PHYSICS

STUDENT TEXTBOOK

GRADE 9

Federal Democratic Republic of Ethiopia
Ministry of Education

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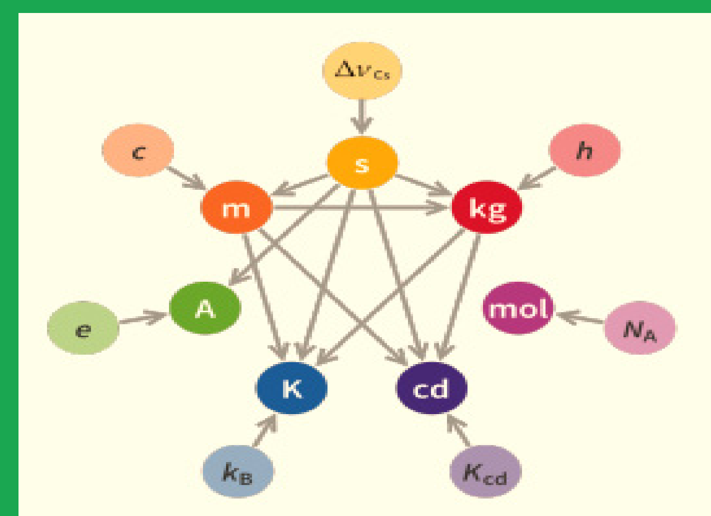
STUDENT TEXTBOOK

GRADE 9

Module 1

PHYSICS AND HUMAN SOCIETY, MEASUREMENT, MOTION IN A STRAIGHT LINE, FORCE, WORK, ENERGY, AND POWER



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Distance Education Material for High School Learners

Grade 9 Physics

Module 1

Physics and Human Society, Measurement, Motion in a Straight Line, Force, Work, Energy, and Power

Writers:

Menberu Mengesha (PhD)

Nebiyu Gemechu (PhD)

Editors:

Mehedi Abdo (MSc) (Curriculum Editor)

Felekech G/Egziabher (Ph.D) (Language Editor)

Designer:

Dagnachew Melesew (MSc)

Evaluator:

Girmaye Defar (MSC)

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☸ Introduction

Dear student! This module deals with physics and human society, measurement, motion in a straight line, force, work, energy and power. It is divided in to four units.

In the first unit of this module, you will learn about physics and human society. The definition, nature, and branches of physics, some related fields and historical contributors to physics will be discussed.

In the second unit of this module, you will learn about physical quantities. Scales, standards, units, measurement and safety, classification of physical quantities, and unit conversion will be discussed.

The third unit focuses on motion in a straight line. The basic concept of position, distance, displacement, speed, velocity, and acceleration will be covered.

Unit four focuses on force, work, energy, and power. You will be introduced to the scientific meaning of work. The basic concepts of force and Newton's laws of motion will be discussed. Definitions of kinetic and potential energies and power including their mathematical formulations will be covered.

Therefore, read each unit carefully and do all the activities, self-test exercises, check list, and end of unit questions and problems. Moreover, use supplementary references whenever appropriate.

Symbols used in the module

This tells you there is an overview of the unit and what the unit is about.

This tells you there is an in-text question to answer or think about in the text.

This tells you to take note of or to remember an important point.

This tells you there is a self-test for you to do

This tells you there is a checklist.

This tells you there is a written assignment

This tells you that this is the key to the answers for the self-tests.

Module Contents

Module Assessment Methods

Dear student! To check your progress, various assessment techniques will be used in this module. These include self-test exercises, activities, and end of unit questions and problems. The written assignment can be used for formative assessment and will be converted to 15%. For summative assessment, students will be evaluated by written examination from 35%. The percentage of evaluation for this module is 50%.

Unit 1

Physics and Human Society

Introduction

Dear student! You learnt about general science in lower grades. General science includes subjects like Biology, Chemistry and Physics. Therefore, in this grade level and in higher grades, you will learn about each of the three subjects and explore their beauty. In this unit you will learn about physics and the human society. In particular, you will learn about definition of physics, different branches of physics, relationship between physics and other fields of study, contributions of prominent scientists in advancing physics, and the way physics knowledge was evolving and changing in history.

After reading this unit, you should be able to:

- *define physics in different ways;*
- *describe the different branches of physics;*
- *describe the relationships between physics and other fields of study;*
- *discuss the contributions of prominent scientists in advancing physics at different periods of time;*
- *describe how aspects of physics are used in other sciences (e.g. biology, chemistry, engineering, etc.) as well as in everyday technology; and*
- *discuss how physics knowledge was evolving and changing in history.*

Unit Contents

The Required Study Time: The time allotted for this section is 6 hours.

Learning Strategies:

- Engage yourself in listening, watching and reading different media such as radio, television, newspaper etc. and enhance about your understanding of the nature of physics.
- Identify different media programs and explain how physics knowledge is applied.
- Describe physics in terms of its objects of study, products, technology it uses, and as a physics community practice.

Section 1.1: Definition and Nature of Physics

Dear student! In this section, you will learn about the definition and nature of physics.

After reading this section, you should be able to:

- *define physics in different ways;*

Have you ever thought about some modern technological devices such as computers, smart phones, tablets etc? Are you familiar with some machines in your surrounding that are used to make tasks much easier? Also think about the fact that our historical heritages such as Harar Jugol, Fasciledes Castle, the Obelisk of Axum and rock-hewn churches of Lalibela buildings have kept their balance and survived for hundreds of years. The working principles of all these rely on physics.

The word physics is thought to have come from the Greek word phusis, meaning nature. Hence, physics is a branch of natural science aimed at describing the fundamental aspects of our universe. These include what things are in it, what properties of those things are noticeable, and what processes those things or their properties undergo. In simpler terms, physics attempts to describe the basic mechanisms that make our universe behave the way it does. For example,

- Physics enables you to understand the working principles of cars, airplanes, space-rockets, refrigerators, radios, televisions, etc. as well as many of your daily utensils and tools.
- Physics explains physical phenomena such as the difficulty of walking on a smooth plane, and why an electric fan rotates etc.
- Physics helps you discover some of the unknown parts of nature and makes you familiar with the modern world.
- Physics helps you to understand some concepts in other subjects like: Biology, Chemistry, Geology, Astronomy, etc.

Studying physics helps you to understand concepts, relationships, principles and laws of nature. A person who studies physics is called a physicist.

Activity 1.1

- Identify other physical phenomena that you may understand in your locality using physics.

Physics is a branch of natural science that attempts to describe the basic mechanisms that make our universe behave the way it does.

Self-Test Exercise 1.1

Part I: Give short answers to the following questions

1. In your own words, define what physics is.
2. Name other technological products in your locality that rely on the principles of physics.
3. What is a physicist?

√ **Check List 1.1**

Dear learner, now it is time to check your understanding of definition and nature of physics. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
Can you define physics in a different ways?	☐	☐

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Section 1.2: Branches of physics

Dear student! Physics covers a wide range of phenomena, from elementary particles (such as electrons) to the largest superclusters of galaxies. Can you mention some scientists who specialized in a specific knowledge (branch) of physics? In this section, you will learn about the different branches of physics.

After reading this section, you should be able to:

- *describe the different branches of physics;*

As our technology evolved over the centuries, physics has expanded into many branches. Some of the branches of physics are summarized in *Table 1.1*.

Table 1.1: Some branches of physics and their descriptions

Branch	Description
Mechanics	Mechanics is the branch of physics which deals with the motion of an object without or with the reference of force. Mechanics can be further divided into two branches namely quantum mechanics and classical mechanics. Quantum mechanics deals with the behavior of smallest particles like neutrons, protons, and electrons, while classical mechanics is the branch that deals with laws of motion of forces and physical objects.

Acoustics	Acoustics is the branch of physics which deals with the study of sound and its transmission, production, and effects.
Optics	Optics is the branch of physics which deals with the behavior, propagation, and properties of light.
Thermodynamics	Thermodynamics is the branch of physics which studies thermal energy and the transfer of heat.
Electromagnetism	Electromagnetism is the branch of physics which deals with the study of electromagnetic force like electric fields, light, magnetic fields, etc. There are two aspects of electromagnetism which are "electricity" and "magnetism".
Nuclear physics	Nuclear physics is the branch of physics which deals with the structure, properties and reactions of the nuclei of atoms.
Astrophysics	Astrophysics is a science that employs the methods and principles of physics in the study of astronomical objects and phenomena.

Activity 1.2

- List other branches of physics which are not discussed in Table 1.1.

The branches of physics include: Mechanics, Acoustics, Optics, Thermodynamics, Electromagnetism, Nuclear Physics, etc.

Self-Test Exercise 1.1

Part I: Give short answers to the following questions

- In List as many physical phenomena in your surroundings as you can. Describe in which branch of physics each physical phenomenon can be categorized.

√ **Check List 1.2**

In the boxes provided for each of the following branches of physics, write 'yes' if you can define them or write 'no' if you cannot.

	Yes	No
Mechanics	☐	☐
Acoustics	☐	☐
Optics	☐	☐
Thermodynamics	☐	☐
Electromagnetism	☐	☐
Nuclear Physics	☐	☐
Astrophysics	☐	☐

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Section 1.3: Related Fields to Physics

Dear student! In this section you will learn about related fields to physics. Without reading the explanation given below, can you list some fields that you think are related to physics?

After reading this section, you should be able to:

- *discuss the relationships between physics and other related fields;*

Physics is the foundation of many important scientific disciplines. Some of them are discussed below.

- **Chemistry:** Chemistry deals with the interactions of atoms and molecules.
  However, it is rooted in atomic and molecular physics.

- **Engineering:** Most branches of engineering also apply physics. For example, in architecture, physics is at the heart of determining structural stability, acoustics, heating, lighting, and cooling for buildings.
- **Geology:** Parts of geology, the study of nonliving parts of Earth, rely heavily on physics, including radioactive dating, earthquake analysis, and heat transfer across Earth's surface.
- **Biophysics:** Biophysics applies principles and methods used in physics to study biological phenomena.
- **Geophysics**: Geophysics applies the principles and methods of physics to the study of the Earth.
- **Medical Physics:** Diagnostics and medical therapy, such as x-rays, magnetic resonance imaging (MRI), and ultrasonic blood flow measurements involve principles of physics.

Activity 1.3

- Identify some other fields or areas of science where physics is applicable.

Physics is the foundation of many important scientific disciplines including, Chemistry, Engineering, Geology, Biophysics, Geophysics, Medical Physics etc.

Self-Test Exercise 1.3

Part I: Give short answers to the following questions

- Explain the application of physics in fields like Geology, Engineering, and Medical Physics.

Check List 1.3

Dear learner, now it is time to check your understanding of related fields to physics. Read each question and put a mark ("X") in the box that corresponds to your answer. Yes No

Can you explain the relationship between physics and other ☐ ☐

related fields such as Chemistry, Engineering, Geology, Biophysics, Geophysics, and Medical Physics?

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Section 1.4: Historical Issues and Contributors

Dear student! In this section, you will learn about historical issues and contributors in physics. Can you list some scientists who are well-known for their discovery or contribution in physics?

After reading this section, you should be able to:

- *recognize at least three issues and four prominent physicists with significant contributions to the development of physics;*
- *collect and use pictures and texts from a library and the internet to present prominent figures in the history of physics;*

Over the last few centuries, the growth of scientific knowledge has resulted in ever-increasing specializations and branching of physics into separate fields.

Physics, as it developed from the renaissance to the end of the 19th century, is called **classical physics**. Revolutionary discoveries starting at the beginning of the 20*th* century transformed physics from classical physics to **modern physic**s.

Many laws of classical physics have been modified during the 20*th* century, resulting in dramatic changes in technology, society, and our view of the universe.

Discoveries of physics find applications throughout the natural sciences and in technology. Some of the physics discoveries that changed the world are discussed below.

- Isaac Newton's contributions laid the foundations for classical physics/classical mechanics. He contributed to the Scientific Revolution of the 16th and 17th century by formulating three laws of motion, known as Newton's laws of motion and showed how the principle of universal gravitation could be used to explain the behavior not only of falling bodies on the earth but also planets and other celestial bodies in the heavens.

- Michael Faraday contributed a lot to the field of electromagnetism. In 1821 he succeeded in producing mechanical motion by means of a permanent magnet and an electric current. Ten years later he converted magnetic force into electrical force, thus inventing the world's first electric generator. In general Michael Faraday changed the world with magnet.
- James Prescott Joule studied the nature of heat, and discovered its relationship to mechanical work. This led to the law of conservation of energy. Joule's work helped lay the foundation for the first of three laws of thermodynamics that describe how energy in our universe is transferred from one object to another or transformed from one form to another.
- Marie Curie conducted pioneering research in the field of nuclear physics, particularly on radioactivity. She is considered as the mother of modern nuclear physics. She discovered elements polonium and radium.
- Albert Einstein is known for developing theory of relativity. This evolutionary theory had a profound impact on classical mechanics and the underlying philosophy of physics. He is widely acknowledged to be one of the greatest physicists of all time. Einstein also made important contributions to the development of the theory of quantum mechanics.

Activity 1.4

- Collect and use pictures and sources from a library and the internet to present prominent figures in the history of physics.

Revolutionary discoveries starting at the beginning of the 20th century transformed physics from classical physics to modern physics. Many laws of classical physics have been modified during the 20th century, resulting in dramatic changes in technology, society, and our view of the universe.

Self-Test Exercise 1.4

Part I: Give short answers to the following questions

- Mention at least four other well-known historical contributors in physics and describe their roles.

√ Check List 1.4

In the boxes provided for each of the following contributors in physics, write 'yes' if you can define them or write 'no' if you cannot.

	Yes	No
Galileo Galilei	☐	☐
Isaac Newton	☐	☐
Michael Faraday	☐	☐
James Prescott Joule	☐	☐
Marie Curie	☐	☐
Albert Einstein	☐	☐

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Unit summary

- Science is a systematized knowledge arising from observation, study and experimentation.
- Physics is the branch of natural science which describes the basic mechanisms that make our universe behave the way it does.
- Physics is the study of everyday phenomena.
- A person who studies physics is called a physicist.
- Physics has several branches such as mechanics, acoustics, optics, thermodynamics, electromagnetism, nuclear physics, astrophysics etc.
- Physics is the foundation of many important scientific disciplines such as chemistry, engineering, geology, biophysics, geophysics, medical physics, etc.
- There are several well-known scientists and engineers that have contributed a lot for the advancement of physics.

Self-assessment questions

1. The Greek word 'phusis' for nature is appropriate in describing the field of physics. Which one of the following is the best answer for this?
   A. Physics is a natural science that studies life and living organisms on habitable planets like Earth.
   B. Physics is a natural science that studies the laws and principles of our universe.
   C. Physics is a physical science that studies the composition, structure, and changes of matter in our universe.
   D. Physics is a social science that studies the social behavior of living beings on habitable planets like Earth.
2. A moving car suddenly comes to a rest after applying brakes. Which branch of physics do you think is appropriate to explain this phenomenon?
   A. Mechanics B. Acoustics C. Electromagnetism
   D. Nuclear physics E. None of the above
3. Which of the following is not one of the branches of physics?
   A. Thermodynamics B. Optics C. Classical physics D. Evolution

4. Which of the following is not a historical contributor in physics?
   A. Willebrod Snell
   B. Daniel Bernoulli
   C. Thomas Young
   D. Charles Darwin
5. Which of the following institution/project does not apply the principle of physics?
   A. Ethiopian Aviation Industry
   B. Grand Ethiopian Renaissance Dam (GERD)
   C. Quality and Standard Authority of Ethiopia
   D. Ethiopian Radiation Protection Authority
   E. None of the above
6. Which branch of Physics is most important when studying the nature and behavior of light?
   A. Quantum Mechanics
   B. Nuclear Physics
   C. Optics
   D. Thermodynamics
7. Galileo's famous experiment at the leaning tower of Pisa demonstrated that
   A. what goes up must come down
   B. all objects fall to earth at the same rate, regardless of their mass
   C. heavier object falls faster than lighter object of the same size
   D. gravity does not act on a falling object

Answer Key for Self-Test Exercise

Self-Test Exercise 1.1: Try to define physics in your own words. You can also name various technological devices that have applications of physics knowledge from your locality?

Self-Test Exercise 1.2: Try to list some physical phenomena in your surroundings. Describe in which branch of physics each physical phenomenon can be categorized.

Self-Test Exercise 1.3: Try to explain the application of physics in fields like Geology, Engineering, and Medical Physics by referring to Table 1.1.

Self-Test Exercise 1.4: There are various other well-known historical contributors in physics. For example:

Archimedes is the greatest scientist of ancient times, who pushed mathematics, physics, and engineering to new heights. He created the physical sciences of mechanics and hydrostatics, discovered the laws of levers and pulleys, and discovered one of the most important concepts in physics – the center of gravity. He applied advanced mathematics to the physical world.

Johannes Kepler broke the tradition of thousands of years of astronomy, discovering that the heavenly bodies follow elliptical paths. Kepler's laws of planetary motion were an absolutely crucial breakthrough in our understanding of the universe.

Ernest Rutherford is the father of nuclear chemistry and nuclear physics. He discovered and named the atomic nucleus, the proton, the alpha particle, the beta particle, and he predicted the existence of the neutron.

There are many other historical contributors in physics which students can come up with by reading various references or online resources.

Answer Key for Self-assessment questions

Part I:

1. B
2. A
3. D
4. D
5. E
6. C
7. B

Unit 2

Physical Quantities

Introduction

Dear student! In unit one you have learned about physics and human society. In this unit you are going to learn about physical quantities.

In our day-to-day activities, any quantitative description of a physical property requires comparison with a scale of different measuring devices. For example, the length needs a meter stick, time needs a watch, and mass needs a beam balance. In this process, we recognize a very obvious fact that properties of different kinds cannot be compared. We cannot compare the time of travel from point A to B with the distance between the two points, although the two quantities may be related. The time of travel (time) is a physical quantity and the distance (length) is also a physical quantity. They are completely different types of physical quantities measured by different measuring devices and units. In the first section of this module, we will learn different types of scales, standards, and units (prefixes). In the second section, we will see measurement and safety. In the third section, we will come through the classification of physical quantities. In the fourth section, we will learn about conversion from one system of units to another.

After reading this unit, you should be able to:

- *list physical quantities;*
- *measure different physical quantities with accuracy;*
- *convert from one system of units to another;*

Unit Contents

2.1. Scales, standards, and unit

2.2. Measurement and Safety

2.3. Classification of physical quantities

2.4. Conversion of units

The required study time

Dear student! You are expected to complete section 1 in 6hrs., section 2 in 6 hrs., section 3 in 6 hrs., and section 4 in 6 hrs.

Learning Strategies

Dear student! In this unit you are expected to use the following learning strategies:

- Follow the symbols in the module material that guide you to learn each section;
- Space out your studying over time;
- After completing each subsection, do each activity and self-test exercise;
- For difficult activities and self-test exercises in each subsection or section, return and read it carefully until you understand the contents;
- Consult a physics teacher in your locality or a tutor for the contents you are unable to understand;
- Do end of unit self-assessment exercises to check whether you understand each section of the unit or not.

Section 2.1: Scales, standards, Units (Prefix) [6 hrs.]

In this section, we will learn about scales, standards of fundamental physical quantities, and units of physical quantities.

Dear student! You learned some concepts of physical quantities in grade 8 General Science.

After reading this section, you should be able to:

- *Identify measurement scales in their surrounding (multiple and fractions of the scales);*
- *State and use standard units of measures and their relationship with units in their surrounding;*

Try to answer the following brainstorming questions.

?

1. What types of different measurement scales are used in your surroundings?
2. What is the physical quantity? How can you measure mass, length, and time? What is their unit of measurement?

Dear student! Reading measurement scales correctly is a corner stone in different disciplines such as physics, chemistry and Engineering. In this section you are going to learn about reading different measurement scales.

☞ A scale on a measuring device contains the markings that show a certain amount of whatever is being measured. The number of marks on a measurement device depends on how accurate a measurement can be. As the number of marks in the measuring device increases the precision of the device also increases. *Figure 2.1* shows that there is a difference of 1 between the successively numbered values and there are ten spaces between them. As the result each space is one-tenth and each smaller mark represents one-tenth (0.1) of the distance to the next larger number. Measurements with this device can be precise to two decimal places. So, we can add a last digit which is estimated.

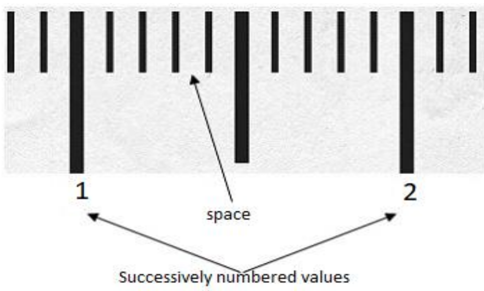


Figure 2.1: Reading scales for a given space

Example 2.1: Determine the length of the red line to two decimal places

Figure 2.2: Reading the measured value of a red line

Solution

The red line goes just past 3.3 but not quite to 3.4. We can estimate the second decimal place. It looks like the line goes roughly half way between 3.3 and 3.4. So, we will say 3.35.

Example 2.2: Show the following values on each of the scales below.

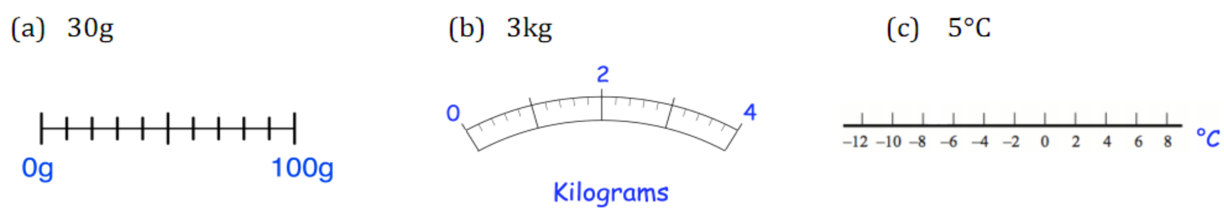


Figure 2.3: Different scales of measurement

Answer for example 2.2

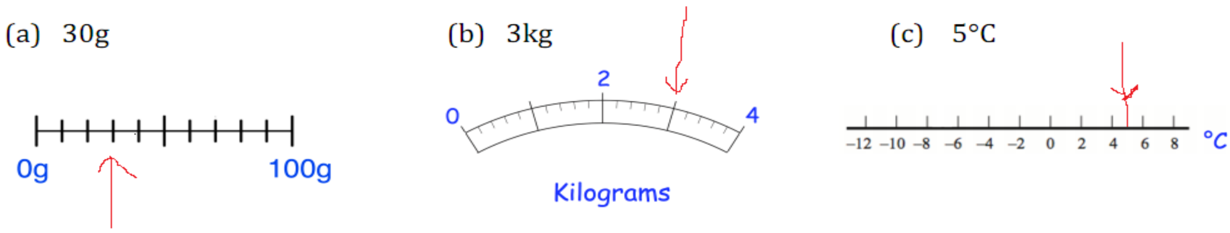


Figure 2.4: Arrows indicating the reading for the given values in example 2.2

Activity 2.1

- Determine the length of the red line to three decimal places in a group and compare your result with other groups result.

Figure 2.5: Red line and number of divisions for a given span

Self-Test Exercise 2.1

1. Read the scales of the following mass measuring devices

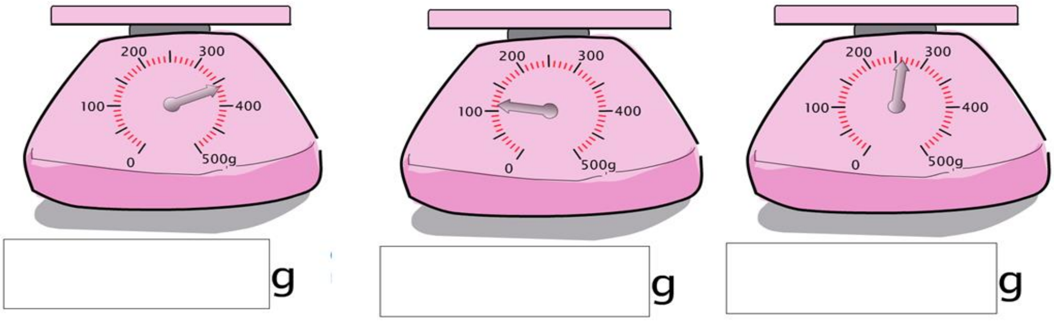


Figure 2.6: Different scales of mass measuring devices

2. Write down the values shown on each of these scales.

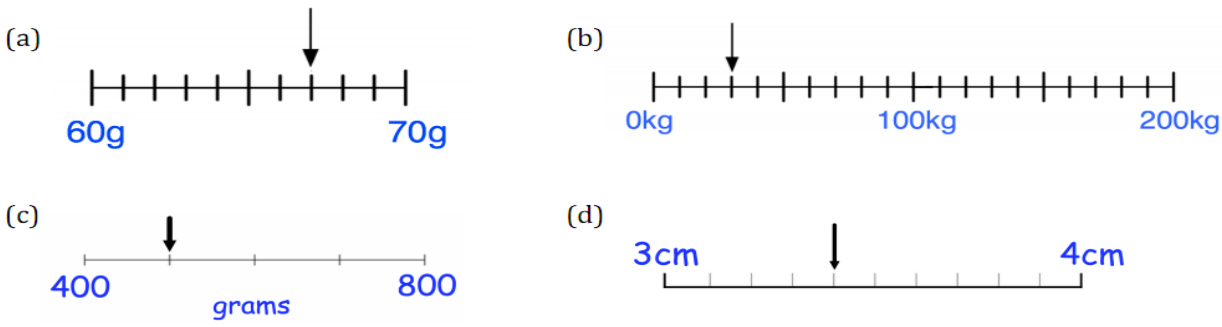


Figure 2.7: Different scales showing the values of measurement

3. Write down the temperature shown in each thermometer.

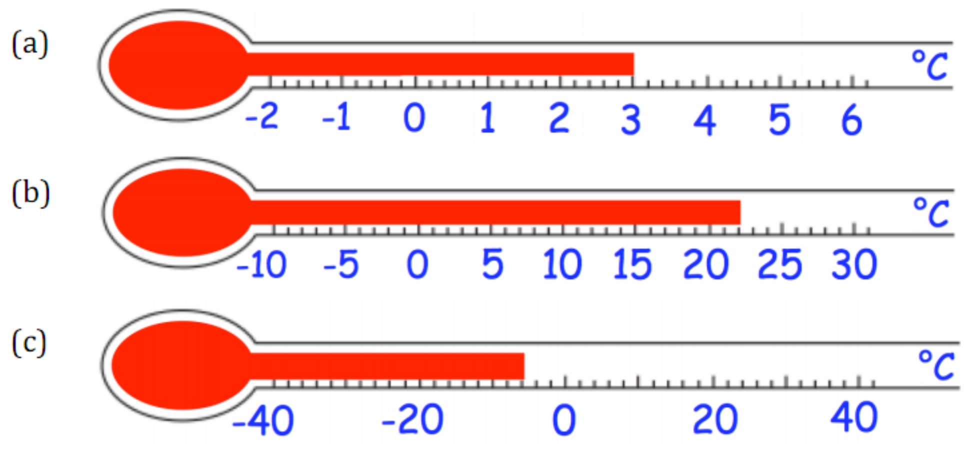


Figure 2.8: Different readings of temperature scale

Thanks to technology, today we have digital instruments that indicate the measured value in digital format which will be the number with its unit. It is very easy to read compared to the usual analog instruments. Moreover, it is an accurate measurement.

☞ In physics, scale is a set of numbers, amounts, etc., used to measure or compare the level of something.

Activity 2.2

1. Observe measurement activities in your local area (home, local market, and workplaces) and write a report on the what, the where, and the how of the measurements observed.
2. Based on your observation, discuss the traditional and commonly used scales and units of measurement for length, mass, time, volume, and temperature.

People in different communities measure physical quantities such as length, time, volume, and mass using traditional measuring units. However, each unit has different values at different times, positions and coordinates.

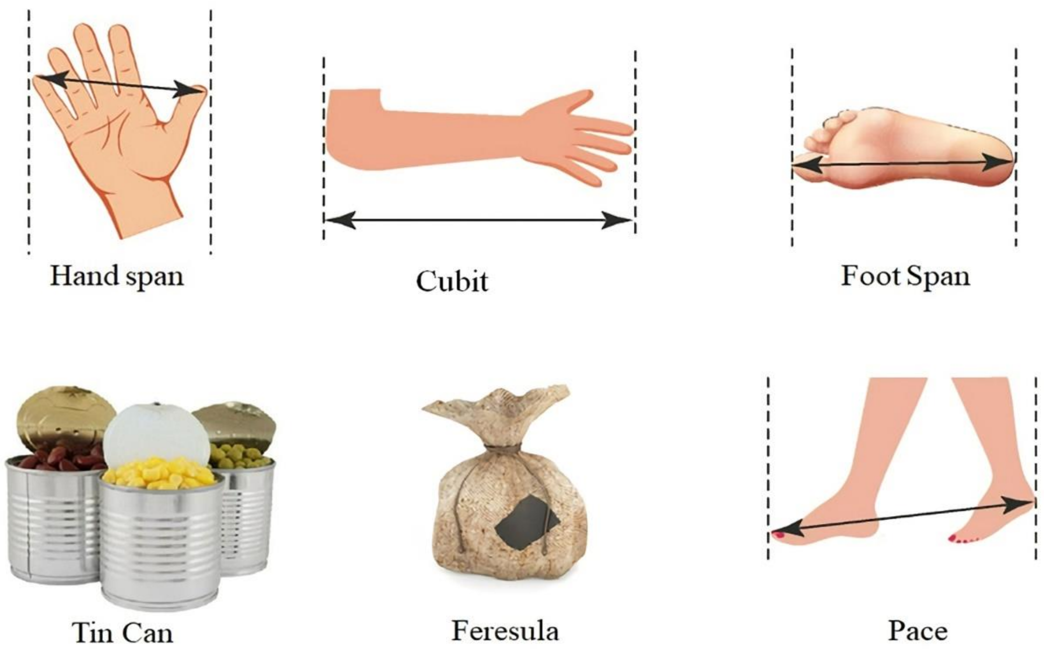


Figure 2.9: Traditional measuring units

Standards of length mass and time

Dear student! You are familiar with different measurement activities from your day-to-day experience. Think of it and answer the following brainstorming questions.

> **?** What is a standard in measurement? In your local area, people measure volume, mass, and area using different measuring materials. Do these measurements have standards?

Dear student! In the previous subsection, you learned about different types of scales. Now you are going to learn the standard units of basic physical quantities. The laws of physics are expressed in terms of basic quantities that require a clear definition. In physics, the seven basic quantities are length (l), mass (m), time (t), temperature (T), current (I), amount of substance (n), and luminous intensity (I_v). All other quantities in physics can be derived from these seven basic or fundamental physical quantities.

Self-Test Exercise 2.2

Six grade 9 students in different parts of Ethiopia are given the same object and measured its mass as shown in *Table 2.1*. Discuss whether the measurement has a standard or not regardless of personal errors.

Table 2.1: Measurement of mass at different places

No.	Name of student	Place	Measured value
1	Student A	Location A	1.6 unit
2	Student B	Location B	2.1 unit
3	Student C	Location C	2.5 unit
4	Student D	Location D	3.0 unit
5	Student E	Location E	1.1 unit
6	Student F	Location F	3.5 unit

Dear student! If your teacher orders you to report the results of a measurement to someone who wishes to reproduce this measurement, a standard must be defined.

☞ Whatever is chosen as a standard:

- It must be readily accessible and possesses some property that can be measured reliably.
- Measurements taken by different people in different places must yield the same result.

The lack of standards in measurement has many consequences. In Ethiopia, for instance, people use their palms to measure things like cotton and footsteps to measure the length of a plot of land. The one with a bigger palm collects more cotton than the one with a smaller palm. Thus, using a palm or footsteps as a measuring device has no standard. It creates inaccuracy in the measured value and bias among people.

In 2019, an International Committee revised a set of standards for length, mass, time and other basic quantities. The system established is an adaptation of the metric system and is called the SI system of units (see *Figure 2.10*)

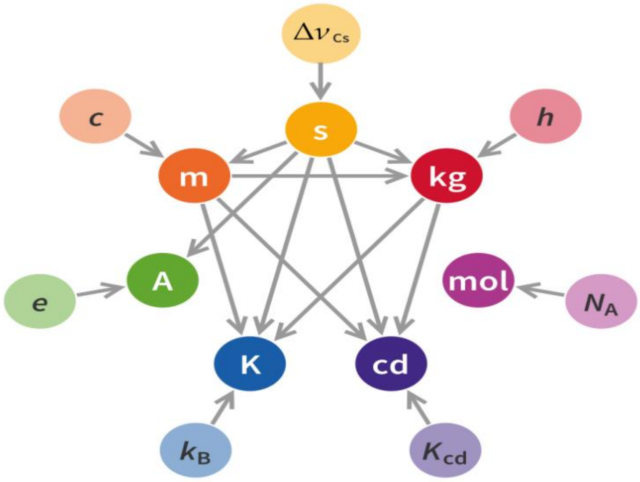


Figure 2.10: The S.I system after the 2019 redefinition

Dear student! To get more information on the definition of SI system units use mobile data or the internet and open the link https://en.wikipedia.org/wiki/2019_redefinition_of_the_SI_base_units.

Length: Meter is the standard or international system (SI) unit for length. There are also other none SI units of length. These are centimeter (cm), millimeter (mm), and kilometer (km). Today, the meter (m) is defined as the distance traveled by light in a vacuum during a time of 1/299 792 458 s.

☞ $1m = \frac{9192631770}{299792458}\frac{c}{\Delta f}$, where c is the speed of light in vacuum (c=299792458 m/s) and $\Delta f = 9192631770/s$ is the hyperfine transition frequency of the caesium-133 atom.

Time: It is defined as the interval between two events. It is a fundamental quantity. The unit of time in the SI system is second (s). None SI units of time are minute (min), hour (hr.), day, month, and year. The second (s) is defined as 9192631770times the period of vibration of radiation from the cesium-133 atom.

☞ $1s = \frac{9192631770}{\Delta f}$

Mass**:** The kilogram (kg) is the standard or international system (SI) unit of mass. None SI units of mass are gram (g), milligram (mg), and tonne. The kilogram(kg) is defined by taking the fixed numerical value of the Plank constant h =6.62607015×10^{-34} when expressed in the units of Js (which is equal to kgm^2/s), where the meter and second are defined in terms of the speed of light in a vacuum(c) and the frequency of the Caesium 133 atom (Δf).

$[1kg = 1.4755214\times10^{40}\frac{h\Delta f}{c^2}]$.

☞ Standard units are conventional units that are used to measure physical quantity scientifically.

Meter: a distance traveled by light in vacuum during a time of 1/299 792 458 s.

Kilogram:1 kilogram (1kg) is $1.4755214\times10^{40}\frac{h\Delta f}{c^2}$.

Second: 9 192 631 770 times the period of vibration of radiation from the cesium-133 atom.

Self-Test Exercise 2.3

Part I: Give short answers to the following questions

1. Explain the need for standards of measurement.
2. Identify the disadvantages of non-standard measurement practices in your locality and in the country at large.

Scientific notation, significant figures and prefixes

Dear student! In the previous subsection, you learned about standards of length, mass, and time. In this subsection, you are going to learn about scientific notation, significant figures, and prefixes.

? What is Scientific notation?

Scientific notation

Scientific notation is a way of writing numbers that are too large or too small to be conveniently written as a decimal. This can be written more easily in scientific notation, in the general form:

$$d\times10^{n},$$

where d is a decimal number between 0 and 10 that is rounded off to a few decimal places; n is known as the exponent and is an integer. If $n>0$ it represents how many times the decimal place in d should be moved to the right. If $n<0$, then it represents how many times the decimal place in d should be moved to the left. For example, 3.24×10^3 represents 3240 (the decimal moved three places to the right) and 3.24×10^{-3} represents 0.00324 (the decimal moved three places to the left).

Significant Figures

? What is a significant figure?

In a number, each non-zero digit is a significant figure. Zeroes are counted only if they are between two non-zero digits or are at the end of the decimal part. For example, the number 2000 has 1 significant figure (the 2), but 2000.0 has 5 significant figures. You estimate a number like this by removing significant figures from the number (starting from the right) until you have the desired number of significant figures, rounding as you go. For example, 6.827 has 4 significant figures, but if you wish to write it to 3 significant figures it would mean removing the 7 and rounding up, so it would be 6.83. The number 600.00 has 5 significant figures (the zeros after the decimal point and before the decimal point is counted in this case). The number 0.00062 has two significant figures. Zeros that are used to position the decimal point are not significant figures.

Self-Test Exercise 2.4

Part I: Give short answers to the following questions

1. Write 0.000001256 in scientific notation to 3 decimal places.
2. How many significant figures are in 7800?
3. How many significant figures are in 507000.0?

Dear student! Adding and subtracting experimentally measured values of two different significant figures (digits) needs to remember the following rule. That is:

☞ When two experimentally measured numbers are added or subtracted, the number of significant figure or digit should be equal to the smallest number of decimal places of any term in the sum or difference.

Example: while adding two measured values 9.65 and 8.4, the least close decimal place is 8.4 cm. The sum of these two numbers is 18.1 and is not 18.05.

Dear student! Multiplying or dividing experimentally measured values of two different significant figures (digits) is based on the following rule.

☞ When two experimentally measured numbers are multiplied or divided, the number of significant digits in the final answer is the same as the number of significant figures in the quantity having the smallest number of significant figures.

Example: While multiplying two measured values 8.65 and 2.035 if you use a calculator your answer is 17.75845 which is completely wrong. The first number 8.65 has three significant figures and the second number 2.035 has four significant figures. According to the rule the smallest number of significant figures is three. So, the correct answer is 17.8.

Activity 2.3

Write the number for each expression with appropriate number of significant figures

A. $1.513 + 27.3$ B. $6.789 - 4.23$ C. $138.0 \div 11.9$ D. 2.1×5.687

Prefixes

? What is a prefix?

In the previous subsections, you learned different basic units. When a numerical unit is either very small or very large, the units used to define its size may be modified by using a prefix. A prefix is an important aspect of dealing with units. Prefixes are words or letters written in front of a word that change the meaning. *Table 2.2* lists a large set of these prefixes. The *kilo- in* kilogram (kg) is a simple example of a prefix. 1 kg is 1000 g or 1×10^3g. Grouping the10^3 and the g together we can replace the10^3 with the prefix k (kilo).

Table 2.2: Unit Prefixes

Prefix	Symbol	Multiplier	Exponent
tera	T	1 000 000 000 000	10^{12}
giga	G	1 000 000 000	10^9
mega	M	1 000 000	10^6
kilo	k	1 000	10^3
hecto	h	100	10^2
deka	da	10	10^1
deci	d	0.1	10^{-1}
centi	c	0.01	10^{-2}
milli	m	0.001	10^{-3}
micro	μ	0.000 001	10^{-6}
nano	n	0.000 000 001	10^{-9}
pico	p	0.000 000 000 001	10^{-12}

☞ Unit prefix is a letter or a syllable that is written directly before a unit name with no space.

Scientific notation: a system in which numbers are expressed as products consisting of a number between 1 and 10 multiplied by an appropriate power of 10.

In a number, each non-zero digit is a significant figure.

Self-Test Exercise 2.5

Write the following physical quantities using appropriate prefixes.

1. The radius of the earth is 6,371,000 m.
2. The diameter of our hair is 0.000 0075 m.

Self-Test Exercise 2.6

Part I: Write True if the statement is correct and False if it is incorrect.

1. Unit of measurement can be duplicated by observers in various locations.
2. The number 15.0 has two significant figures.
3. Candela is the S.I unit of the amount of substances.

Part II: Choose the correct answer from the given alternatives.

1. Which one of the following scales allows addition, subtraction, multiplication, and division?

   A. Nominal scale C. ordinal scale
   B. ratio scale D. interval scale

2. Which one of the following is NOT a fundamental quantity?
   A. Temperature B. density C. time D. mass
3. A nanosecond is
   A. 10^9 s B. 10^{-9} s C. 10^6 s D. 10^{-6} s

Part III: Give short answers to the following questions

1. What is the difference between the interval scale and the ratio scale?
2. What is the difference between traditional measuring units and scientific measuring units?
3. Define the following terms: a) Meter b) second c) kilogram.

√ Check List 1.3

Dear learner, now it is time to check your understanding the following terms or phrases. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. Can you Identify measurement scales in your surrounding?	☐	☐
2. Can you state standard units of measures?	☐	☐
3. Can you show the relationship between the units?	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Section 2.2: Measurement and Safety [6 hrs.]

Dear student! In this section, you will learn about different instruments that are used to measure physical quantities such as length, area, volume, mass, and time. Moreover, you will be involved in measuring activities.

After reading this section, you should be able to:

- *List different instruments used to measure physical quantities such as length, area, volume, mass, and time in their local area;*
- *Measure length, mass, and time using different units;*
- *List length, mass, and time measuring devices;*

Measurement

Dear student! In your day-to-day activity, you are familiar with different measurement activities. Take a few minutes and think of the following brainstorming questions.

?

1. What is meant by measurement?
2. What measuring devices are used to measure volume, mass, and length in your local area?

Measurement is the process of comparing an unknown quantity with another quantity of its kind (called the unit of measurement) to find out how many times the first includes the second. The measurement process has three key elements:

- The physical quantity to be measured.
- The necessary measuring tools.
- Units of measurements used (standard units).

Twenty-first-century civilization is unthinkable without appropriate measurement tools on which everyday life depends. Modern society simply could not exist without measurement. *Figure 2.11* shows some measuring devices applicable today.

Figure 2.11: Examples of measuring tools of some physical quantities

Measuring length

Dear student! When you are measuring the length of objects, you are comparing them with the standard length. The SI unit of length is meter (m) as we discussed before. There are also non-SI units of length. These are millimeters (mm), centimeters (cm), and kilometers (km).

☞ Measurement of any physical quantity involves comparison with a certain basic, arbitrarily chosen, internationally accepted reference standard called unit.

Activity 2.4

1. Observe your local environment and list different instruments used to measure physical quantities.
2. Discuss different measurement activities and related issues in life.

Dear student! Figure 2.4 shows standard length measuring instruments. I hope you came across some of these instruments in your local area.

Figure 2.12: Standard length measuring instruments

☞ Length is one of the fundamental (basic) physical quantities which describe the distance between two points.

Self-Test Exercise 2.7

Part I: Give short answers to the following questions

1. Measure the length and width of your physics module in the meter unit.
2. Calculate the area of the module using the above-measured values in meter square units.
3. A farmer wants to know the length of his plots of land in meters but he has only a long rope, a 50 cm ruler, and a 6 m long stick. How can he easily measure the length of his plot?

Dear student! From the above activity, you may come across units and numbers.

☞ Every physical quantity can be represented by its numerical value and unit.

☞ Measurement is the comparison of an unknown quantity with a known fixed unit quantity. It consists of two parts: the unit and the number indicating how many units are in the quantity being measured.

e.g., the length of the table is 3 meters.

In this example, 3 is the magnitude, and the meter is the standard (unit) of that quantity.

☞ Length: the fundamental physical quantity that describes the distance between two points.

The S.I unit of length is a meter (m).

Dear student! In the previous subsection, you have learnt about the length, how to measure the length of an object, and length measuring devices. Now you are going to learn the basic physical quantity, mass, and how to measure it using mass-measuring instruments.

Measuring mass

Measuring mass is a day-to-day activity in human life. People in various parts of the world measure the mass of an object in different ways.

Activity 2.5

1. What mechanisms do people in your locality use to measure the mass of an object?
2. Which scientific measuring instrument of mass is used in your locality?

☞ Mass is a basic physical quantity. It is defined as the amount of matter contained in a body.

Dear student! *Figure 2.13* demonstrates mass measuring instruments.

Figure 2.13: Different scientific mass measuring instruments

Activity 2.6

- Visit different shops in your living area and carefully observe the procedures for measuring goods. Write the procedures and accuracy of the measurement.

The SI unit of mass is the kilogram (kg). There are also non-SI units (such as gram, pound, etc.) used to measure the mass of an object. In a scientific way, mass is measured by an instrument called beam balance.

Dear student! For the following activity Visit a shop or a school in which a beam balance is available.

Activity 2.5

1. Collect your materials such as a) your physics module, your exercise book, and c) your pen.

....

Mass is a basic physical quantity. It is defined as the amount of matter contained in a body.

The S.I unit of mass is the kilogram (kg).

....

2. Measure the mass of these objects using a beam balance and record the measured values in a table.
3. Request the shopkeeper or a teacher to measure the mass of these objects and compare them with your result.
   If your recorded value is different from that of a shopkeeper or a teacher discuss the possible source of errors.

Measuring time

Dear student! In this subsection, you are going to learn the basic physical quantity, time, how to measure time, and time-measuring instruments.

How long does it take for the sun to rise and set in your location? Do the people in your locality use the sunset and sunrise as time-measuring devices? Some people in the rural parts of Ethiopia traditionally use the position of the sun or the position of shadows of their houses or trees to estimate the time. The use of sunrise and sunset as a time measuring device is called sundial. However, this way of measuring time has no standard and is not accurate.

☞ Time is the basic physical quantity. It describes the duration between the beginning and end of an event. The SI unit of time is second (s). The non-SI units of time are a minute, an hour, a day, a week, a month, and a year.

Activity 2.8

1. Identify the names of scientific time-measuring devices.
2. Record the activities you do from 8 AM to 6 PM. I hope you are effectively using your time to accomplish different activities. Discuss the wise use of time in relation to effectiveness.

Figure 2.14: Different time measuring instruments

Dear student! The following laboratory safety rules are essential when you come across an opportunity to visit a laboratory in high school. Moreover, follow the rules when you are requested to carry out some practical activities in the high school laboratory.

Laboratory Safety Rules

Systematic and careful laboratory work is an essential part of any science program because laboratory work is the key to progress in science. The equipment and apparatus you use involve various safety hazards, just as they do for working physicists. Students should follow the general laboratory safety guidelines so that working in the physics laboratory can be a safe and enjoyable process of discovery. These safety rules are:

- Always wear lab safety goggles.
- Avoid wearing baggy clothing, bulky jewelry, dangling bracelets, open-toed shoes, or sandals.
- NEVER work alone in the laboratory.
- Only books and notebooks needed for the experiment should be in the lab.
- Read the entire experiment before entering the lab.
- Students should not eat, drink, apply cosmetics, or chew gum in the laboratory.
- NEVER taste chemicals. Do not touch.
- Report all accidents to the teacher immediately, no matter how minor.
- Exercise caution when working with electrical equipment.
- Let students perform only those experiments authorized by the teacher.
- Keep work areas and apparatus clean and neat.
- Wash hands thoroughly after participating in any laboratory activities.

Self-Test Exercise 2.8

Part I: Write True if the statement is correct and False if it is incorrect.

1. Measurement is a process of comparing an unknown quantity with a known quantity of its kind.
2. Using a sunset and sunrise is a standard time measuring device.

Part II: Choose the correct answer from the given alternatives.

1. Thickness of a sheet of metal is better measured using an instrument called
   A. Measuring tape C. Carpenter's rule
   B. Vernier caliper D. Meter stick

2. Which one of the following physical quantities is correctly related to its S.I unit?
   A. Time in ampere
   B. Mass in Newton
   C. Length in meter
   D. None
3. Which one of the following methods provides a more reliable measurement of time in daily life activities?
   A. Looking rotation of stars in the sky of trees
   B. Using a digital watch
   C. . looking position of Shadows
   D. looking position of the sun on the sky
4. Which of the following instruments is used to measure long distances?
   A. Meter ruler
   B. Tape measure
   C. Micrometer
   D. Vernier caliper

Part III: Give short answers to the following questions

1. List different types of length measuring instruments and categorize them based on the length of the materials.
2. Which one is used as a time measuring device in the laboratory from the type of time measuring devices in Figure 2.6?
3. Define length, time, and mass.

√ Check List

Dear learner, now it is time to check your understanding of measure physical quantities. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Can you list different instruments used to measure physical quantities in your local area?	☐	☐
2. Can you measure length, mass, and time using different units?	☐	☐
3. Can you list length, mass, and time measuring devices?	☐	☐

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Section 2.3: Classification of Physical Quantities [6 hrs.]

Dear student! In this section, you will learn about the classification of physical quantities into basic (fundamental) and derived as well as scalar and vector physical quantities.

After reading this section, you should be able to:

- *Classify physical quantities as fundamental and derived physical quantities;*
- *Describe derived physical quantities in terms of fundamental quantities;*
- *Differentiate fundamental and derived units;*
- *Classify physical quantities as scalar and vector quantities;*

Physical quantities

Dear student! Take a few minutes and think of the following brainstorming questions.

?

1. What is the difference between fundamental and derived physical quantities?
2. Some physical quantities have only magnitude. However, other physical quantities have both magnitude and direction. Can you mention some examples of these physical quantities?

☞ A physical quantity is anything that you can measure. For example, length, temperature, distance, and time are physical quantities.

Quantities that can be measured directly or indirectly are known as physical quantities. The measured values of physical quantities are described in terms of number and unit. Each physical quantity and its unit have a symbol.

Self-Test Exercise 2.9

Part I: Give short answers to the following questions

- In Self-Test Exercise 2.7you measured the length, width and area of the physics module. Discuss the symbols of the physical quantity and its unit. Is there any difference between length, width and area?

☞ You can observe that some physical quantities are directly measured while other physical quantities are measured by combining two or more measurable quantities. For example you measured the width and length of physics module directly. However, the area is measured indirectly by multiplying the length and width of the physics module ($A = l \times w$). The length or width is a fundamental physical quantity. However, area is a derived physical quantity.

Self-Test Exercise 2.10

Part I: Give short answers to the following questions

- Classify physical quantities: length, mass, speed, volume, force and pressure as fundamental or derived physical quantities.

☞ Physical quantities are classified into two.

- Fundamental or basic physical quantities
- Derived physical quantities

☞ **Fundamental or basic physical quantities** are physical quantities that can be measured directly. They cannot be described in terms of other physical quantities. The units used to measure fundamental quantities are called fundamental units. i.e., the unit of fundamental quantity is called the fundamental unit. It does not depend on any other unit. There are seven fundamental physical quantities as shown in *Table 2.3*.

Table 2.3: The fundamental or basic physical quantities with their units and symbol of units

Basic physical quantities	Symbol	Basic unit	symbol
Length	l	meter	m
Mass	m	kilogram	kg
Time	t	Second	s
Temperature	T	Kelvin	K
Current	I	Ampere	A
Amount of substance	N	Mole	mol
Luminous intensity	I_v	Candela	cd

Self-Test Exercise 2.11

Part I: Give short answers to the following questions

1. Describe volume, density, and speed as a combination of fundamental physical quantities.
2. Determine the units of volume, density, and speed using basic units.

☞ **Derived physical quantities**: Physical quantities which depend on one or more fundamental quantities for their measurements are called derived quantities. The units of derived quantities which depend on fundamental units for their measurement are called derived units. Area, volume, density, and speed are some examples of derived physical quantities. Table 2.4 shows some derived quantities with their units and symbol of units.

Table 2.4: Some derived physical quantities and their units

Physical quantity	Symbol	Formula	SI Unit	Fundamental units involved
Speed	V	$\frac{Distance}{Time}$	$\frac{meter}{second}$	$\frac{m}{s}$
Density	ρ	$\frac{Mass}{Volume}$	$\frac{kilogram}{meter\ cube}$	$\frac{kg}{m^3}$
Acceleration	a	$\frac{Velocity}{Time}$	$\frac{meter}{second\ square}$	$\frac{m}{s^2}$
Force	F	$Mass \times Accelaration$	$Newton$ (N)	$\frac{kg.m}{s^2}$
Work	W	$Force \times Displacement$	Joule (J)	$\frac{kg.m^2}{s^2}$
Pressure	P	$\frac{Force}{Area}$	Pascal (Pa)	$\frac{kg}{m\,s^2}$

Scalar and vector quantities

Dear student! In the previous subsection, you learned about the classification of physical quantities as fundamental and derived physical quantities. Now you will learn the classification of physical quantities as scalar and vector quantities.

☞ Physical quantities can also be classified as scalar and vector quantities. Some physical quantities are described completely by a number and a unit. A number with a unit is called a magnitude. However, other quantities have a direction attached to the magnitude. They cannot be described by a number and a unit only.

☞ Thus, physical quantities are grouped into two. These are:

- Scalar quantity
- Vector quantity

Self-Test Exercise 2.12

Part I: Give short answers to the following questions

- Classify the following physical quantities as scalar and vector quantities: mass, time, area, speed, velocity, acceleration, force, energy, work, pressure, momentum, electric current, current, density, displacement, and temperature.

A **scalar quantity** is a physical quantity that has only magnitude but no direction. Examples are distance, mass, time, temperature, energy, etc.

A **vector quantity** is a physical quantity that has both magnitude and direction. When expressing that the car moves 50 km/h to the east, this gives full information about the velocity of the car that includes magnitude and direction (50 km/h is the magnitude, and east is the direction). Because of this, velocity is a vector quantity. Examples are velocity, acceleration, displacement etc.

Physical quantity: anything that you can measure and describe by a number and unit.

Fundamental physical quantities: physical quantities which can be measured directly.

Derived physical quantities: Physical quantities which depend on one or more fundamental quantities for their measurements.

Scalar quantities: Physical quantities that are described only by their magnitude.

Vector quantities: Physical quantities that are described by their magnitude and direction.

Self-Test Exercise 2.13

Part I: Write True if the statement is correct and False if it is incorrect.

1. Candela is a derived physical quantity.
2. The unit of force can be derived from mass, length, and time.
3. Weight is a scalar physical quantity.

Part II: Choose the correct answer from the given alternatives.

1. Which one of the following is a fundamental physical quantity?
   A. Acceleration C. Temperature
   B. Area D. Volume
2. Which one of the following alternatives is a set of derived quantities?
   A. Density, volume, temperature C. Length, mass, area
   B. Area, speed, Volume D. Time, speed, mass
3. Which one of the following is correct about vector quantity?
   A. It has only direction C. It has both magnitude and direction
   B. It has only magnitude D. it has no magnitude and no direction
4. Which one of the following is an example of a scalar quantity?
   A. Acceleration C. mass
   B. Force D. Velocity

√ Check List

Dear learner, now it is time to check your understanding of classification of physical quantities. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Can you classify physical quantities as fundamental and derived physical quantities?	☐	☐
2. Can you describe derived physical quantities in terms of fundamental quantities?	☐	☐
3. Can you differentiate fundamental and derived units?	☐	☐
4. Can you classify physical quantities as scalar and vector quantities?	☐	☐

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Section 2.4: Unit conversion

Dear student! In this section, you will learn about the conversion of units from one system of units to another.

After reading this section, you should be able to:

- *Convert units of length from one system of units to another;*
- *Convert units of mass from one system of units to another;*
- *Convert units of time from one system of units to another;*

Dear student! In the previous section, you learned about different physical quantities. These physical quantities have SI and non-SI units. It is possible to convert units from an SI unit to a non-SI unit and vice versa. Conversion of units is the conversion between different units of measurement for the same physical quantity, typically through multiplicative conversion factors.

Dear student! Take a few minutes and think about the following brainstorming questions:

?

1. How many meters, centimeters, and millimeters are there in one kilometer?
2. How many grams are there in one kilogram? How many seconds are there in a day?

Dear student! The relation between the meter and other non-SI units is given in *Table 2.5*.

Table 2.5: Conversion between units of length

1 meter (m)	100 centimeter (cm)
1 meter (m)	1000 millimeter (mm)
1 meter (m)	0.001 kilometer (km)
1000 meters (m)	1 kilometer (km)
1 millimeter (mm)	0.001 meter (m)
1 centimeter (cm)	0.01 meter (m)
1 centimeter (cm)	10 millimeter (mm)

Activity 2.9

1. Measure the length and width of your exercise book in meters, centimeters and millimeters.
2. Which measuring instrument of length can you use for measuring the diameter of a small sphere?

Example 2.1 The distance between two houses is 200 meters. What is the distance in

a) Centimeters b) kilometers c) millimeters

Solution

l = 200 m a) 1 m = 100 cm

200 m = ? l in cm = $\frac{200\ \cancel{m} \times 100\ cm}{1\ \cancel{m}} = 20000\ cm$

b) 1 m = 0.001 km l in km = $\frac{200\ \cancel{m} \times 0.001\ km}{1\ \cancel{m}} = 0.2\ km$

200 m ?

c) 1 m = 1000 m l in mm = $\frac{200\ \cancel{m} \times 1000\ mm}{1\ \cancel{m}} = 200\ 000\ mm = 2 \times 10^5\ mm$

200 m = ?

Self-Test Exercise 2.14

Part I: Choose the correct answer from the given alternatives.

1. Which one of the following is a suitable unit to measure the distance between the Earth and the Moon?
   A. mm B. km C. cm D. m E. all
2. Which one of the following is a suitable unit to measure the diameter of electric wire?
   A. mm B. km C. cm D. m E. all
3. A hydrogen atom has a diameter of about 10 nm.
   A. Express this diameter in meters.
   B. Express this diameter in millimeters.
   C. c. Express this diameter in micrometers.

Dear student! In the previous subsection, you learned about the relationship between the SI unit and non-Si units of length. Now you will learn about the relationship between the SI unit and the non-SI units of mass.

The relationship between the SI unit and non SI units of mass are shown in Table 2.6

Table 2.6: Relationship between units of mass

1 kilogram (kg)	1000 gram (g)
1 gram (g)	0.001 kilogram (kg)
1 milligram (mg)	0.001 gram (g)
100 kilogram (kg)	1 quintal
1000 kilogram (kg)	1 ton

Example 2.2 In one of the pans of a beam balance, masses of 1.5 kg, 500 g, 250 g, 25 g, and 0.8 g are placed to measure the mass of an unknown object in the other pan. What is the mass of the object in grams and kilograms in the other pan if they are in balance?

Given: **Required:**

m = 1.5 kg, 500 g, 250 g, 25 g, 0.8 g Total mass in kg

Solution:

Total mass =sum of masses in the pan = 1.5 kg+500 g+250 g+25 g + 0.8 g (convert 1.5 kg to g)

1500 g + 500 g + 250 g + 25 g + 0.8 g =2275.8 g

1000 g = 1 kg

2275.8 g = ?

mass in kg = $\frac{2275.8\ \cancel{g} \times 1\ kg}{1000\ \cancel{g}}$ =2.2758 kg

Dear student! In the previous subsection, you learned about the relationship between the SI unit and non-SI units of time. Now you will learn the relationship between the SI unit and non-SI units of time.

Self-Test Exercise 2.15

Part I: Give short answers to the following questions

1. Express the flowing kilograms in grams and milligrams.
   A. 0.28 kg B. 5.6 kg C. 7.2 kg

The relationship between the SI unit and non-SI units of time are shown in *Table 2.7*

Table 2.7: The relation between different units of time

1 minute (min)	60 second (s)
1 hour (hr.)	60 minute (min)
1 day	24 hours (hrs.)
1 week	7 days
1 month	30 days
1 year	365.25 days

Example 2.3 Convert the following hours into seconds:

a) 2 hours b) 0.5 hour c) 3/5 hour

Solution

a) 1 hr. = 3600 s

2 hr. = ?

$$t = \frac{2\,\cancel{hr} \times 3600\,S}{1\,\cancel{hr}} = 7200\,s$$

b) 1 hr. = 3600 s

0.5 hr. = ?

$$t = \frac{0.5\,\cancel{hr} \times 3600\,S}{1\,\cancel{hr}} = 1800\,s$$

c) 1 hr. = 3600 s

$\frac{3}{5}$ hr = ?

$$t = \frac{\frac{3}{5}\cancel{hr} \times 3600\,S}{1\,\cancel{hr}} = 2160\,s$$

Self-Test Exercise 2.16

Part I: Give short answers to the following questions

1. How many hours, minutes, and seconds are there in a day?
2. Express the following times in minutes and seconds:

   2. 0.25 hr. B. 3.2 hrs. C. 6.7 hrs..

√ Check List

Dear learner, now it is time to check your understanding of the conversion of units. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Can you convert units of length from one system of units to another?	☐	☐
2. Can you convert units of mass from one system of units to another?	☐	☐
3. Can you convert units of time from one system of units to another?	☐	☐

Is there any question for which you marked "no" corresponding to? If so, please go back to your text and read about it.

Unit summary

- A scale is a set of numbers, amounts, etc., used to measure or compare the level of something.
- Measurement is the comparison of an unknown quantity with a known one (standard unit).
- Standard units are conventional units that are used to measure physical quantities scientifically.
- Traditional measuring units are not exact and have no standard.
- Prefixes are used to simplify the description of physical quantities that are very big or very small.
- Quantities that can be measured directly or indirectly are known as physical quantities.
- Physical quantities are characteristics or properties of an object that can be measured or calculated from other measurements.
- Physical quantities are classified as fundamental or basic physical quantities and derived physical quantities.
- Length, time, mass, temperature, current, amount of substance and luminous intensity are fundamental quantities in science. All other physical quantities are derived physical quantities.
- Meter, second, kilogram, Kelvin, ampere, mole, and candela are fundamental (basic) units.
- All physical quantities are either vectors or scalars.

Self-assessment questions

Part I: Choose the correct answer from the given alternatives.

1. The SI standard of time is based on:
   A. The daily rotation of the Earth
   B. The yearly revolution of the Earth about the sun
   C. 9 192 631 770 times the period of vibration of radiation from the cesium-133 atom.
   D. A precision pendulum clock
2. A microsecond is
   A. 10^{9} s B. 10^{-9} s C. 10^{-6} s D. 10^{-12} s

3. What is 3hour + 10 minute + 120 s in minutes?
   A. 182 min B. 202 min C. 212 min D. 192 min
4. Why are fundamental physical quantities different from derived physical quantities?
   A. Fundamental physical quantities are derived from derived physical quantities.
   B. Derived physical quantities are derived from fundamental physical quantities.
   C. Derived and fundamental physical quantities have no relationship.
   D. All of the above are answers.
5. Which quantity is a vector?
   A. Energy B. force C. speed D. time

Part II: Write True if the statement is correct and False if it is incorrect.

1. Candela is a derived physical quantity.
2. One kilometer is 100 meters.
3. Scalar quantity can be described by its magnitude and direction.

Part III: Give short answers to the following questions

1. In one of the pans of the beam balance, masses of 3 kg, 900 g, 90 g and 5 g are placed. What amount of mass should be placed on the other side of the beam balance to make it balanced?
2. The doctor wants to know the age of his patient and asks him how old he is. The patient replies that he is 25 and a half years old. What is the age of the patient in months?
3. How many minutes are there in three days?
4. The distance between the Sun and the Earth is about 1.5×10^{11}m. Express this distance in SI prefix.
5. For each of the following, write the measurement using the correct symbol for the prefix and the base unit: (a) 101 nanoseconds (b) 10 milligrams (c) 72 gigameters

Written Assignment

Part I: Choose the correct answer from the given alternatives.

1. Which one of the following is a derived SI unit?
   A. Second B. Joule C. kilogram D. Kelvin
2. Which one of the following pair of physical quantities have the same unit?
   A. displacement and distance
   B. mass and force
   C. speed and acceleration
   D. volume and area
3. If the mass of bodies A, B, and C is 2 tons, 1 quintal, and 1 kilogram, respectively, the total mass of the bodies is
   A. 221 kg B. 2101 kg C. 2011 kg D. 2001 kg
4. Which of the following would describe a length that is 2.0×10^{-3} of a meter?
   A. a) 2.0km B. 2.0 cm C. 2.0mm D. 2.0μm
5. Which one of the following lists is a set of scalar quantities?
   A. length, force, time
   B. length, mass, time
   C. length, force, acceleration
   D. length, force, mass

Part II: Write True if the statement is correct and False if it is incorrect.

1. The unit of force can be derived from mass, length, and time.
2. For very large or very small numbers, prefixes are used with SI units.

Part III: Give short answers to the following questions

1. What is measurement?
2. Which SI units would you use for the following measurements?
   A. the length of a swimming pool
   B. the mass of the water in the pool
   C. the time it takes a swimmer to swim a lap
3. Write some laboratory safety rules.

Part IV: Workout problems the following questions

1. For each of the following symbols, write out the unit in full and what power of 10 it represents: (a) µg (b) mg
2. A student wants to measure the length of a classroom using a tape meter. The tape meter reads 8m and 40 cm. What is the length of the classroom in cm?
3. If the area of a single ceramic tile is 0.25 m^2, how many ceramic tiles are needed to cover the floor of a classroom whose area is 40 m^2?
4. The volume of the Earth is on the order of 10^{21} m^3. (a) What is this in cubic kilometers (km^3)? (c) What about in cubic centimeters (cm^3)?

Answer Key for Self-Test Exercise

Self-Test Exercise 2.1:

1. 360 g, 110 g and 260 g respectively.
2. a) 67 g b) 30 kg c) 500 g d) 3.4 cm
3. a) 3 °C b) 22 °C c) -6 °C

Self-Test Exercise 2.2:

1. No, the measurements are not standard. For the measurements to be standard, measurements taken by different students in different places must yield the same result.

Self-Test Exercise 2.3:

1. We need a standard unit of measurement to make our judgment more reliable and accurate. For proper dealing, measurements should be the same for everybody. Thus, there should be uniformity in measurement. For the sake of uniformity, we need a common set of units of measurement, which are called standard units.
2. Non-standard units can lead to errors in conversion, and it doesn't work well across different countries and different places. Also, the dimensions of the same physical quantity may differ.

Self-Test Exercise 2.4:

1. 1.26×10^{-6}
2. 2 significant figures
3. 7 significant figures

Self-Test Exercise 2.5:

1. 6.371×10^6 m = 6.371 Mm
2. 7.5×10^{-6} m = 7.5 μm

Self-Test Exercise 2.6:

1. True 2. False 3. False

1. B 2. B 3. B 4.

1. The interval scale lacks a true zero point. But the ratio scale has a true zero point. The interval scale cannot be multiplied or divided. However, it is possible to multiply and divide units on a ratio scale.
2. Traditional measuring units have no standard. However, scientific measuring units have a standard.
3. See section 1 in your physics module (well defined) .

Self-Test Exercise 2.7:

1. Measure the width and length of your physics module in meters. Ask your tutor or anyone to measure your physics module in meters, and compare it with your measured value.
2. Calculate the area of your physics module in a square meter (m^2) and show it o your tutor.
3. First, he has to measure and graduate the rope using the meter stick and then use the rope.

Self-Test Exercise 2.8:

1. True 2. False 3. False

1. B 2. C 3. B 4. B

1. Long length (Tape measure, Yardstick or meter stick, Roll meter)
   Short length or thickness (Caliper, micrometer)
2. Stop watch
3. See section 1 in your physics module (well defined)

Self-Test Exercise 2.9:

1. The symbols for the physical quantities length, width, and area are l, w and A respectively. The units of length and width are the same, and it is the meter (m). However, the unit of area is m^2. Length or width is a fundamental physical quantity. Area is a derived physical quantity.

Self-Test Exercise 2.10:

1. Fundamental physical quantities are mass and length. Derived physical quantities are speed, volume, force and pressure.

Self-Test Exercise 2.11:

1. a) Volume = length × width × height or $V = l \times w \times h$ (length, width and height have the same dimension, and they are fundamental or basic physical quantities.) The SI unit of volume is m^3.

   b) Density is the ratio of mass to volume.

   $Density = \frac{mass}{Volume} = \frac{mass}{length \times width \times height}$.

   Density is derived from two fundamental physical quantities mass and length.

   c) Speed is the ratio of distance to time. Speed=$\frac{distance}{time} = \frac{s}{t} = \frac{l}{t}$

   Speed is derived from two fundamental quantities: length and time.

Self-Test Exercise 2.12:

Mass, time, area, speed, energy, work, pressure, electric current, and temperature are scalar quantities, and they are described by their magnitudes only. They have no direction. However, velocity, acceleration, force, momentum, current density, and displacement are vector quantities. They are described by their magnitude and direction.

Self-Test Exercise 2.13:

1. False 2. True 3. False
1. C 2. B 3. C 4. C

Self-Test Exercise 2.14:

1. B 2. A
2. a) 10 nm = 10× 10^{-9} m = 10^{-8} m

   b) 10^{-5}mm

   c) 0.01 μm

Self-Test Exercise 2.15:

a) 0.28 kg = 280 g = 280,000 mg = 2.8 x 10^5 mg

b) 5.6 kg = 5600 g = 5,600,000 mg = 5.6 x 10^6 mg

c) 7.2 kg = 7200 g = 7,200,000 mg = 7.2 x 10^6 mg

Self-Test Exercise 2.16:

1. a) 1d = 24 hr.

b) 1d = 24 × 60 min =1440 min.

c) 1 d = 1440 × 60 s = 86400 s.

3. a) 0.25 h =0.25× 60 min =15 min, 0.25 h = 15 × 60 s =900 s

b) 3.2 h = 3.2 × 60 min =192 min, 3.2 h = 192 × 60 s = 11520 s

c) 6.7 h = 6.7 × 60 min = 402 min, 6.7 h = 402 × 60 s = 24120 s

Answer Key for Self-assessment questions

1. C 2. C 2. D 4. B 5. B
1. False 2. False 3. False
1. 43200 s
2. See section 3 and 4 in your physics module (it is well defined there)
3. Vernier caliper
4. See section 3 and 4 in your physics module
1. 3.995 kg or 3995 g
2. 2. 25.5 year= 310.675 month (for 1 y =365.5 d)
3. 4320 minutes
4. 0.15 Tm
5. a) 101 ns b) 10 mg c) 72 Gm

Answer Key for Activity

Answer to Activity 2.1

1. Solution: The red line goes just past 2.05 but not quite to 2.1. We can estimate the third decimal place giving us final answer 2.054.

Answer to Activity 2.2

1. Observe measurement activities in the surrounding area (home, local market, and work places) and prepare a report on the what, where, and how of the measurements observed.
2. List traditional and commonly used scales and units of measurement for length, mass, time, volume and temperature based on your observations.

Answer to Activity 2,3

a)28.8 b)2.56 c) 11.6 d) 12

Unit 3

Motion in a Straight Line

Introduction

What do you think is motion? Give some examples of motion that you encounter in your daily life. .In this unit, you will be introduced to the basic concepts of motion. We encounter motion in our day-to-day activities and have enough experience about it. You might have learnt in lower grades that everything in the universe moves. It is because of this that motion is one of the key topics in physics. We use the basic concepts of distance, displacement, speed, velocity and acceleration to express motion. There are different types of motions. Motion in a straight line is one of the simplest forms of motion in a specific direction. The motion of a car on a straight road; the motion of a train along a straight railway track or an object falling freely are examples of one-dimensional motion.

After reading this unit, you should be able to:

- *describe motion in terms of frame of reference, displacement, speed, velocity, and acceleration;*
- *draw diagrams to locate objects with respect to a reference;*
- *solve problems involving distance, displacement, speed, velocity and acceleration;*
- *make practical measurements of distance, displacement, average speed, average velocity and acceleration;*

Unit Contents

The Required Study Time: The time allotted for this section is 16 hours.

Learning Strategies:

- Engage yourself in describing how the locations of places are described.
- Perform a hands-on activity to locate the position of any nearby school.
- Describe the concepts of reference, reference frame, position vector, etc.
- Use Google Maps to locate the positions of important places around your home and record the positions on a paper drawing. The same activity can be repeated by expanding the area to a region and/or a country (Ethiopia).
- Use Google-Maps to measure distance. Determine the distance on the road as well as the areal distance between important locations using the "measure distance" feature. Use the same activity to introduce and distinguish between the concepts of “distance” and “displacement.”
- Engage yourself in a graphical vector addition activity with displacement vectors using diagrams drawn to scale. The activity will be used to introduce vector symbols, magnitude, direction, vector diagrams, measurement of angles, and conversion between scales.

Section 3.1: Position, Distance, and Displacement

Dear student! In this section, you will learn about the concept of position, distance and displacement. In terms of your daily motion, can you explain the differences among position, distance and displacement?

After reading this section, you should be able to:

- *describe motion in terms of frame of reference;*
- *differentiate between position, distance and displacement;*
- *draw diagrams to locate objects with respect to a reference frame;*

The most convenient example to explain about position, distance and displacement is your daily travel from your home to your school. When you go to school, your journey begins from your home. Your home is your original position.

After some time, you will reach your school. Your school is your final position. In this process, you are continuously changing your position. While traveling from home to school, you are increasing the gap between your present position and your home. This continuous change of position is known as motion. Note that your change of position is observed by considering the distance from your school to home. Your home is taken as a **reference frame**. Motion is a continuous change in position of an object relative to the position of a fixed object called reference frame.

A body is said to be at rest in a frame of reference when its position in that reference frame does not change with time. If the position of a body changes with time in a frame of reference, the body is said to be in motion in that frame of reference. The concepts of rest and motion are completely relative; a body at rest in one reference frame may be in motion with respect to another reference frame. For example, if you are 2 m from the doorway inside your classroom, then your reference point is the doorway. Your classroom can be used as a reference frame. In the classroom, the walls are not moving, and can be used as a fixed frame of reference. We commonly use the origin as a fixed reference point to describe motion along a straight line.

Position

To describe the motion of an object, we need to be able to describe the position of the object and how that position changes as the object moves. Motion is the change in the position of the object with respect to a fixed point as the time passes. For one-dimensional motion, we often choose the x axis as the line along which the motion takes place. Positions can therefore be negative or positive with respect to a given origin. *Figure 3.1*shows the motion of a rider in a straight line. Its position changes as it moves.

Have you ever used Google Maps to locate your geographical position while you are moving from some place to another? Google Maps is a Web-based service that provides detailed information about geographical regions and sites around the world. In addition to conventional road maps, Google Maps offers aerial and satellite views of many places. Google Maps provides you with the longitude (east-west position) and latitude (north-south position) coordinates of a location or position of a place.

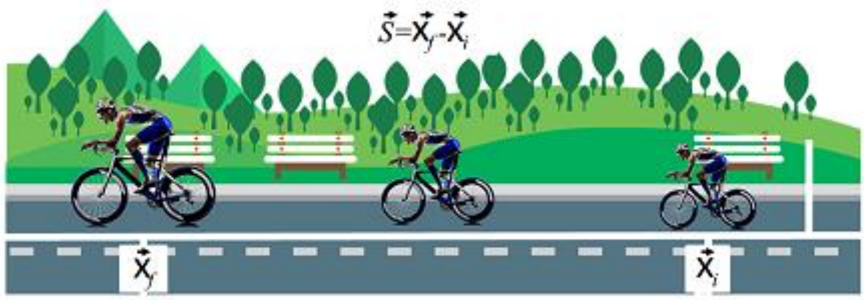


Figure 3.1: A rider in motion changes its position as it moves

Distance (S)

Distance travelled is a measure of the actual distance covered during the motion of a body. In other words, distance is the total path length traveled by the body. The distance travelled does not distinguish between motion in a positive or negative direction. This means that it is a scalar physical quantity. The SI unit of distance is meter (m), though it can also be measured in other non-SI units such as kilometer (km), miles (mi), centimeter (cm), etc. The symbol for distance is S. Pictorial representation of the distance covered by a runner is shown in *Figure 3.2*.

Figure 3.2: The distance covered by a runner

Displacement

When an object moves, it changes its position. This change of position in a certain direction is known as displacement. A displacement is described by its magnitude and direction. Hence, it is a vector quantity. Displacement is independent of the path length taken. For example, you travel from your home to school. After school, you travel to your home. Therefore, the change in your position when you return to your home is zero. In this case, we say that your displacement is zero. The SI unit of displacement is the same as the SI unit of distance that is meter (m). *Figure 3.3* shows the difference between distance and displacement of the motion covered from point A to point B.

Figure 3.1 shows a student on a bicycle at position $\overrightarrow{X_i}$ at time t_i. At a later time, t_f, the student is at position $\overrightarrow{X_f}$. The change in the student's position, $\overrightarrow{X_f} - \overrightarrow{X_i}$, is called a displacement. Thus, the dislacement $\vec{S}$ can be written as

$$\vec{S} = \overrightarrow{X_f} - \overrightarrow{X_i}$$

Figure 3.3: Illustration of Distance and displacement

Table 3.1: Difference between distance and displacement

Distance	Displacement
It is the length of path travelled by an object in a given time	It is the shortest distance between two points in a particular direction
It is a scalar quantity	It is a vector quantity
It depends on the path followed by the object	It depends on the initial and final positions of the object, but not necessarily on the path followed
It can be more than or equal to the magnitude of displacement	Its magnitude can be less than or equal to the distance

Activity 3.1

Three students walked on a straight line. The first student walked 200 m to the right from a reference point A, then returned and walked 100 m to the left and then stopped. The second student walked 200 m from point A to the right, then returned and walked 300 m to the left and stopped. The third student walked 200 m to the right from point A, then returned and walked 200m to the left and stopped at point A. Determine the total distance and displacements of the first, the second and the third student.

A frame of reference is a set of coordinates that can be used to determine positions of objects.

Motion is the change in the position of the object with respect to a fixed point as the time passes.

Position is a measurement of a location, with respect to some reference point (usually an origin).

Self-Test Exercise 3.1.1

Part I: Give short answers to the following questions

- Assume you are sitting on a horse and the horse is moving at a certain speed. Are you at rest or in motion? Discuss it by taking two frames of reference: the horse itself and some fixed point on the ground.

Self-Test Exercise 3.1.2

Part I: Give short answers to the following questions

- What is the distance around a standard football field? Is distance a positive or negative quantity?

Self-Test Exercise 3.1.3

Part I: Give short answers to the following questions

- What is the displacement if the final position is the same as the initial position?

Self-Test Exercise 3.1.4

Part I: Give short answers to the following questions

- Given the following values for the initial position X_i and final position X_f , check whether the value of the net displacement is positive or negative.
  A. $X_f = (5,0)$ and $X_i = (-1,0)$.
  B. $X_f = (10,0)$ and $X_i = (-15,0)$.
  C. $X_f = (6,0)$ and $X_i = (4,0)$.

Example:

A cyclist rides 3 km west and then turns around and rides 2 km east. (a) What is her displacement? (b) What distance does she ride? (c) What is the magnitude of her displacement?

Given: The cyclist rides 3 km west and then 2 km east

Required:

i. The displacement of the cyclist
ii. The distance she rides
iii. The magnitude of her displacement

Solution: To solve this problem, we need to find the difference between the final position and the initial position while taking care to note the direction on the axis.

a) Displacement: The rider's displacement is $\vec{S} = \overrightarrow{X_f} - \overrightarrow{X_i}$ = 1 km west. The displacement is negative if we choose east to be positive and west to be negative.
b) Distance: The distance traveled is 3 km + 2 km = 5 km.
c) The magnitude of the displacement is 1 km.

√ **Check List 3.1**

Dear learner, now it is time to check your understanding the following terms. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Motion	☐	☐
2. Reference frame	☐	☐
3. Position	☐	☐
4. Distance	☐	☐
5. Displacement	☐	☐
6. Can you draw diagrams to locate objects with respect to a reference frame?	☐	☐

Is there any question for which you marked "no" in the box corresponding to it? If so, please go back to your text and read about it.

Section 3.2: Average Speed and Instantaneous Speed

Dear student! In this section, you will learn about average and instantaneous speed. How you define speed? Can you explain the difference between average and instantaneous speed?

After reading this section, you should be able to:

- *differentiate between average speed and instantaneous speed;*
- *compute the average speed of a body moving in a straight line covering a certain distance in a given time;*
- *estimate the speed of moving bodies in your surroundings;*

Speed is a quantity that describes how fast a body moves. Speed is the rate at which an object changes its location. Like distance, speed is a scalar quantity
because it has a magnitude but no direction. Since speed is a rate, it depends on the time interval of motion. Its symbol is v. In other words, speed is the distance covered by a moving body per unit time. The SI unit of speed is meter per second (m/s). Other units of speed include kilometer per hour (km/h) and miles per hour (mi/h). The mathematical equation used to calculate speed is

$$speed = \frac{distance}{time}$$

$$v = \frac{s}{t}$$

One of the most obvious features of an object in motion is how fast it is moving.
In your journey from home to school, you walk slowly for some time, and you run another time to cover the total distance. This shows that the speed for the walk and the speed for the run are different. In this regard, we define average speed.

Speed and average speed are not the same although they are derived from the same formula. The average speed is defined as the total distance travelled divided by the total time it takes to travel that distance:

$$\text{Average speed} = \frac{\text{Total distance covered}}{\text{Total time taken}}$$

$$\mathrm{v_{av}} = \frac{\mathrm{s_{tot}}}{\mathrm{t_{tot}}}$$

Figure 3.4: Speedometer

During a typical trip to school by car, the car undergoes a series of changes in its speed. If you were to look at the speedometer readings at regular intervals, you would notice that it changes. The speedometer of a car gives information about the instantaneous speed of the car. It shows the speed of the car at a particular instant in time. The speed at any specific instant is called the instantaneous speed. To calculate the instantaneous speed, we need to consider a very short time interval-one that approaches zero. For example, a school bus undergoes changes in speed. Mathematically the instantaneous speed is given by:

$$v_{ins}=\frac{\Delta s}{\Delta t} \text{ as } \Delta t \rightarrow 0$$

Instantaneous speed and average speed are both scalar quantities. When you solve the average of all instantaneous speeds that occurred during the whole trip, you will get the average speed.

Example:

1. A car covers a distance between two towns which are 80 km apart. If it takes the car 1hr and 30 minutes to travel between the two towns, calculate the average speed of the car in m/s.

Given: $s = 80 \text{ km}, t = 1\text{hr and } 30 \text{ minutes}$

Required: The average speed v_{av}

Solution: The car takes 1hr and 30 minutes to travel between the two towns. This time is the same as 1.5 hrs. Therefore, the average speed of the car is given by,

$$v_{av} = \frac{s}{t}$$

With $s = 80\text{km}$ and $t = 1.5 \text{ hrs}$, v_{av} becomes,

$$v_{av} = \frac{80 \text{ km}}{1.5 \text{ hrs}} = 53.33 \text{ km/hr}$$

However, we are required to calculate the average speed in m/s. For this purpose, we use $1\text{km} = 1000\text{ m}$ and $1\text{hr} = 3600\text{ s}$. Hence,

$$v_{av} = 53.33\frac{\text{km}}{\text{hr}} = 53.33 \times \frac{1000\text{m}}{3600\text{s}} = 14.81\text{ m/s}$$

2. How far does a student walk in 1.5 hr if her average speed is 5 m/s?

Given: $v_{av} = 5\text{m/s},\ t = 1.5\text{hr}$

Required: S

Solution: To find the distance, we rewrite the equation as

$$v_{av} = \frac{s_t}{t_t}\text{ , and}$$

$$s = v_{av}t$$

$$s = 5400\text{ s} \times 5\frac{\text{m}}{\text{s}} = 27000\text{ m}$$

☞ Speed is the distance covered by a moving body per unit time.

Self-Test Exercise 3.5

Part I: Give short answers to the following questions

- In Figure **3.4,** what does the speedometer read?

Self-Test Exercise 3.6

Part I: Give short answers to the following questions

- What are the differences and similarities between average speed and instantaneous speed?

Self-Test Exercise 3.7

Part I: Give short answers to the following questions

- If a car is travelling at 120 km/h, what is the seed of the car m/s?

√ **Check List 3.2**

Dear learner, now it is time to check your understanding the following terms. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Speed	☐	☐
2. Average speed	☐	☐
3. Instantaneous speed	☐	☐
4. Can you compute the average speed of a body; moving in a straight line	☐	☐
5. covering a certain distance in a given time;	☐	☐

Is there any question for which you marked "no" in the box corresponding to it? If so, please go back to your text and read about it.

Section 3.3: Average Velocity and Instantaneous Velocity

Dear students! In this section, you will learn about average and instantaneous velocity. What is velocity? Can you explain the difference between average and instantaneous velocity? What is the difference between speed and velocity?

After reading this section, you should be able to:

- *differentiate between average velocity and instantaneous velocity;*
- *compute the average velocity of a body moving in a straight line covering a certain displacement in a given time;*

Where an object started and where it stopped does not completely describe the motion of the object. Velocity is a physical quantity that describes how fast a body moves as well as the direction in which it moves. Hence, velocity is a vector quantity. Its symbol is $\vec{V}$ (v with an arrow on the head). The SI unit of velocity is meter per second (m/s). Other units of velocity include kilometer per hour (km/h) and miles per hour (mi/h).

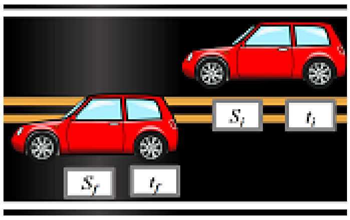


Figure 3.5: The average velocity of the car tells how fast and in which direction the car is moving

Suppose that the positions of the car are $\vec{X}_i$ at time t_i and $\vec{X}_f$ at time t_f. If the details of the motion at each instant are not important, the rate is usually expressed as the average velocity. Average velocity ($\vec{v}_{av}$) of a body is the total displacement covered by that body in a specified direction divided by the total time taken to cover the displacement. Mathematically, it can be written as

$$\vec{v}_{av} = \frac{\vec{X}_f - \vec{X}_i}{t_f - t_i} = \frac{\Delta\vec{X}}{\Delta t} = \frac{\vec{s}}{\Delta t}$$

where $\vec{X}_f$ is the final position at final time t_f and $\vec{X}_i$ is the initial position at time t_i. Average velocity points in the same direction as the displacement. If the displacement points in the positive direction, the average velocity is positive. If the displacement points in the negative direction, the average velocity is negative.

To determine the velocity at some instant, such as t = 1.0 s, or t = 2.0 s etc., we study a small time interval near that instant. As the time interval becomes smaller and smaller, the average velocity over that interval becomes instantaneous velocity. Instantaneous velocity of a body is its velocity at any time t. For a body that undergoes uniform motion, the velocity of the body is uniform and the average velocity and the instantaneous velocity are the same. Instantaneous velocity can be positive or negative. The magnitude of the instantaneous velocity is known as the instantaneous speed.

Example:

1. A student attained a displacement of 360 m north in 180 s. What was the student's average velocity?

Given: $\mathbf{s} = 360\ \text{north}, \text{t} = 180\ \text{s}$

Required: The average velocity $\vec{v}_{av}$

Solution:

We know that the displacement is 360 m north and the time is 180 s. We can use the formula for average velocity to solve the problem.

$$\vec{v}_{av} = \frac{\vec{S}}{\Delta t} = \frac{360m}{180s}\ North = 2\, {}^{m}/_{s}\ North$$

2. A girl jogs with an average velocity of 2.4 m/s east. What is her displacement after 40 seconds?

Given: $\mathbf{v}_{av} = 2.4\text{m/s east}, \text{t} = 180\text{ s}$

Required: The displacement $\vec{S}$

Solution:

$$\vec{S} = \vec{v}_{av} \times \Delta t = 2.4\frac{m}{s}\ East \times 40\ s = 96m\ East$$

3. A bus moving along a straight line (say x-axis) has the following positions in the given time intervals. Calculate the average velocity of the bus for each time interval.

Table 3.1

S in km	20	60	100	140
t in hour	0	1	2	3

Given: S in km, and t in hrs

Required: The average velocity for each time interval

Solution: By computing the displacement of the bus for each time interval, we can calculate the average velocity of the bus as follows.

Between $t_0 = 0$ and $t_1 = 1hr$

$$\Delta\vec{X}_1 = \vec{X}_f - \vec{X}_i = 60\ km - 20\ km = 40\ km$$

The average velocity during this time interval is

$$\vec{v}_1 = \frac{\Delta\vec{X}_1}{\Delta t_1} = \frac{40\ km}{1\ hr} = 40\frac{km}{hr}$$

Between $t_1 = 1hr$ and $t_2 = 2hr$

$$\Delta\vec{X}_2 = \vec{X}_f - \vec{X}_i$$

$$= 100\ km - 60\ km = 40\ km$$

The average velocity of the bus during this time interval is

$$\vec{v}_2 = \frac{\Delta\vec{X}_2}{\Delta t_2} = \frac{40\ km}{1\ hr} = 40\frac{km}{hr}$$

Between $t_2 = 2\ hr$ and $t_3 = 3\ hr$

$$\Delta\vec{X}_3 = \vec{X}_f - \vec{X}_i = 140km - 100km = 40km$$

The average velocity during this time interval is

$$\vec{v}_3 = \frac{\Delta\vec{X}_3}{\Delta t_3} = \frac{40\ km}{1\ hr} = 40\frac{km}{hr}$$

Therefore, for each time interval, the average velocity of the car is constant. This implies that the car is undergoing uniform motion.

Note: you can convert km/hr into m/s by the relation:

$$1\frac{km}{hr} = \frac{1000\ m}{60 \times 60\ s} = \frac{10}{36} m/s$$

☞ **Velocity** is the rate of change of displacement.

Average velocity is the total displacement of a body over a time interval.

Instantaneous velocity is the velocity of a body at a specific instant in time.

Self-Test Exercise 3.8

Part I: Give short answers to the following questions

- Is the average speed the same as the magnitude of the average velocity? Explain.

Self-Test Exercise 3.9

Part I: Give short answers to the following questions

- In 2003, Tirunesh Dibaba won the world junior cross-country title by completing a 5,000-metre in 14 min 39.94 sec (junior world record) and secured the gold at the International Association of Athletics Federations (IAAF) world track and field championships, becoming the youngest-ever world champion in her sport. Calculate her average speed.

Self-Test Exercise 3.10

Part I: Give short answers to the following questions

- Athlete 1 completes 100m in 55 seconds and athlete 2 completes the same distance in 50 seconds. Compare their average speeds. Which athlete has higher average speed?

√ Check List 3.3

Dear learner, now it is time to check your understanding the following terms. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Velocity	☐	☐
2. Average velocity	☐	☐
3. Instantaneous velocity	☐	☐
4. Can you compute the average velocity of a body moving in straight line covering a certain displacement in a given time.	☐	☐

Is there any question for which you marked "no" in the box corresponding to it? If so, please go back to your text and read about it.

Section 3.4: Acceleration

Dear student! In this section, you will learn about acceleration. In your own words, can you explain acceleration?

After reading this section, you should be able to:

- *define acceleration;*
- *calculate the average acceleration of a body if its velocity changes from some initial value to final value in a given time interval;*

The discussion of motion with varying velocity can be dealt with by the introduction of the concept of acceleration. Acceleration is a vector quantity and is a measure of how much the velocity of an object changes in a unit of time (in one second). Acceleration is denoted by $\vec{a}$ and its SI unit is $^{m}/_{s^2}$, that is, meters per second squared or meters per second per second. For example, if a runner travelling at 10 km/h due east slows to a stop, reverses direction, and continues her run at 10 km/h due west, her velocity has changed as a result of the change in direction, although the magnitude of the velocity is the same in both directions. Acceleration occurs when velocity changes in magnitude (an increase or decrease in speed) or in direction, or both as shown in *Figure 3.6*. Acceleration is, therefore, a change in speed or direction, or both.

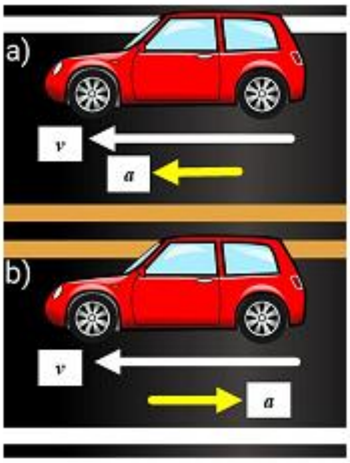


Figure 3.6: (a) positive acceleration (car speeding up) and (b) negative acceleration (car slowing down)

If the initial velocity of a body is $\vec{v_i}$ at a time t_i, and the final velocity is $\vec{v_f}$ at a time t_f , the average acceleration is, from the definition,

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i}$$

If a body starts from rest, then the initial velocity is zero ($\vec{v_i} = 0$). If the velocity of a body decreases, then the final velocity is less than the initial velocity.

Such motion is called decelerating motion. Deceleration is called a negative acceleration. If the body comes to rest, the final velocity is zero ($\vec{v_f} = 0$).

☞ **Acceleration** is the rate of change of velocity.

Self-Test Exercise 3.11

Part I: Give short answers to the following questions

1. If the initial and final velocities of a car are the same, what will be its acceleration?
2. Is the direction of the acceleration always in the direction of the velocity?

Example 3.7: A train moving in the east direction accelerates from rest to 36.0 km/hr in 20.0 s. What is the average acceleration during that time interval?

Given: $\vec{v}_i = 0, \vec{v}_f = 36.0 \text{ km/hr east}, \Delta t = 20.0 \text{ s}$

Required: The average acceleration $\vec{a}_{av}$.

Solution:

$$\vec{a}_{av} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} = \frac{36 \text{ km/hr} - 0}{20 \text{ s}}$$

$$\vec{a}_{av} = \frac{10\text{m/s} - 0}{20 \text{ s}} = +0.5 \frac{m}{s^2} \text{ } east$$

Note that 36 km/hr is equivalent to 10m/s. The plus sign in the answer means that acceleration is to the right. This is a reasonable conclusion because the train starts from rest and ends up with a velocity directed to the right (i.e., positive). So, acceleration is in the same direction as the change in velocity.

Example 3.8: A car traveling at 7.0 m/s to east accelerates at 2.5 m/s^2 to reach a speed of 12.0 m/s in the same direction. How long does it take for this acceleration to occur?

Given: $\vec{v}_i = \frac{7\text{m}}{\text{s}} east, \vec{v}_f = \frac{12.0\text{m}}{\text{s}}$ east , $\vec{a}_{av} = 2.5\ \text{m/s}^2$ east

Required: The time Δt

Solution:

$$\Delta t = \frac{\vec{v}_f - \vec{v}_i}{\vec{a}_{av}} = \frac{12.0\frac{\text{m}}{\text{s}} - 7.0\text{m/s}}{2.5\ m/s^2} = 2\ s.$$

√ Check List 3.4

Dear learner, now it is time to check your understanding about acceleration. Read each question and put a mark (“X”) in the box that corresponds to your answer.

	Yes	No
1. Can you define acceleration?	☐	☐
2. Can you calculate the average acceleration of a body if its velocity changes from some initial value to final value in a given time interval?	☐	☐

Is there any question for which you marked “no” in the box corresponding to it? If so, please go back to your text and read about it.

Section 3.5: Uniform Motion

Dear student! What do you think is a uniform motion? In this section, you will learn about uniform motion.

After reading this section, you should be able to:

- *define uniform motion;*
- *give examples of uniform motion;*

Uniform motion is the motion of an object along a straight line with a constant velocity or speed in a given direction. In a uniform motion, an object travels equal distances in fixed intervals of time. In fact, a moving body does not have a uniform speed throughout its motion. Sometimes the body speeds up or slows down, and other times it moves with a constant speed. This is why describing motion in terms of average quantities (average speed and average velocity) is highly important. Some examples of a uniform motion are a car moving on a straight road with a fixed speed (as shown in *Figure 3.7*) and an airplane flying with a constant speed in a given direction.

Figure 3.7: A car moving with a constant speed without changing the direction of motion

> ☞ Motion at a constant velocity or uniform motion means that the position of the object is changing at the same rate.

The uniform rectilinear motion has the following properties:

- The acceleration is zero (a=0) because neither the magnitude of the velocity nor its direction changes.
- The average and instantaneous velocities have the same values at all times.

Self-Test Exercise 3.12

Part I: Give short answers to the following questions

- Consider the following S-t graph of two cars in motion on a straight line as shown in Figure 3.8. Which car is moving faster and why?

√ Check List 3.5

Dear learner, now it is time to check your understanding about uniform motion. Read each question and put a mark ("X") in the box that corresponds to your answer.

	Yes	No
1. Can you define a uniform motion?	☐	☐
2. Can you give examples of a uniform motion?	☐	☐

Is there any question for which you marked "no" in the box corresponding to it? If so, please go back to your text and read about it.

Section 3.6: Graphical Representation of Motion

Dear student! In this section, you will learn about graphical representation of motion. What do you think is the importance of graphical representation of

After reading this section, you should be able to:

- *plot s-t and v-t graphs;*
- *define the slope of a motion;*
- *calculate the velocity from S-t graph and acceleration from v-t graph;*

The motion of an object travelling even in a straight line can be complicated. The object may travel forwards or backwards, speed up or slow down, or even stop. Where the motion remains in one dimension, the information can be presented in graphical form. The main advantage of a graph compared with a table is that it allows the scope of the motion to be seen clearly.

Position-Time Graph

A position-time graph indicates the position of an object at any time for a motion that occurs over an extended time interval. The data from Table 3.2 can be presented by plotting the time data on a horizontal axis and the position data on a vertical axis, which is called a position-time graph. The graph of the runner's motion is shown in Figure **3.8**. To draw this graph, first plot the runner's recorded positions; then, draw a line that best fits the recorded points.

To determine the velocity or speed of the runner, consider the meaning of the slope. Start with the mathematical definition of slope.

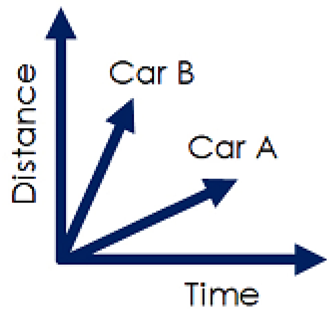


Figure 3.8: The s-t graph for a uniform motion

Table 3.2: Position-time table for the runner

Table 3.2	
Position vs. time	
Time (s)	Position (m)
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0
6.0	30.0

Slope is the rise over the run.

$$slope = \frac{rise}{run} = \frac{\Delta\vec{X}}{\Delta t} = \vec{v}_{av}$$

Therefore, if we take any two points in a straight line the speed from the *S-t* graph is

$Slope = \frac{(5.0-0)m}{(1.0-0)s} = \frac{(10.0-5.0)m}{(2.0-1.0)s} = \frac{5.0m}{s}$ to the positive x-direction.

This shows that the displacement increased by 5.0 m in 1.0s. The **S**-t graph gives a constant velocity.

Velocity- Time Graph

A graph of velocity against time shows how the velocity of an object changes with time. Just as a displacement-time graph shows how far an object has moved, a velocity-time graph shows how its velocity changes during the motion of the object. Table 3.3 shows the data for a car that starts at rest and speeds up along a straight line of a road. The velocity-time graph obtained by plotting these data points is shown in *Figure 3.9*. The positive direction has been chosen to be the same as that of the motion of the car. Note that this graph is a straight line, which means that the car is speeding up at a constant rate. The rate at which the car's velocity is changing can be found by calculating the slope of the velocity time graph. Consider a pair of data points that are separated by 1 s, such as 4.0 s and 5.0 s. At 4.0 s, the car is moving at a velocity of 20.0 m/s. At 5.0 s, the car is travelling at 25.0 m/s. Thus, the car's velocity increased by 5.0 m/s in 1.00 s. The rate at which an object's velocity changes is called the acceleration of the object. When the velocity of an object changes at a constant rate, the object has a constant acceleration.

Table 3.3

Velocity vs. time

Time (s)	Velocity (m/s)
0.0	0.0
1.0	5.0
2.0	10.0
3.0	15.0
4.0	20.0
5.0	25.0

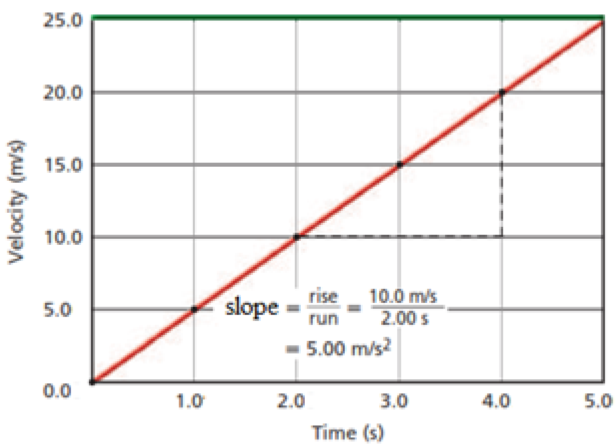


Figure 3.9: The slope of velocity-time graph is the acceleration of the object

In a uniform motion, the v-t graph is a horizontal line as shown in Figure 3.10 indicating that the velocity is constant at any given time. The area under the v-t graph in a uniform motion represents the distance covered by the object.

The area of the rectangle in Figure 3.10 is given by, $area = b \times h = v \times t = s$, which is equal to the distance covered by the object.

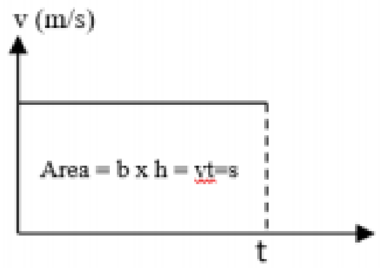


Figure 3.10: The v-t graph of a uniform motion

Speed Limit and Traffic Safety

> ? Have you ever noticed a traffic sign of a speed limit as shown in the Figure 3.11?

What does it indicate and what is its importance? The above *Figure 3.11* shows that drivers are required to keep the speed of their cars at 80 km/hr or below. Drivers violating this speed limit will be charged by the traffic police as they may cause danger. Nowadays, vehicles moving with a very high speed are the main causes for the death of thousands of people and several property damages as they cannot be controlled easily during accident as indicated in *Figure 3.12*. One can easily read the speed of a car from the speedometer. Speedometer is a device used to measure the instantaneous speed of a car. It is very important to keep the speed of cars at the optimum level to save lives and avoid property damages.

Figure 3.11: Traffic accident

Figure 3.12: Speed limit in a typical city road

Activity 3.4

- Identify the type of vehicles causing human/animal deaths and property damages in your area. Can you guess the percentage of the accidents caused by violation of speed limits? Also suggest possible solutions.

The slope of a position-time graph represents the average velocity of an object.

The slope of a velocity-time graph represents the acceleration of an object.

Unit summary

- Motion in a straight line is one of the simplest forms of motion in a specific direction and is called rectilinear motion.
- An object is in motion if it changes position relative to a reference point
- Motion can be described by distance, speed, displacement, and velocity, where displacement and velocity also include direction.
- Distance is a physical quantity which describes the length between two points (places) and is the total path length travelled by a body. Distance is a scalar quantity.
- Displacement is the change in position of a body in a certain direction.
- The speed of an object can be calculated by dividing the distance traveled by the time needed to travel the distance.
- The velocity of an object is the speed of the object with its direction of motion.
- Average velocity is displacement over the time period during which the displacement occurs. If the velocity is constant, then average
  velocity and instantaneous velocity are the same.
- Acceleration occurs whenever an object speeds up, slows down, or changes direction.
- Uniform motion is the motion of an object along a straight line with a constant velocity or speed in a given direction.
- The slope of a position-versus-time graph at a specific time gives instantaneous velocity at that time.
- On a speed-time graph, a horizontal line represents zero acceleration or constant speed.

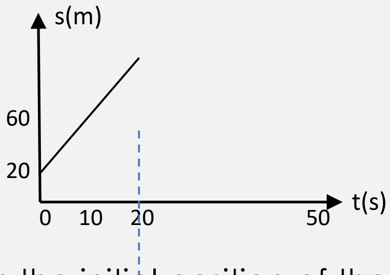
Self-assessment questions

Part I: Conceptual Questions and Workout Problems.

1. How are average velocity and instantaneous velocity related in a uniform motion?
2. What do you think does the area under velocity against time graph

describe in a uniform motion?

3. If the slope of the graph is zero in a distance against time graph, what can one conclude about the motion of the body?
4. When do we say that the acceleration of a body is
   A. positive?
   B. negative?
5. Here are three pairs of initial and final positions respectively along an x axis. Which pairs give a negative displacement: (a) -3 m, 5 m; (b) -3 m, -7 m; (c) 7 m, -3 m?
6. An athlete covers a 100m distance in 55 seconds. Calculate the average speed of the athlete.
7. A car moves with a steady speed of 60 km/hr for 2 hours between two towns A and B. If the average speed of the car for the round trip is 50 km/hr, then compute the speed of the car when it moves from B to A.
8. Based on the distance against time graph of a certain car shown in the figure below, answer the following questions.



   A. What is the initial position of the car? Take your reference frame at the origin.
   B. How fast is the car going?
9. A man riding a horse maintained an average speed of 30km/hr to cover the distance between two villages A and B in 45 minutes. How far apart are villages A and B?
10. Table 3.4 describes the distance covered by a body moving along a straight line to north direction for the first 10 seconds.

Table 3.4

s(m)	0	20	40	60	80	100
t(s)	0	2	4	6	8	10

Based on the information given in the table,

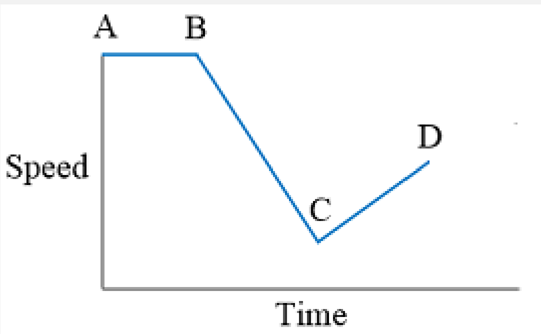
A. plot the distance against time graph using excel worksheet.
B. compute the velocity of the car.
C. plot the velocity against time graph of the car using excel worksheet.
D. determine the initial position of the car

11. An airplane lands with an initial velocity of 70.0 m/s and then decelerates at 1.50 m/s^2 for 40.0 s. What is its final velocity?
12. An athlete swims from the north end to the south end of a 50.0 m pool in 20.0 s and makes the return trip to the starting position in 22.0 s.

A. What is the average velocity for the first half of the swim?
B. What is the average velocity for the second half of the swim?
C. c. What is the average velocity for the round trip?

Part II: Choose the correct answer from the given alternatives.

13. A train is traveling on a straight track at a constant speed. In 80 seconds, it covers a distance of 2400 meters. What is the speed of the train?
A. 30 m/s B. 40 m/s C. 60 m/s D. 100 m/s
14. A car is traveling on a straight highway at a speed of 90 km/h. How far does the car travel in 15 minutes?
A. 50 km B. 30 km C. 22.5 km D.12.5 km
15. A car accelerates from rest to a speed of 20 m/s in 10 seconds. What is the acceleration of the car during this time interval?
A. $1m/s^2$ B. $2m/s^2$ C. $0.5m/s^2$ D. $5m/s^2$
16. The following figure shows the speed versus time graph of a car moving in a straight line. Between which two points is the car experiencing a uniform motion?



A. Between B and C
B. Between C and D
C. Between A and B
D. Between B and C, C and D

17. A man walks 7 km in 2 hours and 2 km in 1 hour in the same direction. What is the man's average velocity for the whole journey?

A. 3 km/h
B. 2 km/h in the same direction
C. 2 km/h
D. 3 km/h in the same direction

Answer Key for Self-Test Exercise

Self-Test Exercise 3.1

A body is said to be at rest in a frame of reference when its position in that reference frame does not change with time. If the position of a body changes with time in a frame of reference, the body is said to be in motion in that frame of reference. The concepts of rest and motion are completely relative; a body at rest in one reference frame may be in motion with respect to another reference frame. Therefore, if your frame of reference is taken to be the horse, your position is not changing with respect to the horse and you are said to be at rest with respect to the horse. However, if your frame of reference is taken to be a point on the ground, obviously your position is changing with respect to the point and you are said to be in motion with respect to it.

Self-Test Exercise 3.2

The SI unit of both length and distance is meter. Concerning the dimension of a standard football field, it is expected that the length has to be minimum 100 meters and maximum 110 meters and the width has to be minimum 64 meters and maximum 75 meters for international matches. Therefore, the minimum distance around a standard football field would be:

$$2\times 100 + 2\times 64 = 328 \text{ meters}$$

The maximum distance is:

$$2\times 110 + 2\times 75 = 370 \text{ meters}$$

Distance is a positive quantity.

Self-Test Activity 3.1

The displacement of the first student is 100 meters to the right of point A.

The displacement of the second student is 100 meters to the left of point A. The third student returned to his initial position and has zero displacement.

Self-Test Exercise 3.3

If the initial and final positions are the same, the displacement is zero.

Self-Test Exercise 3.4

If $x_f > x_i$, the displacement is positive

If $x_f < x_i$, the displacement is negative

If $x_f = x_i$, the initial and final positions are the same and the displacement is zero

Self-Test Exercise 3.5

Speedometer reads the instantaneous speed of a vehicle.

Self-Test Exercise 3.6

Average speed is the speed of a moving body over a given interval of time or it is the overall rate at which the body is moving. However, the instantaneous speed is the speed of the body at any given instant of time. They are both scalar quantities.

Self-Test Exercise 3.7

33.33 m/s

Self-Test Exercise 3.8

No, *average speed* and the magnitude of *average velocity* are not the *same* since speed and velocity are not the *same*. Speed is a scalar while velocity is a vector.

Self-Test Exercise 3.9

The distance covered by Tirunesh during the race was 5000 meters and she took 14 min 39.94 sec (or 879.94 sec) to complete this distance. Her average was:

$$\mathrm{v_{av}} = \frac{\mathrm{s}}{\mathrm{t}} = \frac{5000\ \mathrm{m}}{879.94\ \mathrm{s}} = 5.68\ \mathrm{m/s}$$

Self-Test Exercise 3.10

Athlete 1 completes 100m in 55 seconds. The average speed of athlete 1 is

$$\mathrm{v_{av}} = \frac{\mathrm{s}}{\mathrm{t}} = \frac{100\ \mathrm{m}}{55\ \mathrm{s}} = 1.82\ \mathrm{m/s}$$

Athlete 2 completes the same distance (100 m) in 50 seconds. The average speed of Athlete 2 is:

$$v_{av} = \frac{s}{t} = \frac{100\ \text{m}}{50\ \text{s}} = 2\ \text{m/s}$$

Therefore, the average speed of Athlete 2 is greater than that of Athlete 1.

Self-Test Exercise 3.11

1. Zero
2. No.

Self-Test Exercise 3.12

Car B be is moving faster since it has steeper slope.

Answer to Activity 3.2

Encourage yourself in drawing the graph.

Answer to Activity 3.3

Zero. The graph is horizontal line since the velocity is constant at any time in a uniform motion. The slope of horizontal line is zero.

Answer to Activity 3.4

Investigate the types of vehicles that are causing human/animal deaths and property damages in their area? Guess the percentage of the accidents caused by violation of speed limit.

Answer Key for Self-assessment questions

Part I:

1. In a uniform motion, velocity is constant. This means that the average and instantaneous velocity is the same.
2. In a uniform motion, the area under velocity against time graph describes the distance covered by the body.
3. The body is at rest
4. The acceleration of a body is positive if it has the same direction as the velocity of the body. If the acceleration and velocity have opposite directions, then the acceleration is said to be negative. Negative acceleration is known as deceleration.
5. b and c
6. The average speed of the athlete is 1.82 m/s.
7. The distance between the two towns A and B is 60km/hr × 2 hr = 120 km.

For the round trip, the total distance is 2× 120 km = 240 km. The average speed for the round trip is given to be 50 km/hr. This means that:

$$50\frac{km}{hr} = \frac{240\ km}{t}$$

where t is the total time taken by the car for the round trip. Therefore, t =4.8 hrs. Hence, the time required for the car to travel from town B to A is simply 4.8 hrs− 2 hrs = 2.8 hrs.

Finally, the average speed of the car when travelling from town B to A is

$$v_{av} = \frac{120\ km}{2.8\ hrs} = 42.86\ km/hr$$

8. a 20 m from the origin
   b 2 m/s
9. 22.5 km
10.
    A. Plot the linear graph
    B. 10 m/s
    C. This is the case of constant velocity.
    D. The initial position of the car is at the origin
11. 10 m/s
12.
    A. 2.5 m/s south
    B. 2.27 m/s north
    C. Zero

Part II:

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

4. C
5. D

Unit 4

Force, Work, Energy and Power

Introduction

Dear student! In unit 3, you developed the concepts and ideas needed to describe the motion of a moving body. This branch of mechanics is called kinematics. In this chapter, rather than simply describing the motion, we will consider the forces that cause the motion to occur. Treating motion in this way falls within the branch of mechanics called dynamics. In simple terms, a force can be thought of as simply a push or a pull, but forces exist in a wide variety of situations in our daily lives and are fundamental to the nature of matter and the structure of the universe. In this unit, the different types of forces, Newton's laws of motion, and the concepts of work, energy, and power will be discussed in a brief way.

After reading this unit, you should be able to:

- *understand the different types of forces;*
- *practically measure forces and differentiate between mass and weight;*
- *explain Newton's laws of motion;*
- *know about work and energy;*
- *relate work and power.*

Unit Contents

The Required Study Time: The time allotted for this section is 12 hours.

Learning Strategies:

- Encourage yourself to deform various materials to learn the effects of force.
- Engage yourself in a variety of force activities (pulling, pushing, stretching or compressing springs, etc.).
- Encourage yourself to use anchor charts to visualize students' learning and connect their prior concept of force to the new one.
- Engage yourself in explaining about non-contact forces by using bar magnets or a ball thrown vertically up wards.

Section 4.1: The Concept of Force

Dear student! From your background experience, can you define force? Have you ever used trolleys to carry your luggage? Have you ever used magnets to attract small metals? In such cases force is being applied. In this section, you will learn about the concept of force.

After reading this section, you should be able to:

- *define force, and give examples of forces;*
- *practically measure the gravitational force on an object;*

From your everyday experience, you have a basic understanding of the concept of force. Any time the state of motion of an object changes, a force has been applied. Force can cause a stationary object to start moving or a moving object to accelerate. You exert force to stretch or compress a spring, to throw or kick a ball, to pick your books from a table, to fetch water from a river or well, etc. In mechanics, a force is a push or a pull exerted on a body that changes the state of motion of the body. That means force can change the velocity of a body or cause deformation by changing its shape or size. The push or pull on an object can vary considerably in either magnitude or direction. Because a force is determined by both its magnitude and direction, it is a vector quantity. Forces, like other vectors, are represented by arrows and can be added using the familiar head-to-tail method or trigonometric methods. Examples of forces include friction force, normal force, and the force of gravity.

Contact and Non-Contact Forces

In each of the situations depicted in *Figure 4.1*, forces are being applied. Some are applied directly to an object and some are applied on a body without touching it. Forces that involve physical contact between objects are called contact forces because the bodies will experience the force while contact is maintained. However, forces that do not involve physical contact between objects are known as non-contact forces. Contact forces are the easiest to understand and include the simple push and pull that are experienced daily in people's lives. Applied forces, normal forces, frictional forces, and spring forces are the types of contact forces. You might have already experienced that when you bring a piece of iron close to a magnet, without touching it, the piece of iron will be attracted to the magnet. This magnetic force is one common example of a non-contact force. Another example of a non-contact force is the gravitational force between an object and the earth. If you throw the object vertically upwards, it falls back to earth because of this force.

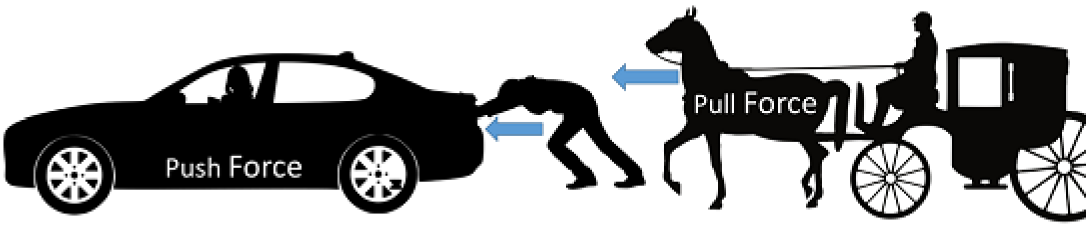


Figure 4.1: Examples of contact forces

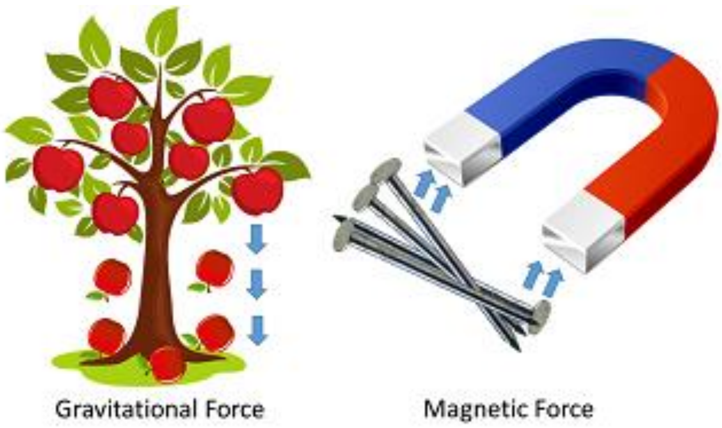


Figure 4.2: Examples of non-contact forces

You might have a day-to-day experience of measuring a force, for example, through observation or by doing it yourself. The most convenient way of measuring a force is by using the deformation of a spring. The spring elongates when the force is applied, and a pointer on the scale reads the value of the applied force. The SI unit of force is the newton and is represented by N.

Figure 4.3: Measuring force

Activity 4.1

- Can a force always cause motion? Discuss in groups and with your teacher.

Activity 4.2

- What do the scales on the roadside or in the bathroom actually measure? Your mass or your weight? Discuss in groups and with your teacher.

Contact forces involve physical contact between two bodies, whereas non-contact forces do not involve any physical contact.

Force is a vector quantity and it is represented as $\vec{F}$ or simply as bold **F**, i.e.,

Weight is the magnitude of the gravitational force acting on a body and is also measured in Newton. The gravitational force is directed towards the center of the earth.

Self-Test Exercise 4.1

Part I: Give short answers to the following questions

- In unit 2, you have already discussed vector and scalar quantities. Therefore, determine whether a force is a vector or a scalar quantity. How do you represent it?

√ **Check List 4.1**

Dear learner, now it is time to check your understanding about the concept of force. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. Can you define force and give examples of forces?	☐	☐
2. Can you practically measure the gravitational force on an object?	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Section 4.2: Newton's Laws of Motion

Dear student! In this section, you will learn about Newton's laws of motion. Suppose you are moving by car. Your body tends to keep moving forward if the car comes to a sudden stop. What do you think is the reason? What do you feel if you push a wall? All such phenomena can be explained by Newton's laws of motion.

After reading this section, you should be able to:

- *define Newton's first, second and third laws of motion;*
- *explain the dependence of acceleration on net force and mass;*
- *explain how gravity affects the motion of objects;*

Newton's First Law of Motion:

Newton's first law of motion is sometimes called the law of inertia. It states that a body continues to be in its state of rest or of uniform motion in a straight line unless it is acted on by an unbalanced force. Newton's first law of motion explains how inertia affects moving and non-moving objects. **Inertia** is a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force. In other words, inertia is the tendency of an object to resist any attempt to change its velocity.

Look at the pool balls in *Figure 4.4*. When a pool player pushes the pool stick against the white ball, the white ball is set into motion. Once the white ball is rolling, it rolls all the way across the table and stops moving only after it crashes into the cluster of colored balls. Then, the force of the collision starts the colored balls moving. Some may roll until they bounce off the raised sides of the table. Some may fall into the holes at the edges of the table. None of these motions will occur, however, unless that initial push of the pool stick is applied.

Newton's first law of motion defines a special set of reference frames called inertial frames. An inertial frame is defined as one in which Newton's first law of motion (also called the law of inertia) is valid. Such a frame of reference is called an inertial frame of reference. If an object does not interact with other objects, it has zero acceleration in an inertial frame of reference. Any reference frame that moves with constant velocity relative to an inertial frame is itself an inertial frame.

Figure 4.4: Pool balls remain at rest until an unbalanced force is applied to them. After they are in motion, they stay in motion until another force opposes their motion

Mass is a measure of the resistance of an object to change in its state of motion. Mass is an inherent property of an object and is constant everywhere. However, weight is the magnitude of the gravitational force acting on an object and can change from one place to another. Objects with large masses have large inertia and are more resistant to changes in their state of motion.

Newton's second law of motion

We have discussed Newton's first law, which explains that an object either remains at rest or moves in a straight line with constant speed when there is no unbalanced force acting on it. But what happens to an object when there is a non-zero unbalanced force acting on it? This question is answered by Newton's second law of motion. To hold an object in your hand, you have to exert an upward force to oppose, or "balance," the force of gravity. If you suddenly remove your hand so that the only force acting on the object is gravity, it accelerates downward. This is one example of Newton's second law, which states, basically, that unbalanced forces or a net external force cause non-zero acceleration.

When you exert some horizontal force **F** on the block, it moves with some acceleration **a**. If you apply a force twice as great, you find that the acceleration of the block doubles. If you increase the applied force to 3F, the acceleration triples, and so on. From such observations, we conclude that the acceleration of an object is directly proportional to the force acting on it. Consider the example of a batter, like the man in *Figure 4.5*. The harder he hits the ball, the greater will be its acceleration. It will travel faster and farther if he hits it with more force.

Figure 4.5: Hitting a baseball with greater force gives it greater acceleration

The acceleration of an object is directly proportional to the force acting on it. Thus, the greater the mass of an object, the less that object accelerates under the action of a given applied force.

Mathematically, Newton's second law can be expressed as

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

where $\vec{F}$ is the force acting on the body, *m* is the mass of the body , and $\vec{a}$ is the acceleration when acted on by the force $\vec{F}$.
From the above equation, you can see that the unit of force, the newton, can be expressed in terms of the units of mass, length, and time.

$$1N = {}^{1kgm}/_{s^2}$$

Therefore, 1*N* is defined as the force that, when acting on an object of mass 1*kg* , produces an acceleration of ${}^{1m}/_{s^2}$.

At this stage, you may be able to guess the gravitational force $\vec{\mathrm{F}}_{\mathrm{g}}$ acting on an object by applying Newton's second law. However, here, $\vec{a}$ is the acceleration due to gravity. The acceleration due to gravity is denoted by 'g' and has a constant value of $9.8\frac{m}{s^2}$ on the surface of the earth and is directed towards the center of the earth. Hence, applying Newton's second law, the magnitude of the gravitational force on an object is given by:

$$\mathrm{F_g = mg}$$

This force is directed towards the center of the earth. $\mathrm{F_g}$ is also called weight of the object. Weight of a body is represented by 'W'. The above equation can also be written as:

$$\mathrm{W = mg}$$

Example 4.1: A force of 10N acts on a block of mass 2kg resting on a smooth horizontal surface. What is the acceleration of the block?

Given: $F = 10\mathrm{N}, m = 2\mathrm{kg}$

Required: The acceleration '*a*' of the block

Solution: The unbalanced force acting on the block is 10N. From Newton's second law of motion we have:

$$F = ma$$

Therefore,

$$a = \frac{F}{m} = \frac{10N}{2kg} = \frac{10kgm/s^2}{2kg} = 5m/s^2$$

The direction of acceleration is the same as the direction of the force.

Example 4.2: A force of 100N acts on a certain object and accelerates it by $2m/s^2$ in the direction of the force. What is the mass of the object?

Given: $F = 100N, a = 2m/s^2$

Required: The mass *m* of the object.

Solution: The unbalanced force acting on the block is 100N. From Newton's second law of motion we have:

$$F = ma$$

Therefore,

$$m = \frac{F}{a} = \frac{100N}{2m/s^2} = \frac{100kgm/s^2}{2m/s^2} = 50kg$$

Example 4.3: What is the weight of a body of mass 10kg on the surface of the earth?

Given: $m = 10kg$

Required: The weight '*W*' of the body.

Solution: The weight of the body is given by:

$$W = mg = 10kg \times 9.8m/s^2 = 98N$$

Newton's Third law of motion

Have you ever pushed a wall or your table with your finger tip? Try to do it again in class. What do you feel?

If you push a wall with your hand with some force, the wall pushes your hand back with the same force. If you push the wall harder, the wall pushes you back with a larger force, and you may feel pain in your hand. This simple activity illustrates an important general principle known as Newton's third law of motion. In fact, the force with which you push the car is equal in magnitude but opposite in direction to the force with which the car pushes you back, as shown in Figure 4.6. In general, if *F*12 is the force exerted by object 1 on object 2 and *F*21 is the force exerted by object 2 on object 1, then,

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

That means *F*12 is equal in magnitude but opposite in direction to *F*21. *F*12 is called action force and *F*21 is called reaction force, though either force can be labeled as the action or reaction force.

Figure 4.6: Action and reaction forces involved when pushing a car

Consider a block of mass m placed on a horizontal table (*Figure 4.7*). What are the action and reaction forces?

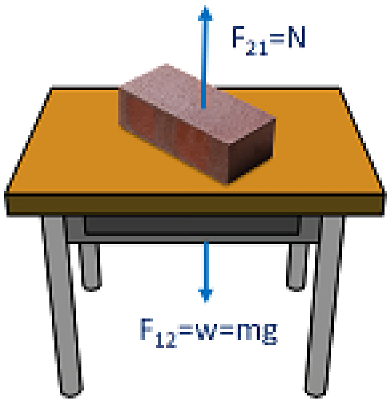


Figure 4.7: Action and reaction forces for a block placed on a horizontal table

The action and reaction forces are represented by *F*12 and *F*21. Let F12 be the force that the block exerts on the table. This force is equal to the weight of the block. *F*12 is directed vertically downwards, as shown in the figure. On the other hand, the table exerts a force *F*21 on the block. *F*21 is directed vertically upwards, but has the same magnitude as *F*12. *F*21 is also called normal force. However, it has to be noted that taking *F*21 as an action force and *F*12 as a reaction force is also possible. Newton's third law of motion states that every action has an equal and opposite reaction. This means that forces always act in pairs.

Activity 4.3

- Let us say you are riding in a car. If the car comes to a sudden stop, your body tends to keep moving forward. However, when the car starts moving again, your body tends to move backward. What do you think is the reason?

Activity 4.4

- What is the relationship between the mass of a body and its inertia? What is the difference between mass and weight? Discuss in groups.

Activity 4.5

- Take a wooden block and place it on a smooth horizontal surface. Push it with some force F. What do you observe? Now increase the force with which you push the wooden block and see what happens. Repeat the activity with even a large pushing force. What can you conclude from this activity?

Activity 4.6

- Take two different wooden (or metal) blocks of different masses and place them on a smooth horizontal surface. Push them with the same force F. Which block accelerates more? What can you conclude from this activity?

☞ According to Newton's first law:

- An object at rest remains at rest as long as no net force acts on it.
- An object moving with a constant velocity continues to move with the same speed and in the same direction as long as no

net force acts on it.

- Mass is a measure of inertia.

Newton's second law of motion states that the acceleration of a body is directly proportional to the net force acting on it and inversely proportional to the mass of the body.

The value of the acceleration due to gravity g varies with location. For example, the value of g on the surface of the moon is about 1/6th of that on the surface of the earth. Moreover, the value of g will change as an object is moved further from the earth's surface.

The action and reaction forces are equal in magnitude but opposite in direction and they act on different objects.

√ Check List 4.2

Dear learner, now it is time to check your understanding about Newton's laws of motion. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. *Can you define Newton's first, second and third laws of motion?*	☐	☐
2. *Can you explain the dependence of acceleration on a net force and mass?*	☐	☐
3. *Can you explain how gravity affects the motion of objects?*	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Section 4.3: Forces of Friction

Dear students! In this section, you will learn about forces of friction. It is difficult for a car to move in a mud. What do you think is the reason? Why it is easier to walk on a rough surface than a smooth surface? These phenomena can be explained in terms of forces of friction.

After reading this section, you should be able to:

- *define the force of friction;*
- *explain the dependence of friction force on the smoothness and roughness of surfaces;*
- *explain the advantages and disadvantages of the force of friction;*

When an object is in motion on a given rough surface, there is a resistance to the motion of the object from the surface. Such a resistance is called force of friction and is denoted by 'f'. Forces of friction are very important in our everyday lives.

They allow us to walk or run and are necessary for the motion of wheeled vehicles.
Why do vehicles easily get stuck in a mud (*Figure 4.8*)? We classify friction forces in to two main types. They are static friction and kinetic friction.

Figure 4.8: Cars stuck in a frictionless surface

The magnitude of a friction force depends on the value of the normal force and on the nature of the contacting surfaces. In general, friction force between rough surfaces is greater than friction force between smooth surfaces. The force of friction is directly proportional to the normal force.

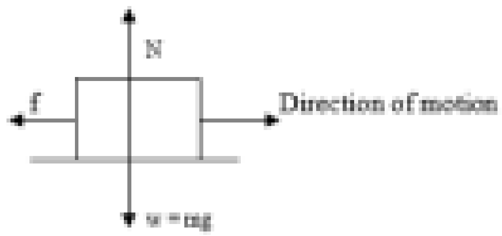


Figure 4.9: Frictional force opposing motion

Static friction: is a kind of friction that exists between two surfaces in contact when one body tends to slide over the other without moving. It requires a large force to overcome this friction.

Kinetic friction: is the friction between two contacting surfaces when one of them slides over the other or when one body rolls over the other. Its effect on motion is less than that of the static friction.

Self-Test Exercise 4.2

Part I: Give short answers to the following questions

- Why is it difficult to walk on a smooth surface? What causes a car moving along a road to stop? What keeps you from slipping when you walk? Discuss in groups.

√ Check List 4.3

Dear learner, now it is time to check your understanding about forces of friction. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. *Can you define the force of friction?*	☐	☐
2. *Can you explain the dependence of friction force on the smoothness and roughness of surfaces?*	☐	☐
3. *Can you explain the advantages and disadvantages of the force of friction?*	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Section 4.4: The Concept of Work

Dear student! In this section, you will learn about the concept of work. What do you think is the scientific meaning if work? Can you say that you are always doing work whenever you apply a force on something?

After reading this section, you should be able to:

- *define the scientific meaning of work;*
- *describe the quantitative relationship between work, force and displacement;*
- *calculate the work done on an object;*

Scientific meaning of work

The word work has a variety of meanings in everyday language. In everyday sense, the term work means to do something that takes a physical or mental effort. But in physics, work has a distinctly different meaning. Consider the following situations:

- A student holds up a heavy chair for several minutes.
- A student carries a bucket of water along a horizontal path while walking at a constant velocity.

Figure 4.10: Work is done because the force is applied in the same direction as the direction of displacement of the box

It might surprise you to know that as the term "work" is used in physics, there is no work done on the chair or the bucket, even though effort is required in both cases. In physics, work means the use of force to move an object. Not all force that is used to move an object does work. For work to be done, the force must be applied in the same direction as the direction of displacement of the object. If a force is applied in a different direction than the direction of displacement of the object, no work is done. *Figure*

4.10 illustrates this fact. As shown in the figure, carrying a box while walking does not result in work being done. Work is done only when the box is lifted up from the ground.

In physics, a force does work on an object if it causes the object to move. Work is done, when a force *F//* is applied to an object and the object moves through a displacement S in the direction of force.

$$W = F_{//}S$$

where $F_{//}$ is the force in the direction of displacement of the object and S is the magnitude of the displacement.

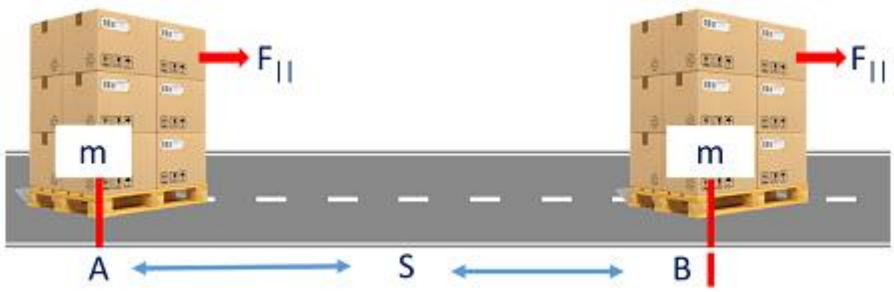


Figure 4.11: A force moves an object from point A to point B

Example 4.4: A boy pushed a box by a force of 60 N through a displacement of 12 m without acceleration. How much work is done by the boy?

Given	**Required**	**Solution**
$F_{\|\|} = 60\ N$	$w = ?$	$w = F_{\|\|} \times s = 60\ N \times 12\ m$
$12\ m$		$w = 720\ N$

Example 4.5: How much vertical force is required to lift a load vertically to a height of 3 m, if the work done is 600 J?

Given	**Required**	**Solution**
$w = 600\ J$	$F_{\|\|} = ?$	$w = F_{\|\|} \times s \quad F_{\|\|} = \frac{w}{s} \Rightarrow$
$s = 3\ m$		$F_{\|\|} = \frac{600\ J}{3\ m} = 200\frac{J}{m} = 200\frac{kg\frac{m^{\cancel{2}}}{s^2}}{\cancel{m}}$
		$F_{\|\|} = 200\ kg\ \frac{m}{s^2} \Rightarrow F_{\|\|} = 200\ N$

The force needed to lift a load to a height of 3 m is 200 N

Work is a scalar quantity. The SI unit of work is a Newton-meter (N m) which is called Joule (J).

One Joule of work is done when 1Newton of force moves an object a displacement of 1 meter in the direction of force. 1Joule = 1 Newton × 1 meter

Self-Test Exercise 4.3

Part I: Give short answers to the following questions

- Write the conditions for work done to be zero. What will be the work done by your hand if you hold your exercise book at 1 m height for two hours?

Check List 4.4

Dear learner, now it is time to check your understanding about the concept of work. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. *Can you define the scientific meaning of work?*	☐	☐
2. *Can you describe the quantitative relationship between work, force and displacement?*	☐	☐
3. *Can you calculate the work done on an object?*	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Section 4.5: Kinetic and Potential Energies

Dear student! In this section, you will learn about kinetic and potential energies. What is the difference between kinetic and potential energy? Explain in your own words. Can potential energy be converted to kinetic energy and vice versa?

After reading this section, you should be able to:

- *define and use the concepts of kinetic and potential energies;*
- *solve problems related to kinetic energy and potential energy of an object;*

In the previous section, you learned about work as the transfer of energy from one object to another through the applied force. In this section, you are going to learn about kinetic and potential energies. Energy is the capacity to do work and is a scalar quantity. Its SI unit is Joule (J), similar to that of work.

Kinetic Energy

An object in motion has the ability to do work and thus can be said to have energy. Kinetic energy (*Ek*) is the form of mechanical energy possessed by an object due to its motion. For example, a rolling ball, a moving car, or a thrown stone all possess kinetic energy due to their motion. The kinetic energy of an object depends on its mass and the speed at which it travels. We define the kinetic energy of the object as:

$$Kinetic\ energy = \frac{1}{2} \times mass \times (speed)^2 \quad \Longrightarrow \quad E_k = \frac{1}{2}mv^2$$

Example 4.6: A ball of $200\ g$ is thrown at a speed of $20\ \frac{m}{s}$. What is the kinetic energy of the ball?

Given:

$m = 200\ g$

$v = 20\frac{m}{s}$

Required:

$E_k\ =?$

Solution:

Convert the unit of mass from g to kg

$$200\ \cancel{g} \times \frac{1\ kg}{1000\ \cancel{g}} = 0.2\ kg$$

To calculate the kinetic energy use

$$E_k = \frac{1}{2}mv^2 = \frac{1}{2} \times 0.2\ kg \times \left(20\frac{m}{s}\right)^2$$

$$E_k = \frac{1}{2} \times 0.2\ kg \times 400\frac{m^2}{s^s} = 40\ kg\frac{m^2}{s^2} = 40\ \text{J}.$$

The kinetic energy of the ball is 40 J

Example 4.7: How fast must a ball of 1 kg move in order to have a kinetic energy of 50 J?

Given	**Required**	**Solution**
$m = 1\ kg$	$v = ?$	N.B: the phrase "how fast" related to
$E_k = 50\ J$		the speed of the ball.

$$E_k = \frac{1}{2}mv^2 \Rightarrow v^2 = \frac{2\times E_k}{m} \Rightarrow v = \sqrt{\frac{2\times E_k}{m}}$$

$$v = \sqrt{\frac{2\times 50\ J}{1\ kg}} = \sqrt{\frac{100\ J}{1\ kg}} = \sqrt{\frac{100\ \cancel{kg}\frac{m^2}{s^s}}{1\ \cancel{kg}}} = 10\ \frac{m}{s}$$

Gravitational potential energy

Potential energy is the stored energy in an object by virtue of its position or configuration. There are two types of potential energy. Examples are potential energy due to gravity and elastic potential energy. However, in this section, you are going to learn about gravitational potential energy. Gravitational potential energy is the energy of an object held in a vertical position due to the force of gravity working to pull it down. The gravitational potential energy depends on the height and mass of an object. The heavier the object and the higher it is above the ground, the more potential energy it holds. The gravitational potential energy (*Ep*) of an object is given by:

$$\mathrm{E_P = mass \times gravitational\ acceleration \times height} \Rightarrow \mathrm{E_p = mgh}$$

Example 4.8: How much potential energy is possessed if an object of 30 kg is placed on the top of 50 m high building? (Use the acceleration due to gravity $g = 10\ \frac{m}{s^2}$).

Given:	**Required**:	**Solution:**
$m = 30\ kg$	$E_p = ?$	$E_p = mgh$
$h = 50\ m$		$E_p = 30\ kg \times 10\frac{m}{s^2} \times 50\ m$
$g = 10\ \frac{m}{s^2}$		$E_p = 15000\ kg\frac{m^2}{s^s} = 15000\ J$

The potential energy possessed by a 30kg object at a height of 50m is 15000J.

Example 4.9: How high should an object of mass 5 kg be lifted in order to have an energy of 1000 J? (use the acceleration due to gravity $g = 10\ \frac{m}{s^2}$).

Given:

$m = 5\ kg$

$E_p = 1000\ J$

Required:

$h = ?$

Solution:

$E_p = mgh \Rightarrow h = \frac{E_p}{mg}$

$h = \frac{1000\ J}{5\ kg \times 10 \frac{m}{s^s}} = \frac{1000\ \cancel{kg}\frac{m^2}{\cancel{s^2}}}{50\ \cancel{kg}\frac{m}{\cancel{s^2}}} = 20\ m$

This means that an object of mass of 5 kg should be lifted to a height of 20 meters in order to have a gravitational potential energy of 1000 J.

The sum of kinetic and potential energies is known as mechanical energy. Thus, we can express mechanical energy as:

Mechanical Energy = Kinetic Energy + Potential Energy

☞ Kinetic energy is a scalar quantity described only by its magnitude. Its SI unit is the Joule (J). 1J $= 1kg\frac{m^2}{s^2}$.

Kinetic energy: energy possessed by an object due to its motion. T

Potential energy: energy possessed by an object due to its position or configuration

Self-Test Exercise 4.4

Part I: Give short answers to the following questions

- What is energy? Can you mention some forms of energy? How can energy transform from one form to another?

Self-Test Exercise 4.5

Part I: Give short answers to the following questions

- What is potential energy? Mention examples of potential energy. If you lift a box and put it on the top of a shelf, what type of energy is possessed by the box? If you stretch a spring, what type of energy does it hold?

Self-Test Exercise 4.6

Part I: Give short answers to the following questions

- Object A has twice the mass of object B. If object B is 4 m above the floor and object A is 2 m above the floor, which one has a greater potential energy? If both objects were lowered by 1 m, would they still have the same ratio of potential energies that they had in their original positions? Explain your reasoning.

√ **Check List 4.5**

Dear learner, now it is time to check your understanding about kinetic and potential energies. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. *Can you define and use the concepts of kinetic and potential energies?*	☐	☐
2. *Can you solve problems related to kinetic energy and potential energy*	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Section 4.6: Power

Dear student! In this section, you will learn about power. You might have seen light bulbs marked as 30 W, 60 W etc. what does this mean? What does it mean by the power of a machine?

After reading this section, you should be able to:

- *define and describe power;*
- *describe quantitative relationships among work, energy and power;*

In the previous section, you learned that work is done by moving an object parallel to the direction of the force applied. But it is important to consider the time taken to do the work.

$$power = \frac{work\ done}{time\ taken} = \frac{Energy\ transferred}{time\ taken}$$

$$P = \frac{W}{t} \quad \text{or} \quad P = \frac{E}{t}$$

Power is a scalar quantity, like work and energy. The SI unit of power is *J/s* (Joule/second) which is called watt (W). 1 *w* is the power developed when one
Joule (1J) of energy is transferred in one second (1 s).

$$1\,W = 1\,\frac{J}{s}$$

Example 4.10: If a car used up to 1500 J of energy in 5 seconds, what is the power developed by the car?

Given: **Required:** **Solution:**

$E = 1500\,J$ $P = ?$ $P = \frac{E}{t} = \frac{1500\,J}{5\,s} = 300\,\frac{J}{s} =$
$300\,W$

$t = 5\,s$ The power developed by the car is 300 W

Example 4.11 : What is the power of a water pump that can lift 500 liters of water through a vertical height of 10 meter in 5 seconds (take $g = 10\frac{m}{s^2}$)?

N.B: 1 liter of water has a mass of 1 kg.

Given: **Required:** **Solution:**

$m = 500\,kg$ $P = ?$ $P = \frac{E_p}{t} = \frac{mgh}{t} = \frac{500\,kg \times 10\frac{m}{s^2} \times 10\,m}{5\,s} =$
$10000\,\frac{J}{s}$

$h = 10\,m$ $P = 10000\,W$

$t = 5\,s$

The power of a water pump is 10000 W or 10 kW.

☞ **Power** is the rate at which work is done or the rate at which energy is being transferred.

Self-Test Exercise 4.7

Part I: Give short answers to the following questions

- A machine lifts a 100 kg of stone to a height of 5 m in 2 seconds. Calculate the power developed by the machine?

√ **Check List 4.6**

Dear learner, now it is time to check your understanding about power. Read each question and put a mark ("X") in the box that is appropriate choice for you.

	Yes	No
1. *Can you define and describe power?*	☐	☐
2. *Can you describe the quantitative relationships among work, energy and power?*	☐	☐

Is there any question for which you marked "no' in the box under it? If so, please go back to your text and read about it.

Unit summary

- In mechanics, a force is a push or a pull exerted on a body that changes the state of motion of the body. That means, force can change the velocity of a body or cause deformation by changing its shape or size.
- Forces can be classified as contact and non-contact forces. Contact forces involve physical contact between two bodies whereas non-contact forces do not involve any physical contact.
- Newton's first law of motion, sometimes called the law of inertia, states that a body continues to be in its state of rest or of uniform motion in a straight line unless it is acted on by an unbalanced force.
- An inertial frame is defined as one in which Newton's first law of motion is valid. Any reference frame that moves with constant velocity relative to an inertial frame is itself an inertial frame.
- Newton's second law of motion states that the acceleration of a body is directly proportional to the force acting on it and inversely proportional to the mass of the body.
- Action and reaction forces are equal in magnitude but opposite in direction. Work is the product of a force and displacement parallel to the direction of the force applied, or a transfer of energy from one object to another through the force.
- Kinetic energy (*Ek*) is the form of mechanical energy possessed by an object due to its motion.
- Potential energy is the energy possessed by an object due to its position or configuration.
- Mechanical energy is the sum of kinetic and potential energies.
- Power is the rate at which work is done or the rate at which energy is transferred.

Self-assessment questions

Part I: Give short answers to the following questions

1. What is the difference between mass and weight?
2. State Newton's laws of motion.
3. What are the action and reaction forces involved when you walk on a surface?
4. What is the acceleration of a 10 kg block when acted on by a force of 50N?
5. Determine the weight of a 50kg mass on the surface of the earth.
6. A certain force F accelerates a 25 kg object by $4m/s2$. Calculate the magnitude of the force F.
7. What is frictional force? Explain some of its advantages and disadvantages.
8. What is the weight of a 250 kg object on the surface of the moon? The acceleration due to gravity on the surface of the moon is one-sixth of that on the surface of the earth.

Part II: Choose the correct answer from the given alternatives.

1. Which of the following units belongs to work?

A. kg m/s^2 B. N/m C. kg m^2/s^2 D. N $/m^2$

2. A box is pulled from point A to point B by a force of 10 N. If the distance between the points is 6 m, what is the work done?

A. 6 J B. 10 J C. 60 J D. 100 J

3. Which one of the following objects DOES NOT have gravitational potential energy?

A. A bottle on the surface of a table
B. A ball on a level ground
C. A stone on the roof of a house
D. A fruit on the branch of a tree

4. A loader lifts a 500 kg stone at a height of 8 m in 2 seconds. The power developed by the loader is (Take $g = 10\ {}^{m}/_{s^2}$).

A. 5000 W B. 20000 W C. 40000 W D. 80 000 W

Answer Key for Self-Test Exercise

Answer to Activity 4.1

A force does not always cause motion

Answer to Exercise 4.1

Force is a vector quantity and can be represented as $\vec{F}$ or **F**.

Answer to Activity 4.2

The scales on the roadsides or in the bathroom actually measure your weight. But for convenience they are calibrated to show a reading in mass units, eg kilograms (or pounds).

Answer to Activity 4.3

It is because of the law of inertia. Inertia is a property of matter by which it continues in its existing state of rest or uniform motion in a straight line, unless that state is changed by an external force. In other words, inertia is the tendency of an object to resist any attempt to change its velocity.

Answer to Activity 4.4

In general bodies of higher mass have higher inertia. Mass is a measure of the resistance of an object to change in its velocity. Mass is an inherent property of an object and is independent of the object's surroundings and of the method used to measure it. However, as discussed above, weight is the magnitude of the gravitational force acting on an object.

Self-Test Exercise 4.3

1) The work done said to be zero; (i) When there is no displacement (S = 0) and,
(ii) When the displacement is normal to the direction of the force (θ = 90°).
2) Zero

Self-Test Exercise 4.4

1. In general if the mass is doubled, the kinetic energy is doubled. Since the mass is doubled, $E_k = \frac{1}{2} \times 2m \times v^2 = 2(1/2\, mv\hat{}2) = 2 \times 40\, J = 80\, J$

2. In general, if the speed is doubled, the kinetic energy is quadrupled. Since the speed is doubled,

$$E_k = \frac{1}{2} \times m \times (2v)^2 = 4((1/2\, mv\text{^}2)) = 4 \times 40\, J = 160\, J$$

3. In general, if the speed is tripled, the kinetic energy is nine times. Since the speed is tripled

$$E_k = \frac{1}{2} \times m \times (3v)^2 = 9((1/2\, mv\text{^}2)) = 9 \times 40\, J = 360\, J$$

Self-Test Exercise 4.5

1. Given Required Solution
   $m_A = 2m_B$ Compare E_p of object A and B Start from the definition

$$h_B = 4\, mE_p = mgh$$
$$h_A = 2\, mE_{pA} = m_A g h_A = 2m_B g(2\, m) = (4m_B\, g\,)\, m$$
$$E_{pB} = m_B g h_B = m_B g(4\, m) = (4m_B\, g\,)\, m$$

   Object A and object B have the same potential energy $(E_{pA} = E_{pB})$

2. Given Required Solution
   $m_A = 2m_B$ Compare E_p of object A and B Start from the definition

$$h_B = 3\, mE_p = mgh$$
$$h_A = 1\, mE_{pA} = m_A g h_A = 2m_B g(1\, m) = (2m_B\, g\,)\, m$$
$$E_{pB} = m_B g h_B = m_B g(3\, m) = (3m_B\, g\,)\, m$$

Potential energy of object B is greater than that of object A $(E_{pB} > E_{pA})$

Self-Test Exercise 4.6

Given Required Solution

$$m = 100\, kg P =?\, P = \frac{E_p}{t} = \frac{mgh}{t} = \frac{100\, kg \times 10 \frac{m}{s^2} \times 5\, m}{2\, s}$$

$$P = \frac{5000\, kg \frac{m^2}{s^s}}{2\, s} = 2500 \frac{J}{s} = 2500\, W$$

Answer Key for Self-assessment questions

Part I:

1. Mass is a measure of the resistance of an object to change in its velocity. Mass is an inherent property of an object and is independent of the object's surroundings and of the method used to measure it. However, as discussed above, weight is the magnitude of the gravitational force acting on an object.
2. **Newton's first law of motion** is sometimes called the law of inertia. It states that a body continues to be in its state of rest or of uniform motion in a straight line unless it is acted on by an unbalanced force.

   Newton's second law of motion states that the acceleration of a body is directly proportional to the force acting on it and inversely proportional to the mass of the body.

   Newton's third law of motion states that every action force has an equal and opposite reaction.
3. If you take the force that your feet exert on the surface as an action force, the reaction force is the force that the surface exerts back on your feet.
4. Yes. This is the case of a uniform motion on a straight line.
5. No. We can only say that the net force on the object is zero.
6. 5 m/s2
7. 490 N
8. 100 N
9. Friction force is the resistance to the motion of a body when it is in motion on a given rough surface. Forces of friction are very important in our everyday lives. They allow us to walk or run and are necessary for the motion of wheeled vehicles.
10. 400 N

Part II:

5. C	7. C
6. C	8. B

Part III:

1. Given Required Solution

$m = 2.5\ kgW\ =?$ Equation of work

$$F = 50\ NW = F_{||}s = 50\ N \times 2\ m = 100\ Nm$$

$$s = 2\ mW = 100\ J$$

2. i) Given Required Solution

$m = 50\ kgE_k$=? Equation of kinetic energy: $E_k = \frac{1}{2}mv^2$

$$v = 20\ \frac{m}{s}E_k = \frac{1}{2} \times 50\ kg \times \left(20\ \frac{m}{s}\right)^2 = 25\ kg \times 400\frac{m^2}{s^2}$$

$$E_k = 10000\ kg\ \frac{m^2}{s^s} = 10000\ J$$

ii) Given Required Solution

$m = 200\ g$ = 0.2 kg E_k=? Equation of kinetic energy:

$E_k = \frac{1}{2}mv^2$

$$v = 300\ \frac{m}{s}E_k = \frac{1}{2} \times 0.2\ kg \times \left(300\ \frac{m}{s}\right)^2 = 0.1\ kg \times 90000\frac{m^2}{s^2}$$

$$E_k = 9000\ kg\ \frac{m^2}{s^s} = 9000\ J$$

iii) Given Required Solution

$m = 1000\ kgE_k$=? Equation of kinetic energy: $E_k = \frac{1}{2}mv^2$

$$v = 80\ \frac{m}{s}E_k = \frac{1}{2} \times 1000\ kg \times \left(80\ \frac{m}{s}\right)^2 = 500\ kg \times 6400\frac{m^2}{s^2}$$

$$E_k = 3200000\ kg\ \frac{m^2}{s^s} = 3200000\ J = 3.2 \times 10^6\ J = 3.2\ MJ$$

3. i) Given Required Solution

$m = 10\ kgE_p\ =?$ Equation of potential energy: $E_P = mgh$

$$h = 10\ mE_p = 10\ kg \times 10\frac{m}{s^2} \times 10\ m = 1000\ kg\frac{m^2}{s^2}$$

$$g = 10\frac{m}{s^2}E_p = 1000\ J$$

The potential energy of a 10 kg stone at a height of

10 m is 1000 J

i) Given Required Solution

$m = 10\ kg$ $h = ?$ Equation of potential energy: $E_P = mgh$

$$E_p = 400\ J \quad h = \frac{E_p}{mg} = \frac{400\ J}{10\ kg \times 10\frac{m}{s^2}} = \frac{400kg\frac{m^{\cancel{2}}}{\cancel{s^2}}}{100\ kg\frac{\cancel{m}}{\cancel{s^2}}} = 4\ m$$

$g = 10\frac{m}{s^2}$ The 10 kg stone is at a height of 4m from the ground.

4. Given Required Solution

W= 1.5×10^5 J $P = ?$ Equation of power: $P = \frac{W}{t}$

$$t = 10\ s \quad P = \frac{W}{t} = \frac{1.5 \times 10^5 J}{10\ S} = 1.5 \times 10^4 \frac{J}{s} = 1.5 \times 10^4\ Watt$$

The rate at which the work is done by the Crane is 1.5×10^4 Watt