temperature may occur if there are exceptional moments such as flowing volcano over the bridge.

Area expansion: is two dimensional expansions, in which an object expands both in length and width.

- Consider the plate of surface area A_0 at a temperature T_0, as shown in figure 5.3. for small change in temperature of ΔT, the change in area ΔA is given by:

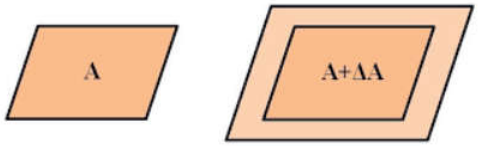
$$\Delta A = A_0 \beta \Delta T$$

Where, $\Delta A = \text{change in area} = A - A_0$

$\Delta T = \text{change in temperature} = T - T_0$

$A_0 = \text{original area}$

$\beta = \text{surface coefficient of expansion}$



- The relationship between α and β is given by:

$$\beta = 2\alpha$$

Example: The surface area of one side of a circular brass plate at temperature 100°C is 3850 cm^2. To put this plate inside a cylinder, you need to cool it to 0 °C. What is the base area of the cylinder?

Given: $T_0 = 100℃, \quad T = 0℃, \quad A_0 = 3850cm^2, \quad \alpha_{brass} = 1.9 \times 10^{-5}K^{-1}$

Solution: $A = A_0(1 + 2\alpha\Delta T) = 3850cm^2(1 + 2 \times 1.9 \times 10^{-5}K^{-1} \times 100K) = 3835.37cm^2$

Therefore, In order for the plate to pass into the cylinder, either side of its surface area should be reduced to below 3835.37 cm^2.

Volume expansion: When the length, width and thickness of the object are increases as the temperature increases.

- Volume expansion is three dimensional expansions.
- Consider the cube of volume V_0 at a temperature T_0. For small change in temperature of ΔT, the change in volume ΔV is given by:

$$\Delta V = V_0 \gamma \Delta T$$

Where, $\Delta V = \text{change in volume} = V - V_0$

$\Delta T = \text{change in temperature} = T - T_0$

$V_0 = \text{original volume}$

$\gamma = \text{volume coefficient of expansion}$

- The relation of γ with α and β is given by:

$$\gamma = 2\beta = 3\alpha$$

- The real and apparent coefficient of volume expansion is given by:

$$\gamma_{real} = \gamma_{apparent} + \gamma_{container}$$

Thermal expansion of gases: gases expand more at ordinary temperature than solid and liquid.

- In the case of gases, both temperature and pressure determine the change in volume of the gas.
- Increasing the temperature leads to increase in volume of the gas while the increase in pressure leads to decrease in volume.
- In this case, you cannot use the method used in liquids and solids to determine the volume expansion coefficient of a gas.

Some applications of thermal expansion are:

- Riveting two metal sheet tightly
- Bimetallic strip

SELF TEST-11

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. Which one of the following expansion of objects or substances are one dimensional, two dimensional and three dimensional respectively?

A. Linear expansion, Volume expansion, Surface expansion
B. Volume expansion, Linear expansion, Surface expansion
C. Surface expansion, Linear expansion, Volume expansion
D. Linear expansion, Surface expansion, Volume expansion

2. A steel bridge is built in several segments, each **20m** long. the bridge was constructed when the temperature was **20°C**. If a gap of **4cm** is left between neighboring segments. What would be the maximum temperature that the bridge can manage before buckling? $(\boldsymbol{\alpha_{steel} = 1.1 \times 10^{-5} K^{-1}})$

A. 100℃ C. 180℃
B. 200℃ D. 20℃

3. A physics student derived the formula for the surface expansion, $\Delta\mathbf{A}$, of a rectangular plate in terms of its linear expansion coefficient, $\boldsymbol{\alpha}$. which of the following formulas is possibly derived by the student? (Assume that $\Delta\mathbf{T}$ is the change in temperature of the plate and $\mathbf{A_0}$ is its initial area)

A. $\Delta A = 3A_0\alpha\Delta T$ C. $\Delta A = A_0\alpha\Delta T$
B. $\Delta A = 2A_0\alpha\Delta T$ D. $\Delta A = \frac{1}{2}A_0\alpha\Delta T$

4. Pick the **INCORRECT** statement:

A. Gases expand more at ordinary temperature than solid and liquid.

B. Both temperature and pressure determines the change in volume of gases.

C. Increasing the temperature leads to increase in the volume of the gas.

D. Increase the pressure leads to increase in volume of the gas.

5. Mercury of volume **10000cm^3**, which is filled in a brass container, is heated from **10°C** to **80°C**. What will be the real and apparent volume expansions of mercury in the brass container respectively? $(\boldsymbol{\gamma_{Mercury} = 18 \times 10^{-5} K^{-1}}$ **and** $\boldsymbol{\gamma_{brass} = 5.7 \times 10^{-5} K^{-1}})$

A. 126cm^3 and 100cm^3 C. 126cm^3 and 86cm^3

B. 60cm^3 and 126cm^3 D. 86cm^3 and 126cm^3

6. The length of a copper wire at **0°C** is **100cm** and it is shorter by **0.05 cm** from a steel wire at the same temperature. To what value should the temperature on the two wires be increased so that the two wires attain the same length?

given: $(\boldsymbol{\alpha_{Cu} = 17 \times 10^{-5} °C^{-1}}$ **and** $\boldsymbol{\alpha_{steel} = 11 \times 10^{-6} °C^{-1}})$

A. 96.52℃ C. 75.56℃

B. 83.41℃ D. 45.54℃

7. Two brass rods and one steel rod of equal length L_0 and equal cross-sectional are joined rigidly at their ends. All rods are in the state of zero tension at **0° C**. What is the length of the system when the temperature is increased to **T**? $(\boldsymbol{\alpha_b = \alpha_{brass}}$ **and** $\boldsymbol{\alpha_s = \alpha_{steel}})$

A. $L = [3 + (2\alpha_b + \alpha_s)T]L_0$ C. $L = [3 + (\alpha_b + \alpha_s)T]L_0$

B. $L = [3 + (\alpha_b + 2\alpha_s)T]L_0$ D. $L = [3 + (\alpha_b + 3\alpha_s)T]$

5.5. Change of phase

- At the end of this section, you will be able to:
  - Discuss the phenomena of change of phase

Change of phase: is the transition from one phase to another phase (solid to liquid, liquid to gases and vice versa).

Latent heat: is the energy absorbed or released by a substance during a change in its physical state (phase) that occurs without changing its temperature.

- The amount of heat absorbed or released by an object of mass, m is given by:

$$\boxed{Q = mL}$$

Where, L is called latent heat fusion of substance

- Latent heat depends on the nature of the phase changes as well as on the properties of the substances.

Latent heat of fusion (L_f): is the amount of heat absorbed by 1kg of a substance from solid to liquid leaving the temperature of the system unaltered.

Latent heat of vaporization (L_V): is the amount of heat absorbed by 1kg of the substance to change its phase from liquid to gas.

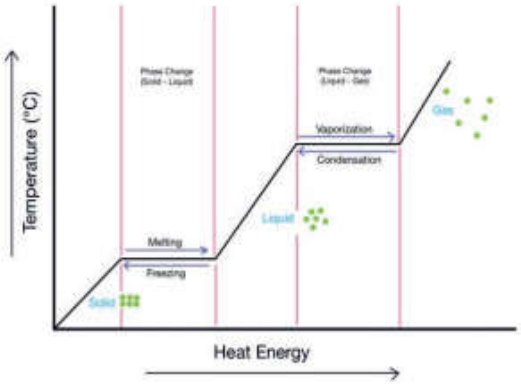


Figure 5.2.Temperatures versus heat diagram

Exercise 5.2

1. Suppose the temperature of **4kg** of water is increased from **-50°C** to steam at **100°C**, at standard pressure. How much energy is absorbed by the water when ice changed into steam?

Given: $\begin{cases} \text{Specific heat capacity of ice } (c_i) = 2100 J/kg\,.K \\ \text{Specific heat capacity of water } (c_w) = 4200 J/kg.K \\ \text{Latent heat of fusion of water } (L_f) = 3.36 \times 10^5 J/kg \\ \text{Latent heat of vaporization of water } (L_v) = 32.25 \times 10^6 J/kg \\ \text{Melting point of water } (T_m) = 0°C \\ \text{Boiling point of water } (T_b) = 100°C \end{cases}$

Phase diagram: is a graphical representation of the physical states of a substance under different conditions of temperature and pressure.

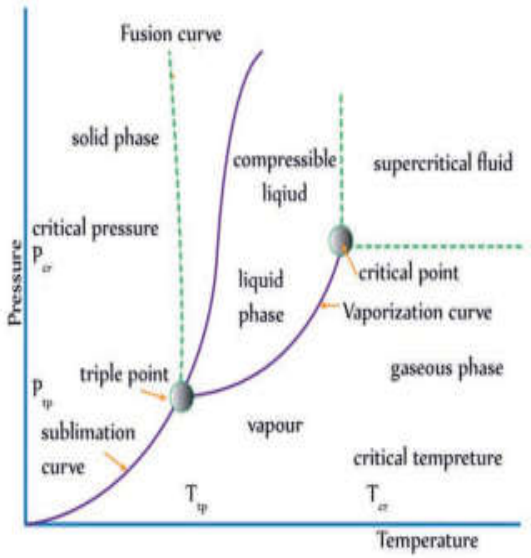


Figure 5.3. Phase diagram

The triple point: represents the combination of pressure and temperature that facilitates all phases of matter at equilibrium.

- Triple point occurs at exactly 273.1600K and a partial vapor pressure of 611.657Pa.

Critical Point: is the point in temperature and pressure on a phase diagram where the liquid and gaseous phases of a substance merge together into a single phase.

- For water the critical point is 647K and 22MPa.

Exercise 5.1

1. Why does the melting point of ice get lower at higher pressures?
2. Define critical temperature. Does it vary with pressure? Is it the same as boiling point?
3. Does the boiling point increase indefinitely with increased pressure?
4. Collect the triple points of water, carbon dioxide, mercury, and zinc, in the internet. Compare temperatures of these at triple point with the corresponding melting points at standard pressure.
5. Is it possible to compress steam to form a liquid if the temperature is higher than 374°C?
6. Calculate the heat energy required to melt 10 g of copper at its melting point. (Lf for copper = 209 000 J/kg).
7. Calculate the heat energy released to cool 0.1kg of aluminum from 2,470°C (boiling point of Al) of aluminum gas to solid aluminum at 660.3°C (melting point of Al) at standard pressure.

5.6. Calorimetry

- **At the end of this section, you will be able to:**
  - Solve problems associated with Calorimetry.
  - Investigate a phenomena related with heat capacity from every day experience.

Calorimetry: is the measurement of the quantity of heat exchanged between substances.

- The law of calorimetry state that, the amount of heat absorbed by cold body is equal to the amount of heat lost by hot body.

Heat absorbed by cold body = heat lost by hot body

Example: A 0.05 kg bar of unknown metal is heated to 200.0°C and then immersed into a container with 0.40 kg of water initially at 20.0°C. If the final equilibrium temperature of the system is 22.4°C, find the specific heat of the metal.

Solution: by using the law of calorimetry,

$$Q_w = -Q_s$$

$$m_w c_w (T_f - T_c) = -m_s c_s (T_f - T_h)$$

By inserting the above given we have,

$$0.4\text{kg} \times 4186\text{J/kg} \times (22.4℃ - 20.0℃) = -0.05\text{kg} \times c_s \times (22.4℃ - 200.0℃)$$

Solving this for c_s we have,

$$c_s = 453 J/kg.℃$$

- For a given mass, m_s and change in temperature, ΔT, the specific heat capacity c_s can be determined from the principle of calorimetry as:

$$Pt = m_s c_s \Delta T$$

Where, P = power rating of the heater

Example: A 100W electrical heater, running for 5 minutes, warmed a 0.50 kg block of an unknown metal. The initial temperature of the metal block was 20.0 °C and its final temperature was 86.6 °C. Determine the type of the metal.

Solution:

$$c_s = \frac{Pt}{m_s c_s \Delta T} = 900.90 J/kg.℃$$

Summary of unit

- Heat is energy in transit due to temperature deference.
- Two objects are said to be in thermal equilibrium if they are equal in temperature.
- Two or more objects, which are in thermal equilibrium, do not exchange heat energy.
- Internal energy of a system or a body with well defined boundaries is the total of the kinetic energy due to the motion of molecules and the potential energy associated with the vibrational motion and electric energy of atoms within molecules. It includes the energy in all the chemical bonds.
- Internal energy increases with rising temperature and with changes of state or phase from solid to liquid and liquid to gas.
- Heat and work are two different ways of transferring energy from one system to another.
- Heat is the transfer of thermal energy between systems, while work is the transfer of mechanical energy between two systems.
- Heat can be transformed into work and vice verse, but they aren't the same thing.
- Heat and work both contribute to the total internal energy of a system.
- Conduction is the process by which heat energy is transmitted through collisions between neighboring atoms or molecules.
- Convection (or convective heat transfer) is the transfer of heat from one place to another due to the movement of fluid.
- Radiation heat transfer occurs via electromagnetic waves.
- Unlike conduction and convection, radiation does not need a medium for transmission.

- Thermal expansion is the tendency of matter to change in shape, volume, and area in response to a change in temperature.
- Thermal expansion of solids can be classified in to three: linear expansion, surface (area) expansion and volume expansion. We can determine only cubic thermal
- Latent heat depends on the nature of the phase change as well as on the properties of the substance.
- Latent heat of fusion is the amount of heat absorbed to convert a unit mass of a substance from solid to liquid - leaving the temperature of the system unaltered.
- Latent heat of vaporization is the amount of heat absorbed to change a unit mass of liquid to gas.
- Phase diagram is a graphical representation of the physical states of a substance under different conditions of temperature and pressure.
- The triple point represents the combination of pressure and temperature that facilitates all phases of matter at equilibrium.
- Critical Point is the point in temperature and pressure on a phase diagram where the liquid and gaseous phases of a substance merge together into a single phase.
- Calorimetry is the measurement of the quantity of heat exchanged between substances.
- The experimental approach of measuring heat capacities and the heat changes during chemical and physical processes is called calorimetry.
- Calorimeter is a device used to measure specific heat capacity and specific latent heat of solids or liquids.
- There are several methods we can use to determine the specific heat capacity of a substance, but all methods always involve heat exchange and the following should be known:
    - The mass of the substance.
    - The amount of heat energy supplied.
    - It's starting temperature.
    - The final temperature.
- The law of calorimetry states that for an isolated system, the heat energy lost from the hot body will equal the heat gained by the cold body (Heat gained by cold object = Heat lost by hot object).

Key terms: *calorimetry, conduction, convection, expansion, latent heat, heat capacity, phase change, radiation, specific heat, thermal expansion.*

Study time: Total study time for this unit is **20 hours.**

UNIT SIX

6. ELECTROSTATICS AND ELECTRIC CIRCUIT

INTRODUCTION

Electrostatics is the study of the properties of electric charges at rest and current electricity is the study of properties of charges in motion. The main difference between static and current electricity is that with static electricity, the charges are stationary and build on the surface of an insulator, while in current electricity electron flowing through a conductor form what we call an electric current.

- **At the end of this unit, you will be able to:**
  - Calculate the electric field resulting from a point charge.
  - Determine the magnitude and direction of the electric force among any point charges.
  - Acquire knowledge and understanding in electrostatic phenomenon.
  - Demonstrate an understanding of the components and functions of electrical circuits that are commonly found at home and in the workplace.
  - Construct, analyze, simple electrical circuits, using schematic diagrams, working with electrical tools and components, and examining small everyday electrical devices and appliances.
  - Define a capacitor and explain some of its applications in life.
  - Apply Kirchhoff's rules to solve circuit problems.

6.1. Coulomb's Law

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

- State Coulomb's law.
- Calculate the magnitude and direction of electric force between any two charges.
- Solve problems involving Coulomb's law.
- Explain Coulomb's law using the idea of vectors.
- Explain the meaning of a coulomb.

Charge: is the fundamental property of matter associated with electrons and protons which are found in any atom.

- There are only two types of charges: negative and positive charges.
- By convection, negative charges are carried by electrons and positive charges are carried by protons.
- A negatively charged object contains more electrons than protons and a positively charged object contains more protons than electrons.
- The SI unit of charge is called Coulomb (C).

Properties of charges: some properties of charges are listed below:

1. There are two kinds of electric charges.
2. Two similarly charged bodies repel each other and two oppositely charged bodies attract each others.

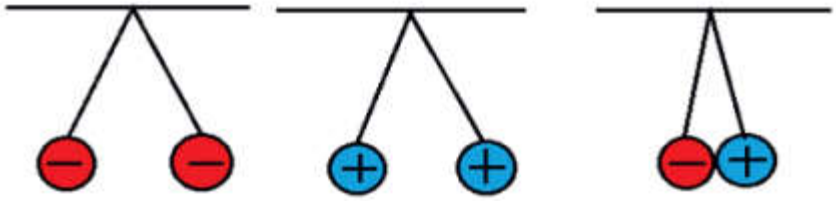


Figure 6.1 Like charges repel and unlike charges attract each others.

3. Electric charge is always conserved, i.e., it cannot be created or destroyed. In any charging process, the number of electrons gained by one object is equal to the number of electrons lost by the other.
4. Electric charge is quantized. Charge comes in discrete packets; it means that charge (q) always occurs as some integral multiple of the charge of an electron (e). it can be written as: $q = \pm ne$ (where $n = 1,2,3, \dots$)

- The smallest unit of charge that is carried by one electron and proton is called the elementary charge (e).
- The magnitude of the charge of an electron is:

$$\boxed{1e = -1.6 \times 10^{-19}C}$$

- The charge carried by a proton is also the same as that of the charge carried by an electron except it is positive.

$$\boxed{1p = +1.6 \times 10^{-19}C}$$

Example: What number of protons needed to make a charge of +1.0 C?

Solution: $n = \frac{q}{e} = \frac{1C}{1.6\times10^{-19}C} = \mathbf{6.25 \times 10^{28}}$ **protons**

Electrostatic Force: a force of attraction or repulsion between two charged bodies is known as the electrostatic force.

- Electrostatic force is either attractive or repulsive, unlike the gravitational force which is only attractive.
- If objects have opposite charges they attract each other, while if their charges are similar, they repel each other.

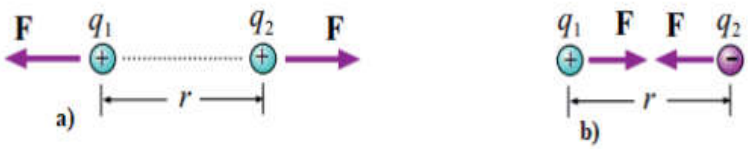


Figure 6.2 repulsive and attractive forces between two charges

Coulomb's law: state that, the force between two charges is directly proportional to the product of the magnitude of the two charges and inversely proportional to the square of the separation between the two charges.

- Mathematically, coulomb's law is given by:

$$F = K\frac{|q_1||q_2|}{r^2} = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$

Where, $K = \text{Coulomb constant} = 9 \times 10^9\ Nm^2/C^2$

Example: Two tiny spherical water drops with identical charges of $-1 \times 10^{-10}C$, have a center-to-center separation of 10.0cm. a) What is the electrostatic force acting between them? b) How many excess electrons are on each drop giving it its charge imbalance?

Solution:

a) $F = K\frac{|q_1||q_2|}{r^2} = 9 \times 10^9 Nm^2/C^2 \frac{1 \times 10^{-10}C \times 1 \times 10^{-10}C}{(0.1m)^2} = 9.0 \times 10^{-17}N$

b) $n = \frac{q}{e} = \frac{1 \times 10^{-10}C}{1.6 \times 10^{-19}C} = \mathbf{6.25 \times 10^8}$

This means $\mathbf{6.25 \times 10^8}$ electrons give this charge imbalance so that the two charged water $9.0 \times 10^{-17}N$ drops exert of repulsive force to each other.

Force on a Charge due to Multiple Electric Charges: electrostatic force is a vector quantity. Therefore, if there are more than one force acting on a charged particle, then the resultant force acting on the particle will be the vector sum of all these forces. This is known as the superposition principle.

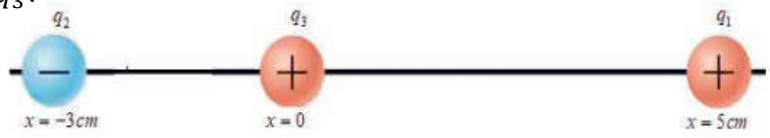
- Consider a system of n stationary charges $q_1, q_2, q_3 \ldots q_n$ in vacuum. The force on q_1 *due to* $q_2, q_3 \ldots q_n$ is obtained by taking the vector sum of the individual forces.

$$\vec{F}_{net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} \ldots . \vec{F}_{1n}$$

Where, F_{12} is the force that charge q_2 exert on q_1, F_{13} is the force that q_3 exert on q_1, $\ldots F_{1n}$ is the force that q_n exert on q_1.

Example: three point charges are placed on the x-axis: q_1= +6μC at x_1 = 5.0cm, q_2 = -5μC at x_2 = -3.0cm, and q_3 = +2μC at the origin (x = 0). What is the magnitude and direction of the total electrostatic force acting on q_3?

Solution:



$$F_{13} = K\frac{|q_1||q_3|}{r_{13}^2} = 9 \times 10^9 Nm^2/C^2 \frac{6 \times 10^{-6}C \times 2 \times 10^{-6}C}{(0.05m)^2} = 43.2N, \text{to the left.}$$

$$F_{23} = K\frac{|q_1||q_3|}{r_{23}^2} = 9\times10^9 Nm^2/C^2\,\frac{5\times10^{-6}C\times2\times10^{-6}C}{(0.03m)^2} = 100N, \text{to the left.}$$

Therefore, the net electrostatic force exerted on q_3 is given by:

$$F_R = F_{13} + F_{23} = 143.2N, to\ the\ left = (-143.2N)i$$

Exercise 6.1

1. Two charges +3μC and +12μC are fixed 1 m apart, with the second one to the right. Find the magnitude and direction of the net force on a -2μC charge when placed halfway between the two.
2. Two small, identical conducting spheres repel each other with a force of 0.050N when they are 0.25m apart. After a conducting wire is connected between the spheres and then removed, they repel each other with a force of 0.060N. What is the original charge on each sphere?

6.2. Electric Fields

- At the end of this section, you will be able to:
  - Define the terms, electric field, and electric flux.
  - Sketch electric field lines.
  - Solve problems involving electric field.
  - Map an electric field lines pattern using electric lines of force.
  - Calculate the magnitude and direction of electric field due to a point charge and two point charges.

Electric field: is a region in space where one charge experiences a force from another charge.

- Electric field is a vector quantity.
- The direction of electric field is depends on the sign of charges.
- Always the direction of electric field is outward from positive charge and inward to negative charge.

Electric field lines: the line that are used to indicate the direction of electric fields.

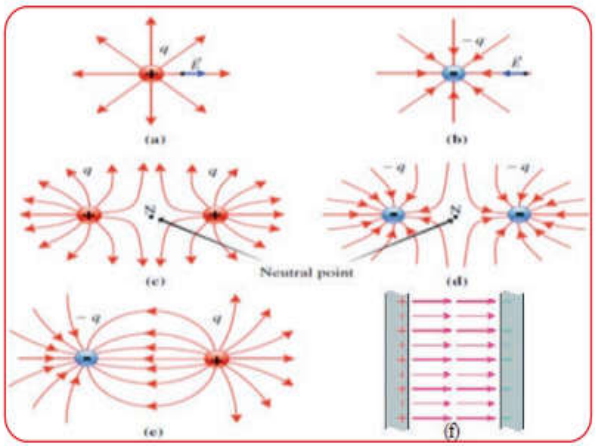


Figure 6.3 the direction of electric field indicated by electric field lines.

Properties of electric field lines are:

1. Electric field lines do not cross each other.
2. Electric field lines begin on positive charges and radiate away from them toward negative charges, where they terminate.
3. Electric field lines are always perpendicular to the surface of the charged body.
4. The closer the lines, the stronger the electric field, and the farther apart they are the weaker is the field.
5. Equally spaced electric field lines indicate the field is uniform. The electric field between two parallel plates is a common example of a uniform electric field.

Electric field strength: is the electric force per unit of charge and given by:

$$E = \frac{F}{q} = K\frac{Q}{r^2}$$

Where E is the electric field strength due to a point charge Q, and r is the distance from charge Q to the point of interest.

- The electric field strength is depends on the source charge and the distance r, it is independent of the test charge.
- The SI unit of electric field strength is Newton per meter (N/m).

Example: Calculate the strength and direction of the electric field E due to a point charge of 2.0 nC (nano-Coulombs) at a distance of 5.0 mm from the charge.

Solution:

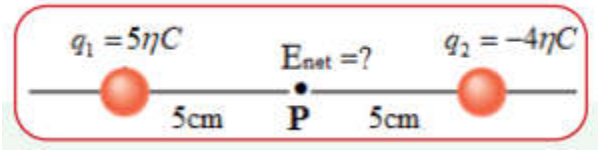
$$E = K\frac{Q}{r^2} = 9\times10^9 Nm^2/C^2 \times \frac{2.0\times10^{-9}C}{(0.005m)^2} = 7.2\times10^5 N/C, \text{away from charge}$$

- The electric field due to multiple charges is given by:

$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 \ldots . \vec{E}_n$$

Example: Two-point charges $q_1 = 5\mu C$ and $q_2 = -4\mu C$ and are separated by a distance of 10 cm. What is the magnitude of the electric field in between the charges?

Solution:



$$\vec{E}_1 = K\frac{q_1}{r_1^2} = 9\times\frac{10^9 Nm^2}{C^2}\times\frac{5.0\times10^{-9}C}{(0.05m)^2} = 1.8\times10^4 N/C$$

$$\vec{E}_2 = K\frac{q_2}{r_2^2} = 9\times10^9 Nm^2/C^2 \times\frac{-4.0\times10^{-9}C}{(0.05m)^2} = 1.44\times10^4 N/C$$

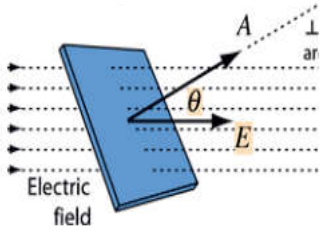
Therefore, the net electric field is given by:

$$\vec{E}_{net} = \vec{E}_1 + \vec{E}_2 = 3.24 \times 10^4 \text{N/C to the right} = (3.24 \times 10^4 \text{N/C})i$$

Electric flux: is a measure of the number of electric field lines that cross a given area.

- Electric flux is scalar quantity.
- Its SI unit is Nm^2/C.
- The product of the electric field and the surface area A, perpendicular to the field is called the electric flux and represented by the symbol Φ and given by:

$$\Phi = E.A = EAcos\theta$$



Where, Φ = electric flux

EAcosθ = the projection of area normal to E

Example: A 2cm × 2cm square lies in the xy-plane. Find the electric flux through the square for the electric field vectors, $\vec{E} = (50i + 20j)N/C$.

Solution: $\Phi = E.A = (50i + 20j)N/C.(4 \times 10^{-4}k)m^2 = 0.02Nm^2/C$

Exercise 6.2

1. Define the following terms, (a) electric field, (b) electric field strength, (c) electric field lines, and (f) electric flux.
2. Map electric field lines for different arrangement of charges.
3. Compare and contrast the following gravitational quantities with their counterpart electrical quantities:
   - **A.** Gravitational field and electric field.
   - **B.** Gravitational field strength and electric field strength
4. How field lines indicate the magnitude of the field they represent?
5. What is the net electric field strength at point P in the system shown below?

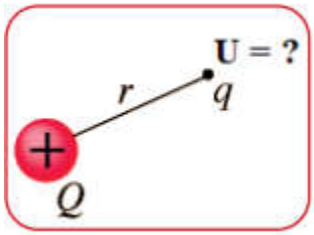
6. A particle of charge 2 x 10^{-8} C experiences an upward force of magnitude 4 x 10^{-6} N when it is placed in a particular point in an electric field.
   (a) What is the electric field at that point?
   (b) If a charge q = -1.0 x 10^{-8} C is placed there, what is the force on it?

6.3. Electric Potential

- **At the end of this section, you will be able to:**
  - Define the terms electric potential, equipotential surface.
  - Solve problems involving electric potential.
  - Explain the meaning of a volt, potential difference, and emf.

Electric potential energy: we define electrical potential energy of a test charge q in terms of the work done on the charge q. work done by the external force in bringing a unit positive charge from one point to another and given by:

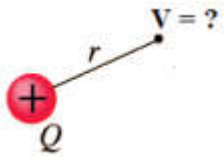
$$U = \frac{KqQ}{r}$$



Electric potential: is defined as the work done per unit positive charge to move a positive test charge from infinity to its current position within an electric field.

- The equation of electric potential at a distance r from a source charge is given by:

$$V = K\frac{Q}{r}$$



- Electric potential is scalar quantity and its SI unit is Volt (V).

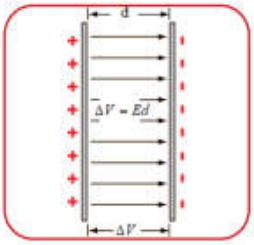
Example: Determine the electric potential produced by a charge of 1μC at a distance of 1mm from it.

Solution:

$$V = K\frac{Q}{r} = 9 \times 10^9 Nm^2/C^2 \times \frac{1 \times 10^{-6} C}{0.001m} = 9MV$$

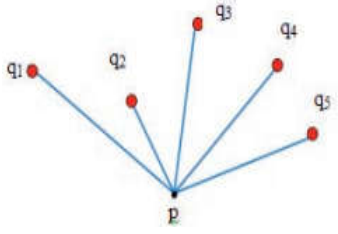
- The potential difference due to uniform electric field (field between parallel plates) is given by:

$$V = Ed$$



- The electric potential due to multiple charges is given by:

$$V = V_1 + V_2 + V_3 + \cdots + V_n$$



Example: Calculate the change in electrical potential energy in moving a 1nC from 5cm to 0.1 cm from a charged sphere with a charge of $1\mu C$.

Solution: $U = W = q\Delta V = q(V_B - V_A) = q\left(\frac{KQ}{r_B} - \frac{KQ}{r_A}\right)$

$$= 9 \times 10^9 Nm^2/C^2 \times 10^{-6}C \times 10^{-9}C\left(\frac{1}{0.01} - \frac{1}{0.05}\right) = 72mJ$$

Equipotential lines: are lines connecting points of the same potential.

- Characteristics of equipotential lines or surfaces are:
  1. Two equipotential lines never intersect each others.
  2. The equipotential lines of a uniform field are parallel to each other and the equipotential lines of a point charge are concentric sphere.
  3. Since the electric field (E) is stronger near the charge, so equipotential surfaces of point charge are crowded near the charge.
  4. No work is required to move a charge along an equipotential line because there is no change in potential.
  5. Equipotential lines are always perpendicular to the electric field lines.

Exercise 6.3

1. Two charges 3×10^{-8}C and -2×10^{-8}C are located 15cm apart. At what point on the line joining the two charges is the electric potential zero? Take the potential at infinity to be zero.
2. What are the signs and magnitudes of a point charge that produces a potential of -2.0V at a distance of 1.0 mm?
3. What is the strength of the electric field between two parallel conducting plates separated by 1.0 cm and having a potential difference between them of 1.5V?
4. Two-point charges are located on the corners of a rectangle with a height of 0.05m and a width of 0.15m. The first charge ($q_1 = -5\mu C$) is located at the upper left-hand corner, while the second charge ($q_2 = +2\mu C$) is at the lower right-hand corner.
   (a) Determine the electric potential at the upper right-hand corner of the rectangle.
   (b) What is the potential difference for a point at the right-hand corner of the rectangle relative to the lower left-hand corner?
5. Two point charges 10pC and -2pC are separated by a distance of 1.0. Find the potential mid-way between them.

6.4. Electric Current, Resistance and ohm's law

- **At the end of this section, you will be able to:**
  - Define the terms electric current, current density, resistance, conductivity, resistivity and drift velocity.
  - Explain the effect on the current (brightness) and potential difference of connecting light bulbs in series.
  - Explain the effect on the current (brightness) and potential difference of connecting light bulbs in parallel.
  - Draw electric circuits consisting of three resistors connected in series and parallel.
  - Determine equivalent resistance of resistors connected in series and parallel.
  - Describe the principles of potentiometer and Wheatstone bridge.
  - Describe how to convert galvanometer to a voltmeter and ammeter.
  - Explain the meaning of an ohm, resistance.
  - Explain the SI units of electric current, current density, resistance, resistivity, conductivity.
  - State and apply Kirchhoff's laws.
  - Solve problems involving network of resistors.

Electric current: is the flow of charge.

- Electric current is defined as the rate of flow of charges through some cross-sectional area.
- If the net charge (q) that flows through a cross-sectional area (A) in time (t), then the current (I) is given by the equation:

$$\boxed{I = \frac{\Delta q}{\Delta t}}$$

- The SI unit of current is called Ampere (A).
- One Ampere of current is a flow of one coulomb of charge in one second.

Current density: is the quantity which is used to describe the density of an electric current.

- It is denoted by the symbol (J), defined as the magnitude of the electric current per cross-sectional area.

$$\boxed{J = \frac{I}{A}}$$

- The SI unit of current density is amperes per unit square meter(A/m^2).
- Current density is a vector quantity, which means has both magnitude and direction.
- Current density is also assumed to be proportional to the electric field (E), that produces it, and the conductivity (σ) of the conductor through which it flows.
- Mathematically given by:

$$J = \sigma E = \frac{E}{\rho}$$

Where, σ conductivity of the conductor, and ρ resistivity. The SI unit of resistivity is Ohm meter ($\Omega.m$), where $1\Omega.m = 1V/m$ and the SI unit of conductivity is Siemens per meter (S/m) or Ω^{-1}.

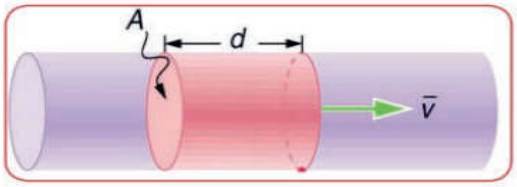
Example: A current of 6mA, flows through a copper wire of correctional are 12mm². What is the current density?

Solution:

$$J = \frac{I}{A} = \frac{6 \times 10^{-3}A}{12 \times 10^{-6}m} = 500A/m^2$$

Drift velocity: is the average velocity attained by electrons.

- In a time interval Δt, an electron moves a distance, $d = v\Delta t$, along the wire. If the number of electrons per unit volume of wire is n then the number of electrons in the shaded cylinder as shown in figure below is $nAv\Delta t$. Therefore the total charge on this volume of electrons is $nAve\Delta t$.



- Therefore, the current in the circuit is given by:

$$I = \frac{Q}{\Delta t} = nAve$$

Exercise 6.4

1. Calculate the mean drift velocity of the electrons in a copper wire of cross-sectional area $5.0 \times 10^{-6}m^2$carrying a current of 1.0 A. there are $8.5 \times 10^{-6}m^2$ free electrons in one m^3 of copper.
2. What are the directions of the following quantities in an electric circuit? (a) electrons, (b) electric current, (c) current density, (d) electric field, and (d) drift velocity

Resistance: is a measure of the opposition to current flow in an electrical circuit.

Ohm's Law: state that, the current in a metal is directly proportional to potential difference between its ends, provided that physical conditions, such as temperature remain constant.

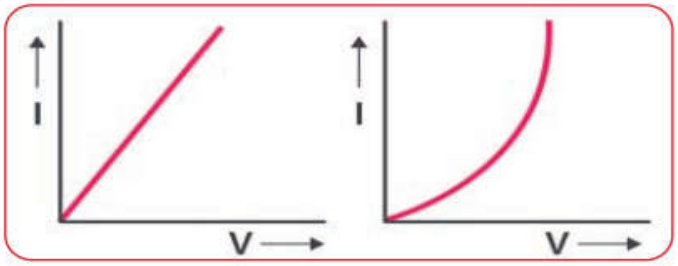


Figure 6.4 current versus voltage for an Ohmic and non-Ohmic conductor

- Mathematically, Ohm's law is given by:

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

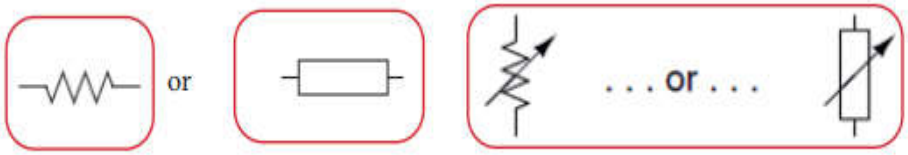
Example: What is the resistance of an automobile headlight through which 2.50A, flows when 12.0V is applied to it?

Solution:

$$R = \frac{V}{I} = \frac{12V}{2.5A} = 4.8\Omega$$

Combination of resistors: resistor is an object of conducting material, having a resistance of desired value.

- in an electric circuit, a resistor is represented by symbol:



a) b)

Figure 6.5 Symbol of a) resistor and b) variable resistor

- There are two basic ways in which to connect more than two resistors. They are series and parallel.

1. **Series combination:** in series connection components are connected end-to-end in a line to form a single path for electrons to flow. The defining characteristic of a series circuit is that there is only one path for electrons to flow.

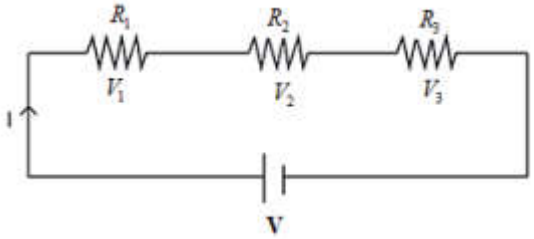


Figure 6.6 Series combination of resistors

- The amount of current through each resistor is the same.

$$\boxed{I = I_1 = I_2 = I_3 = \cdots = I_n}$$

- The total potential difference is given by:

$$\boxed{V = V_1 + V_2 + V_3 + \cdots + V_n}$$

- The total resistance of the circuit is given by:

$$\boxed{R_{total} = R_1 + R_2 + R_3 + \cdots + R_n}$$

2. **Parallel combination:** in parallel connection there are more than one path for electron to flow. The defining characteristic of a parallel circuit is that all components are connected between the same set of electrically common points (P and N).

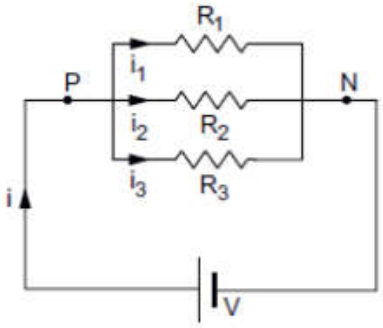


Figure 6.7 parallel combinations of resistors

- The potential difference drops on each resistor is the same.

$$V = V_1 = V_2 = V_3 = \cdots = V_n$$

- The total current through a circuit is given by:

$$I = I_1 + I_2 + I_3 + \cdots + I_n$$

- The total resistance of the circuit is given by:

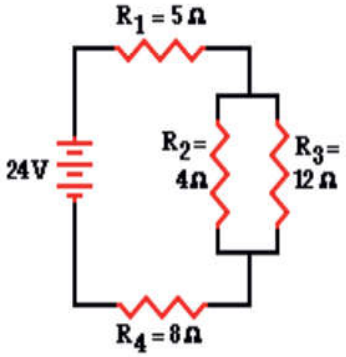
$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$$

Example: For the circuit shown in the figure below, determine:

(a) The equivalent resistance of the circuit

(b) The current through each resistor, and

(c) The potential difference across each resistor.



Solution a) since, $R_2 // R_3$:

$$\frac{1}{R_{23}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{4} + \frac{1}{12}$$

$$R_{23} = 3\Omega$$

Therefore, all resistors are in series and the total resistance is given by:

$$R_{total} = R_1 + R_{23} + R_4 = 5\Omega + 3\Omega + 8\Omega = 16\Omega$$

b) First we have to determine total current by using Ohm's law:

$$I = \frac{V}{R} = \frac{24V}{16\Omega} = 1.5A$$

Therefore, $I = I_1 = I_{23} = I_4 = 1.5A$

By using the value of current we determine the potential difference drops on each resistors.

$$V_1 = I_1R_1 = 1.5A \times 5\Omega = 7.5V$$

$$V_{23} = I_{23}R_{23} = 1.5A \times 3\Omega = 4.5V$$

$$V_4 = I_4R_4 = 1.5A \times 8\Omega = 12V$$

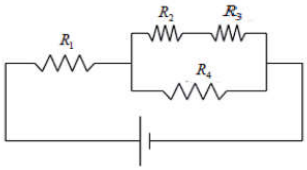
Therefore, the current through each resistor is given by:

$$I_2 = \frac{V_2}{R_2} = \frac{4.5V}{4\Omega} = 1.125A$$

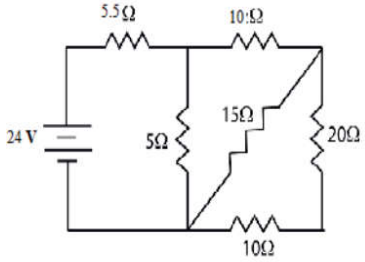
$$I_3 = \frac{V_3}{R_3} = \frac{4.5V}{12\Omega} = 0.375A$$

Exercise 6.5

1. For the circuit shown below, list resistors that are connected (a) in series, and (b) in parallel.



2. What is the equivalent resistance of the circuit shown in the figure? (b) What current flows through the 5Ω resistor?



<u>Measurement of current</u>: an ammeter is a device used to measure current flowing in a circuit.

- To measure the current flow in a circuit the ammeter must be connected in series with the resistor, so that the same current passes through both the resistor and the ammeter.
- The internal resistance of an ammeter should be as small as possible, so that little energy dissipated in it.

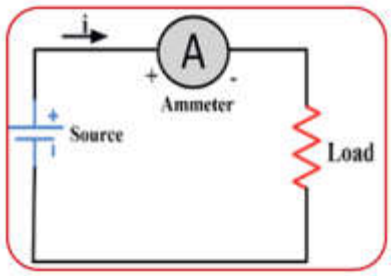


Figure 6.8 Connection of Ammeter

<u>Measurement of Voltage</u>: Voltmeter is a device used to measure the potential difference between two points in the circuit. For this reason, they are connected in parallel. It could be voltage across the terminal of a battery or across a resistor or any other circuit element

- Voltmeter should have a very high resistance to take as little current as possible.
- The ideal resistance of a voltmeter would be infinite.

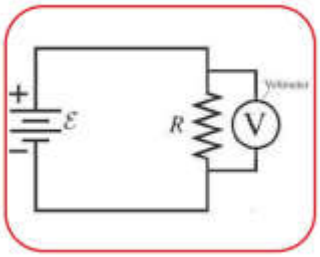


Figure 6.9 Connection of Voltmeter

Converting Galvanometer into Ammeter: since a galvanometer is a very sensitive instrument it can't measure heavy currents.

- In order to convert a galvanometer into an ammeter, a very low resistance known as "shunt" resistance is connected in parallel to it.
- The shunt allows most of the current passes through it and the remaining small current through the galvanometer.

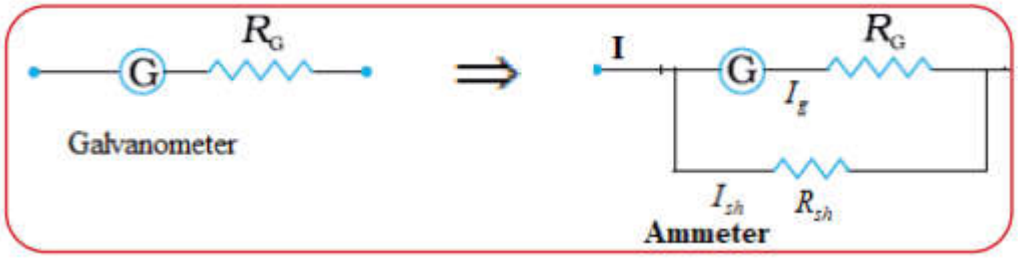


Figure 6.10 converting galvanometer into an ammeter

- Let R_g be the resistance of the galvanometer and I_g be the current for full scale deflection in the galvanometer. The value of shunt resistance required to convert the galvanometer into an ammeter is,

$$R_{shunt} = \frac{I_g}{I - I_g} R_g$$

Example: A galvanometer of full-scale deflection 5mA is to be converted into a 10A ammeter. If its coil has a resistance of 50 Ω, what value shunt must be fitted?

Solution: $R_{shunt} = \frac{I_g}{I - I_g} R_g = \frac{5\times10^{-3}A}{10-5\times10^{-3}A} \times 50\Omega = 0.025\Omega$

Converting Galvanometer into Voltmeter: a galvanometer can be converted into voltmeter by connecting with it with a very high resistance called multiplier in series with it as shown below.

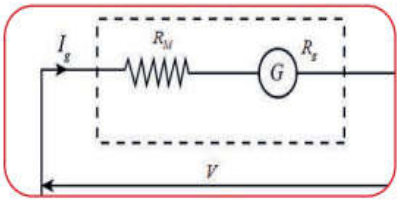


Figure 6.11 converting galvanometer into voltmeter

- Let R_g be the resistance of a galvanometer and R_M the resistance of the multiplier connected in series with it. Let V volt be the potential difference to be measured by the voltmeter and I_g be the current. Potential difference across the resistors in the circuit is the sum of potential difference across galvanometer and potential difference across the multiplier.

$$\boxed{R_M = \frac{V}{I_g} - R_g}$$

Example: a galvanometer has a resistance of 40Ω and is of 3mA full scale deflection. How would you modify it to 0-10V voltmeter?

Solution:

$$R_M = \frac{V}{I_g} - R_g = \frac{10V}{3 \times 10^{-3}A} - 40\Omega = 1960\Omega$$

Potentiometer: is a three-terminal resistor with a sliding or rotating contact that forms an adjustable voltage divider. It works by varying the position of sliding contact across a uniform resistance wire.

- The potentiometer can also be used for the following purposes:
  - To measure the emf of a given cell
  - To measure the internal resistance of a cell
  - To compare the emf of different cells
  - Used as a variable resistor

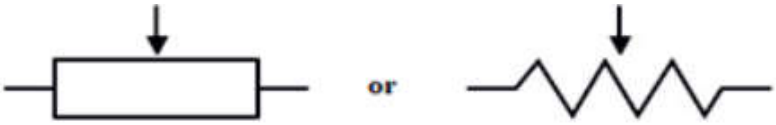


Figure 6.12 symbols of potentiometer in an electric circuit

<u>Measurement of Resistance</u>: resistance can be measured directly by using ohmmeter.

- Experimentally resistance is measured using ammeter-voltmeter and Wheatstone bridge methods.

Wheatstone bridge: the more precise method of measuring resistance.

- Is in arrangement of four resistances which can be used to measure one of them in terms of the rest. The arrangement is shown as below.

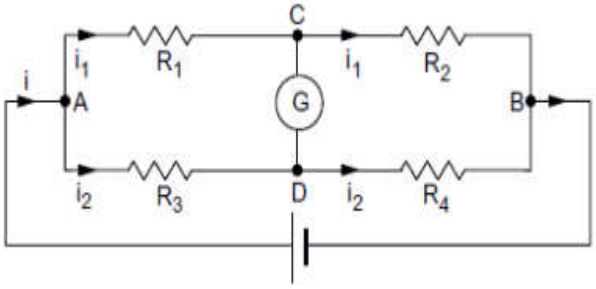
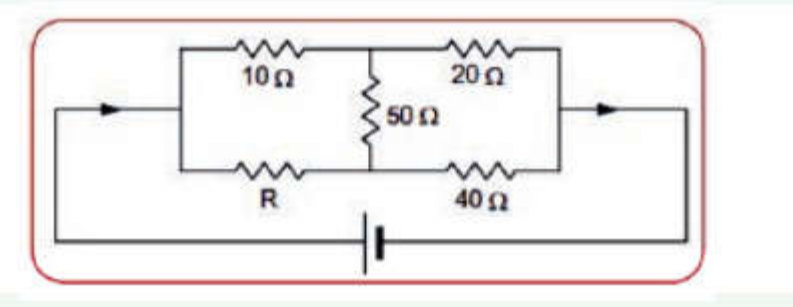


Figure 6.13 Wheatstone bridge

- Condition for the Wheatstone is balanced is given by:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

Example: Find the value of R in the figure below so that there is no current in the 50 Ω resistor.



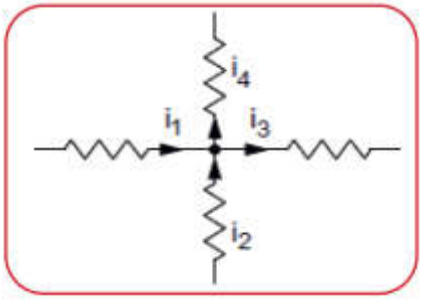
Solution:

$$R = \frac{R_1 R_4}{R_3} = \frac{10 \times 40}{20} = 20\Omega$$

Kirchhoff's rule: is a circuit rule, which can be used to analyze any dc circuit, regardless of how many loops and cells are in the circuit.

Kirchhoff's first rule (Junction rule): states that, at any junction in a circuit, the total current entering the junction is equal to the total current leaving the junction. This means, the sum of all the currents directed towards a junction in a circuit is equal to the sum of all the currents directed away from that junction.

$$I_1 + I_2 = I_3 + I_4$$



- Kirchhoff's junction rule is based on conservation of charge.

Kirchhoff's second rule (loop rule): for any complete loop of a circuit, the sum of the emf round the loop is equal to the sum of the potential drops around the loop.

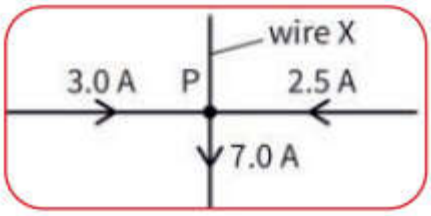
- It follows from the law of conservation of energy
- When using this rule, one starts from a point on the loop and goes along the loop, either clockwise or anticlockwise, to reach the same point again.
- **In using Kirchhoff's loop rule consider the following points:**
  1. Assume all voltage sources and resistances are given.
  2. Label each branch with a branch current.
  3. Apply junction rule at each junction.
  4. Applying the loop rule for each of independent loops of the circuit.
  5. Solve equations by substitutions.

➢ **For Kirchhoff's loop rule, the following convention is used:**

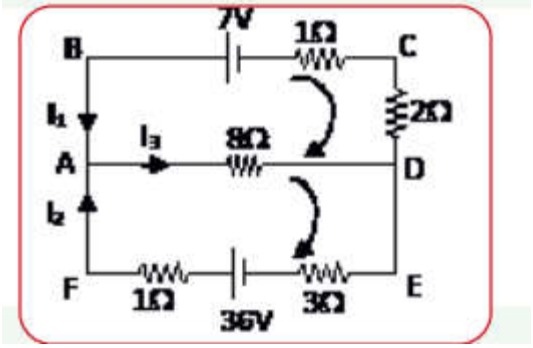
1. The e.m.f of the cells is taken as positive when the direction of motion is from negative terminal to the positive terminal, but negative when traversing from positive to negative terminal.
2. The potential difference across a resistor (IR) is taken as positive if we move in the opposite direction to the current and negative when moving in the direction of the current.

Exercise 6.4

1. Figure below is part of a circuit. Calculate the current in the wire X. State the direction of this current (towards P or away from P).



2. Find the currents I_1, I_2 and I_3 in the circuit shown below.



6.5. Capacitors and capacitance

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

- ❖ Define the terms capacitors, capacitances, dielectric.
- ❖ Explain the effect of inserting dielectric in the gap between the plates of a capacitor.
- ❖ Solve problems related to capacitance of parallel plate capacitor.
- ❖ Calculate the equivalent capacitance of capacitors connected in series and parallel.

Capacitor: is a device used to store electric charge, and hence electric energy.

Capacitance: is the ability to store electric charge at lower potential.

➢ For a given capacitor, the charge Q stored on the capacitor is proportional to the potential difference V between the plates. Thus,

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

- The SI unit of capacitance is called Farad (F).

Parallel plate capacitor: consists of two large plane plates placed parallel to each other with a small separation between them.

- Suppose the area of each of the facing surface is A and the separation between the two plates is d. also, assume that the space between the plates is filled with vacuum.

$$C = \varepsilon_0 \frac{A}{d}$$

- if a dielectric material of dielectric constant K is inserted between the plates, the equation for capacitance became:

$$C = k\varepsilon_0 \frac{A}{d}$$

Example: Consider a parallel plate capacitor with plates of area 200cm^2 and separated by a sheet of mica thickness 2mm and dielectric constant 6. If the capacitor is connected to 12V source, determine the charge stored on the plates of the capacitor.

Solution:

$$C = k\varepsilon_0 \frac{A}{d} = 6 \times 8.85 \times 10^{-12} \times \frac{0.02m^2}{0.002m} = 5.31 \times 10^{-10}F$$

$$Q = CV = 5.31 \times 10^{-10}F \times 12V = 6.37nF$$

Combinations of capacitors: capacitors can be combined in two ways, series and parallel combinations.

Quantities	Series combination	Parallel combination
Total charge	$Q_T = Q_1 = Q_2 = Q_3 = \cdots Q_n$	$Q_T = Q_1 + Q_2 + Q_3 += \cdots + Q_n$
Total voltage	$V_T = V_1 + V_2 + V_3 += \cdots + V_n$	$V_T = V_1 = V_2 = V_3 = \cdots V_n$
Total capacitance	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_n}$	$R_T = R_1 + R_2 + R_3 + \cdots + R_n$

6.6. Electric circuit in our surrounding

- **At the end of this section, you will be able to:**
  - Apply the knowledge about electric circuits to explain household electric installation.

Household Electric installations: in our country Ethiopia, the voltages of the mains are 220V-240V.

- Heating appliances include electric kettle, immersion heater, electric irons, hair driers and electric stoves.
- All heating appliances contain a heating element that converts electrical energy into heat energy.

Summary of unit

- Electric charges are quantized and are integral multiples of a fundamental charge e.
- There are two types of charges: positive and negative. Unlike charges attract each other and like charges repel each other.
- The electrostatic force between two charges is directly proportional to the product of the two charges and inversely proportional to the square of the separation between them. This law is called Coulomb's law.
- The electrostatic force is positive if the force is repulsive and negative if the force is attractive.
- Electric field lines originate from the positive charge and terminate into the negative charge.
- Electric field lines do not cross to each other and are perpendicular to the surface of the charge source.
- The total resistance of an electrical circuit with resistors wired in a series is the sum of the individual resistances.
- Each resistor in a series circuit has the same amount of current owing through it.
- The total resistance of an electrical circuit with resistors connected in parallel is less than the lowest resistance of any of the components.
- Each resistor in a parallel circuit has the same full voltage of the source applied to it.
- The current flowing through each resistor in a parallel circuit is, depending on the resistance.
- If a more complex connection of resistors is a combination of series and parallel, it can be reduced to a single equivalent resistance by identifying its various parts as series or parallel, reducing each to its equivalent, and continuing until a single resistance is reached.
- If a circuit contains a combination of capacitors in series and parallel, identify series and parallel parts; compute their capacitances, and then find the total.
- Capacitors are devices that store charge and electrostatic energy.
- A capacitor consists of two isolated conductors (the plates) with equal and opposite charges +q and –q.
- Its capacitance C is defined from , where V is the potential difference between the plates.
- The SI unit of capacitance is the farad. (1 farad =1coulomb per volt)
- Other practically applicable units of capacitance are: micro Farad, nano Farad and picoFarad.
- When two or more capacitors are connected in series, the reciprocal of the equivalent capacitance is the sum of the reciprocals of the individual capacitance of the capacitors.
- When two or more capacitors are connected in parallel, the equivalent capacitance is the sum of the capacitance of each capacitor.

Key terms: *charge, capacitors, electric field, electric force, electric flux, electric potential, resistors*

Study time: Total study time for this unit is **15 hours**.

SELF TEST-12

CHOOSE THE CORRECT ANSWER FOR THE FOLLOWING QUESTIONS.

1. The charges from some atom can be removed and transferred to another material in the process known as charging but the overall number of positive and negative charges does not change. This statement implies that:

A. Conservation of energy
C. Conservation of momentum
B. Conservation of charge
D. Conservation of mass

2. What is the net charge on a conductor having 20 protons and 12 electrons?

A. 1.28×10^{-19} C
C. 1.28×10^{-15}C
B. 1.28×10^{-18} C
D. 1.28×10^{-12}C

3. The redistribution of electrical charge in an object, caused by the influence of nearby charges is _____

A. Conduction B. Induction C. Rubbing D. Convection

4. **Thunderstorm** is formed due to:

A. Magnetism B. electrostatics C. dynamics D. kinematics

5. In **conduction** process, charge flows from:

A. Neutral object to charged object
C. unknown
B. Charged object to neutral object
D. all

6. Which one of the following is **INCORREC**T?

A. A positive charge experiences a force in the direction of the field.
B. A negative charge experiences a force in the opposite direction to the field.
C. The net electric field at a point due to many point charges is obtained by a vector sum of each field at that point.
D. A negative charge experiences a force in the direction of the field.

7. Two negative point charges are 2m apart and repel each other with a force of 2N. when the distance between the charges is doubled, the force between them is :

A. One fourth as great
C. Twice as great
B. One half as great
D. Four times as great

8. What is the magnitude of the electric force between two protons separated by $2 \times 10^{-15}m$? (given: $K = 9 \times 10^{9}\ \mathrm{N\,m^2/C^2}$)

A. 67.5N B. 115.0N C. 57.5N D. 83.4N

9. One of the following statements is **NOT** characteristics of electric field:

A. An electric field is a region around a charged body where another charged body experiences a force.

B. Lines of electric field have a direction which moves away from negative towards positive.

C. The direction of electric field is in the direction of the force acting on a small positive charge.

D. Lines of electric flux do not cross over each other.

10. What is the electric field at the mid-point of the two charges $Q_1 = -2\mu C$ and $Q_2 = 2\mu C$, which is separated by 12cm?

A. $1 \times 10^7 \text{N/C}$ C. $2 \times 10^{-7} \text{N/C}$

B. $2 \times 10^7 \text{N/C}$ D. $1 \times 10^{-7} \text{N/C}$

11. Coulomb's law states that about:

A. The field formed by point charge C. The direction of the electric field

B. The force between two point charges D. The attraction force between planets

12. Three charges 2C each are placed at the corners of an equilateral triangle. If the force between any two charges is F, then the net force on any charge will be:

A. 3F B. 2F C. $\sqrt{2}$F D. $\sqrt{3}$F

13. From the three main technologies of charging the fluid, one is uses the friction of the fluid:

A. Direct charging C. Tribo charging

B. Post-atomisation charging D. Indirect charging

14. Four charges each q, are placed at the four corners of a square of side a, then what is the electric potential at the center of the square?

A. $2\sqrt{3}\frac{Kq}{a}$ C. $4\sqrt{3}\frac{Kq}{a}$

B. $4\sqrt{2}\frac{Kq}{a}$ D. $4\sqrt{5}\frac{Kq}{a}$

15. The electric force due to point charge is depends on:

A. The size of charge C. The closeness of the field lines

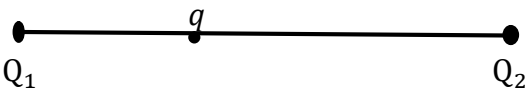
B. The strength of electric field D. All

16. Two point charges Q_1 and Q_2 are separated by a distance of 90cm exerts a force of 0.05N on each other. If $Q_1 + Q_2 = 4.5\mu C$, what is the magnitude of Q_1 and Q_2 ?

A. 3μC and 1.5μC C. 8μC and 4.5μC

B. 6μC and 3.5μC D. 2.5μC and 3.8μC

17. A charge q is located between Q_1 and Q_2 as shown q is closer to Q_1 than Q_2. If the net force on q is zero, what would you say about Q_1 and Q_2?



A. Q_1 and Q_2 are equal in magnitude and the same in sign

B. Q_1 and Q_2 are equal in magnitude and the opposite in sign

C. Q_1 and Q_2 are unequal in magnitude and the opposite in sign

D. Q_1 and Q_2 are unequal in magnitude and the same in sign

18. What is the strength of the electric field, if the lines of fields are closest to each other?

A. Weak B. strong C. uniform D. non uniform

19. The value of electric potential at a point due to a point charge is:

A. Inversely proportional to square of the distance.

B. Directly proportional to square of the distance.

C. Inversely proportional to the distance from point charge.

D. Directly proportional to the distance from point charge.

20. On bringing 0.4C of charge from infinity to point P the work done is 20J. then the electric potential at point P is:

A. 50V B. 8V C. 1000V D. 160V

21. As far apart from point charge, the electric potential will be:

A. Increase B. decrease C. stay the same D. un known

22. What is the change in potential energy of a charge of 2nC as it moved from 20cm to 8cm from a $4\mu C$ point charge?

A. 54×10^{15}J B. 54×10^{11}J C. 54×10^{9}J D. 54×10^{12}J

23. Pick the **correct** statement about forces in gravitational and electric field:

A. Both are directly square relationship

B. Both are inversely square relationship

C. both are repulsive forces

D. both are directionally undetermined

24. Identify the **incorrect** statement

A. The equipotential lines in uniform electric field are parallel to each others.

B. The equipotential lines in radial field are concentric circles and not parallel to each others.

C. The equipotential lines in complex electric field are parallel to the fields.

D. The equipotential lines in complex electric field are perpendicular to the fields.

25. The **SI** unit of capacitance is:

A. Coulomb B. Farad C. Tesla D. Newton

26. A 2μF capacitor is connected to 1.5V battery. What is the charge stored on the capacitor?

A. 2μC B. 4μC C. 3μC D. 6μC

27. The equivalent capacitances of the parallel and the series combinations of two capacitors are 5μF and 1.2μF, respectively. What are the capacitances of each capacitor?

A. 1μF, 4μF C. 2.5μF, 2.5μF

B. 3μF, 2μF D. 3.5μF, 1.5μF

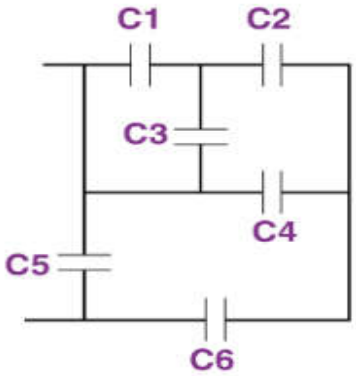
28. What is the effective capacitance of the circuit shown below, if the capacitance of each capacitor is 2μF?

A. 15/4μF

B. 13/4μF

C. 18/4μF

D. 9/4μF



29. Two capacitors of capacitances 20μF and 60μF are connected in series. If the potential difference between the two ends of the combination is 40 V, what are the terminal potential differences of each capacitor respectively?

A. 30V, 10V C. 12V, 28V

B. 10V, 30V D. 28V, 12V

30. If two capacitors that has equal magnitudes of capacitance, combined in series and parallel separately, then in which combination does the more effective capacitance you get?

A. Series B. parallel C. equal in both D. un known

31. Two capacitors having capacitances 0.1μF and 0.01μF are joined in series. A potential difference of 22 V is applied to the combination. If the capacitors are now joined in parallel, what will be the change in stored energy?

A. 244.2J B. 266.2J C. 22J D. 224J

32. Three capacitors of capacitance 8μF, 12μF and 24μF are connected in series and then in parallel. What is the ratio of equivalent capacitances in series and in parallel?

A. 1:11 B. 11:1 C. 1:1 D. 1:3

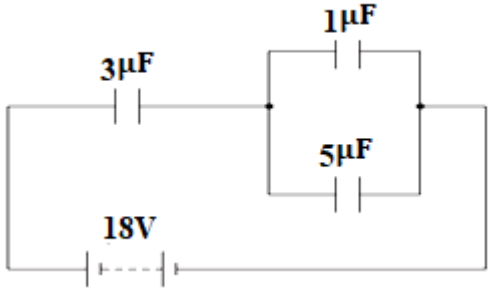
33. For the following circuit what is the amount of charge stored on 5μF?

A. 36μC

B. 6μC

C. 30μC

D. 12μC



34. Based on the above circuit what is the potential difference (p.d) drops across a capacitor of 1μF?

A. 12V B. 6V C. 18V D. 8V

35. 12μF If two capacitors A and B have the same area and dielectric constant but the distance between the plates of A is twice that of B, then what is the relation between the capacitance of the two capacitors?

A. Capacitance of A is twice that of B
B. Capacitance of B is twice that of A
C. Capacitance of A is one third of B
D. All

36. What is the capacitance of an air filled parallel plate capacitor of plates area $100cm^2$ and plates separation 0.1mm? ($\varepsilon_0 = 8.85 \times 10^{-12}$)

A. $8.85 \times 10^{-12}F$ B. $8.85 \times 10^{-11}F$ C. $8.85 \times 10^{-10}F$ D. $8.85 \times 10^{-9}F$

37. What is the capacitance of a capacitor that should be connected with 2 other capacitance of 4μF and 8μF all in series to produce an effective capacitance of $\frac{24}{11}$μF?

A. 12μF B. 10μF C. 8μF D. 4μF

38. Which one of the following changes to a parallel plate capacitor would not increase energy stored?

A. Increasing the area of the plates
B. Increasing the dielectric constant
C. Decreasing the charges on the plates
D. Increasing the distance between the plates

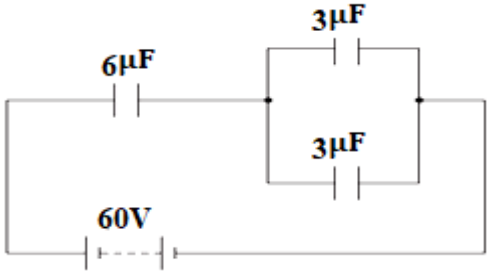
39. Which of the following factors affecting capacitance of parallel plate capacitor?

A. Area of plates
B. Separation of plates
C. Dielectric materials
D. All

40. Two capacitors have a combined series capacitance of 4μF and a combined parallel capacitance of 8μF. What is the capacitance of each capacitor?

A. 12μF and 8μF
B. 12μF and 6μF
C. 12μF and 4μF
D. 6μF and 8μF

41. What is the total capacitance of the following combination of capacitors and the potential difference across 6μF respectively?



A. 4μF, 30V
B. 3μF, 30V
C. 12μF, 30V
D. 6μF, 30V

42. What is the potential energy on 6μF ?

A. 27mJ B. 270mJ C. 2.7mJ D. 2700mJ

UNIT SEVEN

7. NUCLEAR PHYSICS

INTRODUCTION

Nuclear physics is the field of physics that studies atomic nuclei and their constituents and interactions that hold them together. Nuclear interactions include radioactive decay, the break-up of a nucleus (fission), and the merging of nuclei (fusion). The main driving strong nuclear force produced by the nucleus of an atom acts within a very short distance-just a few fathometers (10^{-15}) across. The strong nuclear force is the force that is responsible for the binding of protons and neutrons into atomic nuclei. The strong binding energy will help to produce strong radiation up on different reaction processes and radiation decay.

Nuclear physics is the field of physics that studies atomic nuclei and their constituents and interactions that hold them together. A nuclide may be stable or unstable. Unstable nuclides emit radiations spontaneously. These radiations have different forms which are known as alpha, beta and gamma radiations with charges similar to proton, electron and neutron in the atomic system. Through research, nuclear physicists are leading us on a journey of discovery into the nucleus of the atom-the very heart of matter. The goal is a roadmap of matter that will help unlock the secrets of how the universe is put together. Significant efforts have been made from the early 19^{th} century on the observation of different subatomic systems by different scientists. Nowadays, the research reactor (RR) and the power reactor (RR) are widely in use globally.

- **At the end of this unit, you will be able to:**
  - Appreciate the basic concept of the atomic nucleus.
  - Describe qualitatively the basic nuclear processes (concepts of radioactivity, and nuclear reaction).
  - Discuss the types of nuclear forces.
  - Explain application of radioactivity and nuclear reaction to society.
  - Describe the application of radioactivity and nuclear reaction to explain the energy source of stars.
  - Define terms like nuclear fission, nuclear fusion, and isotope.
  - Gain the basic knowledge of nuclear medicine.
  - Demonstrate high level of awareness to protect themselves and their community from radiation hazard.

7.1. The Nucleus

- **At the end of this section, you will be able to:**
  - Identify particles inside the nucleus.
  - Discus the historical origins of the particles of the nucleus.
  - Define and discuss isotope of an atom.
  - Describe the relationships between nuclear mass and binding energy of isotopes.
  - Calculate binding energy of the nucleus of different isotopes.
  - Identify the nuclear forces, (strong nuclear force, and weak nuclear force).

Atomic nucleus: consists of electrically positively charged particles called protons and electrically neutral particles called neutrons. These are held together by the strongest known fundamental force called the strong nuclear force.

Isotopes: are members of a family of an element that all have the same number of protons but different numbers of neutrons.

- Some examples of isotopes of elements:

  Carbon isotope: ${}^{12}_{6}\mathrm{C}$, ${}^{13}_{6}\mathrm{C}$ and ${}^{14}_{6}\mathrm{C}$

  Hydrogen isotopes: ${}^{1}_{1}\mathrm{H}(\mathrm{protium})$, ${}^{2}_{1}\mathrm{H}(\mathrm{deuterium})$ and ${}^{3}_{1}\mathrm{H}(\mathrm{tritium})$

  Uranium isotopes: ${}^{232}_{90}\mathrm{U}$, ${}^{233}_{90}\mathrm{U}$, ${}^{234}_{90}\mathrm{U}$, ${}^{235}_{90}\mathrm{U}$, ${}^{236}_{90}\mathrm{U}$ and ${}^{138}_{90}\mathrm{U}$

- The atom and nucleus are assumed as spherical and the atomic radius is given by:

$$\boxed{\mathrm{R} = \mathrm{R}_0\mathrm{A}^{1/3}}$$

Where, A = mass number of the atom.

$\mathrm{R}_0 =$ the radius of the nucleus$(1.2\mathrm{fm} = 1.2 \times 10^{-15}\mathrm{m})$

Example: Calculate the radii of the smallest isotope of hydrogen (${}^{1}_{1}\mathrm{H}$) and uranium-238. And Compare the volume of U-238 atom with the volume of its nucleus.

Solution:

Radius of ${}^{1}_{1}\mathrm{H}(\mathrm{protium})$ is given by: $\mathrm{R} = \mathrm{R}_0\mathrm{A}^{1/3} = 1.2 \times 10^{-15}\mathrm{m} \times 1^{1/3} = 1.2\mathrm{fm}$

Radius of ${}^{138}_{90}\mathrm{U}$ is given by: $\mathrm{R} = \mathrm{R}_0\mathrm{A}^{1/3} = 1.2 \times 10^{-15}\mathrm{m} \times 238^{1/3} = 7.437\mathrm{fm}$

The volume of U-238 atom is given by:

$$\mathrm{V}_{\mathrm{atom}} = \frac{4}{3}\pi\mathrm{R}^3 = \frac{4}{3}\pi(7.437\mathrm{fm})^3 = 12819.01\mathrm{fm}^3$$

The volume of the nucleus of U-238 atom is given by:

$$\mathrm{V}_{\mathrm{nucleus}} = \frac{4}{3}\pi\mathrm{R}_0^3 = \frac{4}{3}\pi(1.2\mathrm{fm})^3 = 7.24\mathrm{fm}^3$$

Taking the ratio of the volume of the atom and nucleus, we have:

$$\mathrm{V}_{\mathrm{nuleus}} = \left(\frac{7.437\mathrm{fm}^3}{12819.01\mathrm{fm}^3}\right)\mathrm{V}_{\mathrm{atom}} = 5.65 \times 10^{-4}\mathrm{V}_{\mathrm{atom}}$$

Therefore, the volume of the nucleus is 0.0565% of the volume of the atom.

Discovery of nucleus: in 1909, two of Lord Rutherford's students, Geiger and Marsden, aimed positively charged particles (stream of helium nuclei-$^{4}_{2}He^{+2}$)at an extremely thin piece of gold foil (100nm thickness). In order to study the deflection caused by the $\alpha - particle$, they placed a fluorescent zinc sulfide screen around the thin gold foil.

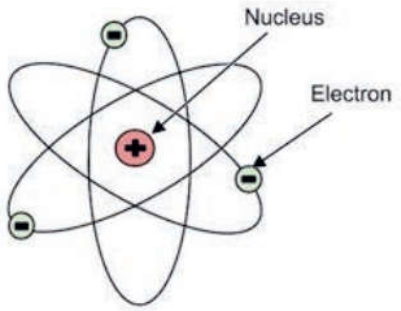


Figure 7.1. Rutherford's atomic model

Discovery of Proton: Rutherford thought that a hydrogen nucleus must be the fundamental building block of all nuclei, and also possibly a new fundamental particle.

- Rutherford postulated the hydrogen nucleus to be a new particle in 1920, which he called proton.

Discovery of the neutron: the British physicist James Chadwick discovered the neutron in 1932.

- He conducted experiments very similar to those of Rutherford.
- In Chadwick's case, he fired his atomic bullets at the element beryllium, not gold. The resulting collisions produced a new kind of particle that was just as massive as proton, but it penetrated through several inches of lead.

The Strong Nuclear Force: is an attractive force between protons and neutrons that keeps the nucleus together.

The Weak Nuclear Force: is responsible for the radioactive decay of certain nuclei.

Nuclear binding energy: is the energy required to separate an atomic nucleus completely into its constituent protons and neutrons, or, equivalently, the energy that would be liberated by combining individual protons and neutrons into a single nucleus.

- The binding energy is given by:

$$\boxed{BE = \Delta mc^2}$$

- Masses of subatomic particles are measured in atomic mass unit(amu or u)

$$1\ amu = 1.660 \times 10^{-27} kg$$

- Nuclear energy is assumed in atomic energy unit (aeu) or mega electron volt (MeV).

$$1MeV = 1.602 \times 10^{-13} J\ and\ 1\ aeu = 931.1MeV$$

- The mass defect of an atom can be calculated by:

$$\boxed{\Delta m = Zm_p + (A - Z)m_n - M}$$

Where, Zm_p = the total mass of the protons.

$(A - Z)m_n$ = the total mass of the neutrons and M = mass of the nucleus

- Therefore, the mass is given in amu, the nuclear binding energy of the nucleus in MeV becomes:

$$\boxed{BE = [Zm_p + (A - Z)m_n - M] \times 931.1MeV}$$

Where, masses of subatomic particles are given by:

$$m_p = 1.0072766u, \quad m_n = 1.0086654u \text{ and } m_e = 0.00054858u$$

Binding energy per nucleon: binding energy per nucleon (BEN) is the average energy required to remove an individual nucleon from a nucleus. It is one of the most important experimental quantities, which is defined by:

$$\boxed{BEN = \frac{BE}{A}}$$

Where, BE is binding energy and A is the atomic number of the atom

Example: You know that an atom of oxygen has the form ${}^{16}_{8}O$.

a) What is the mass defect in oxygen nucleus?

b) What is the binding energy per nucleon in Oxygen?

Solution: $Z = 8, A = 16, m_p = 1.00728u, m_n = 1.00867u, M = 16u$

a) The mass defect is given by:

$$\Delta m = Zm_p + (A - Z)m_n - M = 8 \times 1.00728u + (16 - 8) \times 1.00867u - 16u = 0.1276u$$

b) The binding energy in oxygen is:

$$BE = [Zm_p + (A - Z)m_n - M] \times 931.1MeV = \Delta m \times 931.1MeV$$

$$= 0.1276u \times 931.1MeV = 118.808MeV$$

The binding energy per nucleon in oxygen is:

$$BEN = \frac{BE}{A} = \frac{118.808MeV}{16} = 7.4MeV$$

Nuclear stability: is determined by the binding energy per nucleon.

- The net binding energy of a nucleus is that of nuclear attraction, minus the disruptive energy of the electrostatic force.

Exercise 7.1

1. Two nuclei have mass numbers in the ratio 27:125. What is the ratio of their nuclear radii?
2. Consider the atoms ${}^{16}O$, ${}^{18}O$, ${}^{18}F$, ${}^{18}Ne$ and ${}^{20}Ne$.
   a. Which atoms are isotopes of the same element?
   b. Which ones have the same number of neutrons?

3. X and Y are two elements with the same mass number but different atomic numbers 28 and 30, respectively. If X has a mass number of 58, what is the number of neutrons in Y? Are X and Y isotopes of the same element?
4. In his experiment of gold foil, when Rutherford bombarded the alpha particles on a very thin sheet of gold foil, only very few of the projectiles were observed deflecting back.
   a. Which force was responsible for the deflection?
   b. What does it imply that most of the alpha particles were passed undeflected?
5. What were failures in Rutherford's planetary model of the atom?
6. Describe how neutrons were discovered.
7. What are differences between strong nuclear force and weak nuclear force?
8. What are the major differences between the electrostatic and nuclear forces?
9. Calculate the binding energies per nucleon of the nuclei 56 26Fe and Bi 209 83 in units of MeV. Use the following data: m(Fe-56) = 55.934939u, m(Bi-209) = 208.980388u, mp= m(H-1)=1.007900 u, m (neutron)=1.008665 u.
10. Explain factors affecting nuclear stability of isotopes.

7.2. Radioactivity

- **At the end of this section, you will be able to:**
  - Define the terms radio-activity, and distinguish between the three types of emissions, alpha radiation, beta- radiation and gamma- radiation.
  - Recognize and discuss dangers of ionizing radiation.
  - Discuss radioactive dating and radiation detectors.
  - Identify radioactive sources in the school, home, and workplace.
  - Recommend protective measures to the school community.

Radioactivity: is the phenomenon of the spontaneous disintegration of unstable atomic nuclei to atomic nuclei to form more energetically stable atomic nuclei.

Radioactive decay: is a highly exoergic, statistically random, process that occurs with a small amount of mass being converted to energy

Types of nuclear radiation: there are three types of nuclear radiations:

1. Alpha (α) radiation
2. Beta (β) radiation
3. Gamma (γ) radiation

Alpha-particle radiation: alpha particles are subatomic fragments consisting of two neutrons and two protons or helium nuclei (He-4).

- Alpha radiation occurs when the nucleus of an atom becomes unstable (the ratio of neutrons to protons is too low) and alpha particles are emitted to restore balance.
- Alpha decay occurs in elements with high atomic numbers, such as uranium, radium, and thorium.
- The nuclei of these elements are rich in neutrons, which makes alpha particle emission possible.
- When a radioactive atom decays by alpha emission, it leaves a daughter nucleus of atomic number two less than the parent atom of atomic mass number four less than that of the parent atom. Thus,

$$\boxed{{}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He}$$

Where, X and Y are chemical symbols of the parent and the daughter nuclei, respectively.

Example: the abundant isotope of uranium, U-238, decays by alpha emission to give a thorium atom to which can be written in a form:

$${}^{238}_{92}U \rightarrow {}^{234}_{90}U + {}^{4}_{2}He$$

- Some sources of alpha radiation are americium-241, plutonium-236, uranium-238, thorium-232, radium-226, radon-222 and polonium-210.

Beta-particle radiation: unlike alpha radioactivity, beta radioactivity requires the weak nuclear force.

- There are two beta decay types: beta minus (-) and beta plus (+).

Beta minus particles: are energetic electrons emitted from a radioactive nucleus.

- Beta minus particle emission occurs when the ratio of neutrons to protons in the nucleus is too high.
- An excess neutron transforms into a proton and an electron.
- The proton stays in the nucleus and the electron is ejected energetically. This process decreases the number of protons by one. Thus,

$$\boxed{{}^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}\beta}$$

- As we see in this reaction equation, any decay by beta-emission accompanies emission of an antineutrino. Take a look at the decay of the uranium daughter product thorium-234 into protactinium-234;

$${}^{A}_{Z}Th \rightarrow {}^{234}_{91}Y + {}^{0}_{-1}\beta$$

- Some beta negative emitters are tritium, cobalt-60, strontium-90, technetium-99, iodine-129, iodine-131, and cesium-137.

Beta plus particle: there is also positron (${}^{0}_{1}e^{+}$) or beta plus emission, like the beta particle, a positron is immediately rejected from the nucleus upon its formation.

- Positron emission decreases the atomic number by one, but the mass number remains the same. Thus,

$$ {}^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}\beta $$

Example: potassium-38 decays by positron emission, becoming argon.

Gamma-particle radiation: gamma rays are high energy, high frequency, electromagnetic radiations.

- Gamma radiation usually accompanies alpha or beta decay.
- They have no charge and no mass so they rarely interact with particles in their path, so they have the least ionizing power of the three radiations.
- They never completely absorbed, although their energy can be significantly reduced by several centimeters of lead, or several meters of concrete.
- If the energy is reduced to a safe level, gamma rays are often said to have been absorbed.
- Gamma emitting radioisotopes are the most widely used radiation sources.
- The three radionuclide's by far useful are: cobalt-60, cesium-137, and technetium-99m.

Radiation detectors: is a device that measures the ionization of radiations (i.e., creating electrons and positively charged ions), such as beta radiation, gamma radiation, and alpha radiation with the matter.

- There are different types of radiation detectors, most widely ones of which are discussed below.

Scintillators: is a general term for substances that emit fluorescence when exposed to radiations of high energy, it is a type of phosphor.

- When a radiation collides with this substance, it absorbs its energy and internal electrons move from the ground state (stable state) to the excited state. When this electron returns to the original stable state, it releases its energy in the form of light emission (visible light or ultraviolet light), and this phenomenon called scintillation.

Geiger counter: also known as the Geiger-Muller tube, is used to quickly detect and measure radiation.

- It exploits the natural process of ionization to detect and measure radiation.
- When exposed to radioactive radiations, the stable gas within the chamber ionizes. This generates an electrical current that the counter records over a period of 60 seconds.

Half life: The half life of a radioactive isotope is the amount of time it takes for one half of the radioactive isotope to decay.

- The rate of isotope decay depends on two factors:
  1. The total number of undecayed nuclei present in the system. That is, on doubling the average number of undecayed nuclei must double the rate of decay.

2. The stability of the isotope. Some isotopes decay more rapidly than others. The rate of decay gives the number of nuclei that decay per second.

- In general, the decay rate, called the activity (A) is given by:

$$\boxed{A = \frac{\Delta N}{\Delta t} = -\lambda N}$$

Where, the negative sign shows the decrease in the number of the radioactive nuclei with time, N is the number of undecayed nuclei at the subsequent time t.

Decay constant (λ): is defined as probability of decay per unit of time; having SI unit s^{-1}. It is a positive rate also called the exponential decay constant, disintegration constant, rate constant, or transformation constant.

- The SI unit of activity (A) is Becquerel (Bq); where 1Bq = 1 decay per second. We can also use the unit Curie (Ci) where, $1Ci = 3.7 \times 10^{10} Bq$.
- The quantity of the parent radioactive nuclei is subject to exponential decay since it decreases at a rate proportional to its current value.
- This exponential decay law is given by:

$$\boxed{N = N_0 e^{-\lambda t}}$$

Where N_0 is the number of undecayed nuclei at an initial time $t_0 = 0$.

- Therefore half life for a certain decay is calculated by:

$$\boxed{t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda}}$$

Where, λ = decay constant

$t_{\frac{1}{2}}$ = half life time

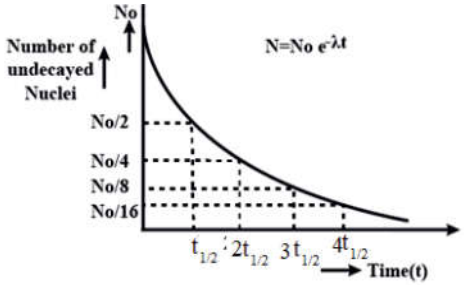


Figure 7.2 Number of undecayed nuclei versus time graph of a radioactive isotope

Example 1: The half-life of radium is equal to 1590years. What is the activity of 1g of radium-226?

Solution: the gram molecular weight of Ra-226 is M = 226.0254098 g/mol. there are NA = 6.023×10^{23} atoms/mol of radium. Therefore, the number of atoms of 1g of Ra-226 would be:

$$N = \frac{N_a \times 1g}{M} = \frac{1g \times 6.023 \times 10^{23} \text{atoms/mol}}{226.0254098 \text{g/mol}} = 2.664 \times 10^{21} \text{atoms}$$

The decay constant is,

$$\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{50176584000s} = 1.381 \times 10^{-11} s^{-1}$$

The desired activity is,

$$A = \lambda N = 1.381 \times 10^{-11} Bq \times 2.664 \times 10^{21} = 3.6793 \times 10^{10} Bq$$

$$A = \lambda N = \left(\frac{0.693}{t_{1/2}}\right) N = 1.23 \times 10^{10} Bq$$

That is, the number of decays per second in one gram of radium is 12300 million.

Example 2: The radioisotope strontium-90 has a half-life of 38.1 years. If a sample contains 400 mg of Sr-90, how many milligrams will remain when the age of the sample is 190.5 years?

Solution:

$$\lambda = \frac{0.693}{t_{1/2}} = \frac{0.693}{38.1\text{yr}} = 0.018189\text{yr}^{-1}$$

Then the mass remained after 190.5 years becomes;

$$m = m_0 e^{-\lambda t} = 400\text{mg} \times e^{-0.018189 \times 190.5} = 12.509\text{mg}$$

Exercise 7.2

1. In the radioactive decay of radon-222, both alpha and gamma radiation are emitted, with the latter having energy of 8.2×10^{-14} J per nucleus decayed:
$$^{222}_{86}\text{Rn} \rightarrow {}^{218}_{84}\text{Po} + {}^{0}_{0}\gamma + {}^{4}_{2}\text{He}$$
2. How much energy does 1mol of Rn release in the form of gamma radiation?
3. What can be the reason that tritium (H-3) isotope is a radioisotope where there is no electrostatic repulsive force in its nucleus? How does this isotope decay?
4. Why does Uranium 235 decay via alpha decay (by the way of Thorium-231) into 231 Pa?
5. You know that excessive exposure to radiation may damage living tissues and organs, depending on the amount of radiation received (i.e. the dose). Write some factors on which the extent of the potential damage depends on?
6. It is known that radioactive decay is a statistical process. Is it possible to determine the constancy of t, or 1/2 λ for a given radioactive element with one of few atomic nuclei?
7. Determine the reaction equations of the decays of U-238 by alpha emission and Th-234 by beta minus emission?
8. Does the probability per unit time that a radioactive nucleus will decay, increase, decrease or remain the same independent of time?
9. Compare Geiger counter with Scintillators.

10. Given alcohol, argon gas, oxygen and hydrogen gas, which one of these acts as ionizing gas in Geiger Muller counter?

11. What is the activity of a sample of 100 million atoms of carbon-14? The decay constant, λ, is $3.84 \times 10^{-12}\ s^{-1}$.

7.3. Nuclear reaction and energy production

- **At the end of this section, you will be able to:**
  - Distinguish between the two types of nuclear reaction.
  - Appreciate the sun as a big nuclear reactor.
  - Discuss the use (energy production, production of important isotopes, etc.) and misuse (nuclear bomb) of artificial nuclear reaction.
- Nuclear reactions are processes in which one or more nuclides are produced from the collisions between two atomic nuclei or from the collisions between a nucleus and subatomic particles.
- In general, there are two types of nuclear reactions, namely:
  - ✓ Fission reaction
  - ✓ Fusion reaction

7.3.1. Nuclear fission reaction

- Is the splitting of a nucleus of an atom into two or more smaller nuclei.
- Nuclear fission is a form of nuclear transmutation, meaning that the starting atoms are not the same elements as the resultant or daughter product atoms.
- In nuclear reactors, nuclear fission usually takes place by inducing neutrons into parent nuclei.
- In neutron induced fission reaction, two additional neutrons are released per one incident neutron.
- Nuclear fission is accompanied by the release of a large amount of energy. Part of this energy is converted into kinetic energy of the fission fragments and the remaining energy is converted into different forms such as heat and sound.

Example 1: consider the fission reaction equation on U-235, given by:

$$^{235}_{92}\mathrm{U} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{144}_{56}\mathrm{Ba} + {}^{89}_{36}\mathrm{Kr} + 3{}^{1}_{0}\mathrm{n} + 200\mathrm{MeV}$$

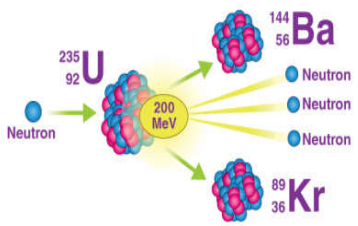


Figure 7.3 The atomic fission of $^{235}\mathrm{U}$

- In this reaction, the sum of the nuclear binding energy U-235 and the kinetic energy of the incident neutron (n-1) is equal to the sum of kinetic energy of the two daughter nuclides (Ba-144 and Kr-89); the kinetic energy of the three neutrons and the 200MeV energy, which is directly released.

Example 2: A nuclear fission reaction is given below. Complete the equation, find the value of X and determine the type of the element, Y.

$$^{235}\text{U} + {}_0^1n \rightarrow {}^{X}\text{Y} + {}^{139}\text{Cs} + 2{}_0^1n + \text{energy}$$

Solution: the equation is balanced on both sides so the total mass number on the left side must be the same as the total mass number on the right side. Thus,

$$235 + 1 = \text{X} + 139 + 2$$

$$\text{X} = 95, \text{which corresponds to Rb} - 95$$

7.3.2. Nuclear fusion reaction

- Nuclear fusion is a reaction in which two or more atomic nuclei are combined to form one or more different atomic nuclei and subatomic particles.
- Nuclear fusion reaction is a process of making a single heavy nucleus from the combination of two or more lighter nuclei.
- In most cases, fusion reaction releases more energy than fission reaction.
- The process releases energy because the total mass of the resulting single nucleus is less than the mass of the two original nuclei. The left over mass becomes energy.

Example: the heavy isotopes of hydrogen, a deuteron, and a triton also undergo fusion at extremely high temperatures. They form a helium nucleus and a neutron:

$$^2_1\text{H} + {}^3_2\text{H} \rightarrow {}^4_2\text{He} + {}^1_0\text{n}$$

- The figure shown below shows the cyclic sun fusion reaction to form a very strong in the electromagnetic radiation.

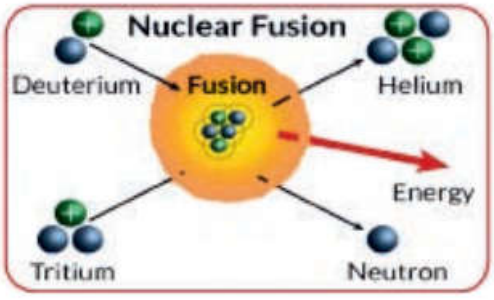


Figure 7.4 Nuclear fusion reaction processes of the H isotopes

Hydrogen bomb: one of the misuses of nuclear fusion reaction is its application for hydrogen bomb, which has higher destructive power and greater efficiencies than atomic bombs. Fusion weapons are also referred to as thermonuclear bombs.

Exercise 7.3

1. List uses of applications of nuclear reaction
2. What are the basic differences between nuclear fission and fusion reaction processes?
3. Complete the following nuclear reactions:
   a) $^{9}_{4}\text{Be} + {}^{1}_{1}\text{H} \rightarrow {}^{6}_{3}\text{Li} + _____$
   b) $^{10}_{5}\text{B} + {}^{4}_{2}\text{He} \rightarrow {}^{13}_{7}\text{N} + _____$
4. Describe the nature of research reactors by comparing it with the power reactors.
5. Why is Technetium-99 considered as the most important radioactive isotope for medical applications?
6. Is nuclear energy from radioisotopes in use for space travel?
7. Is there any radiation hazard from nuclear wastes of nuclear reactors? If so, how?
8. Caesium-137 is a by-product of nuclear fission within a nuclear reactor.

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{137}_{55}\text{Cs} + {}^{95}_{x}\text{Rb} + y\,{}^{1}_{0}\text{n}$$

   a) Copy and complete this equation which describes the production of $^{137}_{55}\text{Cs}$ by finding x and y.
   b) The half-life of Cesium is 30 years. When the fuel rods are removed from a nuclear reactor core, the total activity of caesium-137 is 5.8×10^{15} Bq. After how many years will this have fallen to 1.6×10^{6} Bq?
   c) Comment on the problems of storage of the fuel rods over this time period.
9. Does Fusion produce radioactive nuclear waste the same way fission does?
10. Is there chain reaction in nuclear fusion? Can fusion cause a nuclear accident?
11. Can fusion reactors be used to produce weapons?
12. In the fusion reaction below, determine the mass defect

Summary of unit

- A member of a family of an element with the same number of protons but different number of neutrons is called an isotope.
- the strong nuclear force is a very short-range attractive force that acts between nucleons: protons and neutrons.
- The strong nuclear force is strong enough to withstand the electrical repulsion up within a distance of slightly more than the radius of a nucleon, 10-15 m.
- Both nucleons are affected by the nuclear force almost identically.
- The weak nuclear force acts inside of individual nucleons, which means that it is even shorter ranged than the strong nuclear force.
- The weak nuclear force is a force that causes decay of an atom by beta emission.

- Nuclear binding energy is the energy that holds nucleons together. Another equivalent definition of binding energy is the minimum energy that is required to disassemble the nucleus of an atom into its constituent nucleons.
- The mass of an atomic nucleus is less than the sum of the individual masses of the free constituent protons and neutrons.
- The energy equivalent to this difference in mass can be calculated by the Einstein equation.
- Radioactivity is the phenomenon of the spontaneous disintegration of unstable atomic nuclei to atomic nuclei to form more energetically stable atomic nuclei.
- Radioactive decay is a highly exoergic, statistically random, process that occurs with a small amount of mass being converted to energy
- Gamma rays are high energy, high frequency, electromagnetic radiations.
- Gamma radiation usually accompanies alpha or beta decay.
- Radiations damage cells by ionizing atoms or molecules by removing electrons from them.
- Absorbed dose describes the amount of energy deposited per unit mass in an object or person.
- The units for absorbed dose are gray (Gy, international unit) and rad; where 1Gy = 1J/kg and 1rad = 0.01 Gy = 0.01 J/kg.
- Radiation doses above 3 Gy (300 rad) can be fatal and doses above 6 Gy (600 rad) are almost certain to be fatal, with death occurring within several months (in shorter times at higher doses).
- A radiation detector is a device that measures the ionization of radiations (i.e., creating electrons and positively charged ions). Scintillators, Gaseous ionization detectors and Geiger counter.
- The half-life is defined as the time at which half of the original nuclei have decayed.
- Fission occurs when a neutron slams into a larger atom, forcing it to excite and split into two smaller atoms also known as fission products.
- Nuclear fusion reaction is a process of making a single heavy nucleus from the combination of two or more lighter nuclei.
- A nuclear reactor is a device used to initiate and control a fission nuclear chain reaction or nuclear fusion reactions.

Key terms: *alpha radiation, beta radiation, fission reaction, fusion reaction, half- life, gamma radiation, isotopes, radioactivity.*

Study time: Total study time for this unit is **12 hours**.

SELF TEST-13

1. Discuss (a) Rutherford and (b) Bohr model of an atom.
2. What are the radii of U-238 and U-235?
3. What do you mean by reduced mass? How is this mass related with the nuclear binding energy?
4. State some uses of radioactive isotopes.
5. State one risk or danger associated with radioactivity.
6. What are the basic differences between nuclear fission and fusion reaction processes?
7. Write the nuclear reaction equation for K-242 that decays by beta minus emission. Do the same for Pu-239 decays by alpha emission.
8. Compare alpha and beta emission in terms of their nature, relative ionizing effect, relative penetrating power, the effect of magnetic and electric field on the radiation, and the common detectors.
9. What are research reactors (RR)? How are RR important for the in agriculture and medical applications? How are the research reactors (RR) different from the power reactors (PR)
10. When a patient undergoes radiotherapy, how does medical staff protect themselves from radiation?
11. What effects can high doses of radiation have on the human eyes?
12. Iodine-131, in the form of iodine chloride is used to treat thyroid cancer. Why does the patient radioactive substance orally to treat the cancer?

REFERENCES

For further, I recommend you to refer the following reference books:

1. Fundamental of physics
2. Galaxy physics Vol (I) 11-12
3. Galaxy physics Vol (II) 11-12
4. Mega secondary physics 9-12
5. Royal preparatory physics 11-12
6. Comet supplementary physics 9-10
7. Top physics 11-12
8. Top exam book 9-10
9. Effective physics 9-10
10. The new millennium physics 9-10
11. Key preparatory natural science 11-12
12. Top exam book university entrance