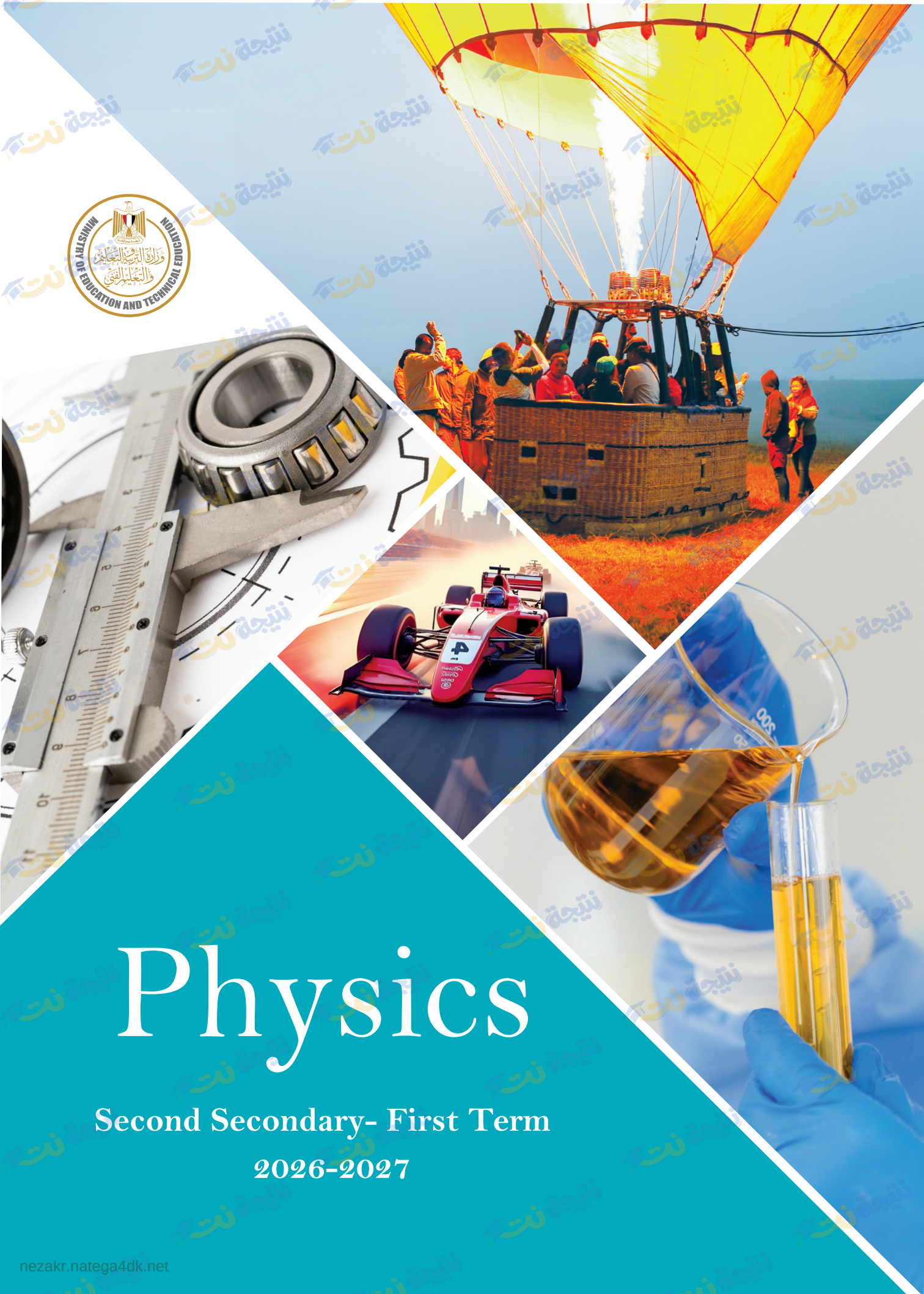
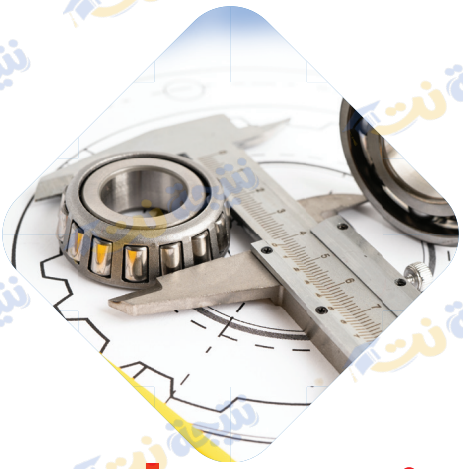


Physics

Second Secondary- First Term

2026-2027

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Physics

Second Secondary- First Term 2026 - 2027

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Introduction

This textbook represents a fundamental component of the developed Physics curriculum for the second year of secondary education. Together with the accompanying activities and exercises, it contributes to achieving the objectives of curriculum development and equipping students to face the challenges of the twenty-first century, which began with a rapidly advancing revolution in information and communication technology

The curriculum aims to achieve the following objectives:

- Developing students' awareness of the relationship between science and technology in physics and their impact on development.
- Emphasizing students' ability to act consciously and effectively in dealing with technological outputs.
- Fostering a scientific mindset, enabling students to engage in self-directed learning that is both stimulating and motivating.
- Encouraging students to rely on exploration in acquiring knowledge and gaining further experiences.
- Providing opportunities to practice the responsibilities of citizenship through self-learning methods, teamwork, negotiation, persuasion, accepting others' opinions, rejecting bias, and combating extremism.
- Equipping students with life skills by giving greater attention to practical and applied aspects.
- Promoting positive environmental attitudes towards the use of natural resources and the preservation of ecological balance both locally and globally.

This textbook is structured into a series of integrated units, each designed to achieve the expected learning outcomes. The units are as follows:

1. Physical Quantities and Units of Measurement
2. Linear Motion
3. Properties of Matter
4. Heat

We hope that this book will serve as a reliable resource for students, supporting the development of their scientific understanding and analytical skills.

Authors

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Unit

One

Physical Quantities and Units of Measurement

Chapter One: Physical Measurement



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Chapter

One

Physical Measurement



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Expected Learning Outcomes

By the end of this chapter, you will be able to:

1.Distinguish between fundamental and derived physical quantities.

2. Identify the fundamental physical quantities in the International System (SI) and their units of measurement.

3. Name the instruments used to measure length, mass, and time.

4. Drive the dimensional formula of physical quantities.

5. Determine the SI units of derived physical quantities.

6. Use dimensional equations to verify the validity of physical laws.

7. List the sources of error in measurement.

Chapter Terminology

Physical Quantity

Measuring Unit

Introduction

Natural sciences are concerned with studying the phenomena that occur in the universe. They describe these phenomena, attempt to explain them, and subject them to experimentation with the aim of benefiting humanity. Such phenomena cannot be accurately described without conducting precise measurements of various physical quantities.

The Concept of Physical Measurement

Describing a person's temperature as "high" is scientifically imprecise. It is better to say, for example, that his temperature is 40 degrees Celsius (40°C). Measurements transform our observations into quantitative values that can be expressed numerically.



Figure (1)
Various Measurements in Daily Life

What is Measurement?

Measurement is the process of comparing an unknown quantity with another quantity of the same kind (called the unit of measurement) to determine how many times the first contains the second.

The process of measurement involves three main elements:

1. Physical quantities – the quantities to be measured.
2. Measuring instruments – the tools required for measurement.
3. Units of measurement – the standard units used.

Each of these elements will be discussed in detail.

The quantities we deal with—such as mass, time, length, volume, and others—are called physical quantities, and we need to measure them accurately in our daily lives.

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Physical Quantities Can Be Classified Into:

A. Fundamental Physical Quantity:

A physical quantity that is not defined in terms of other physical quantities.

Examples include: length, time, and mass.

B. Derived Physical Quantity:

A physical quantity that is defined in terms of fundamental physical quantities.

Examples include: volume, speed, and acceleration.

For example:

Volume of a rectangular prism = length × width × height

$$V_{ol} = L_1 \times L_2 \times L_3$$

This means that volume is derived from length.

There are several systems around the world for defining fundamental physical quantities and their units of measurement, including:

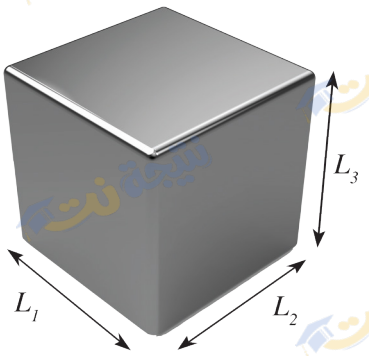


Figure (2)
Rectangular Prism

	Units of Measurement		
Fundamental Quantity	**French System (Gauss System) (C.G.S)**	**Imperial System (F.P.S)**	**Metric System (M.K.S)**
Length	Centimeter	Foot	meter
Mass	Gram	Pound	Kilogram
Time	second	second	second

Integration with Mathematics

Physical quantities and their relationships are always expressed using mathematical equations. These equations serve as concise representations of physical descriptions. Each physical equation carries a specific implication, which we refer to as its physical meaning.

International System of Units (SI)

It is also known as the modern metric system, and during the 11th General Conference on Weights and Measures, held in 1960, an agreement was made to add four new units to the previous metric system. Thus, the system took the following form:

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series	Physical Quantity	Unit in the International System of Units
1	Length (L)	Meter (m)
2	Mass (M)	Kilogram (kg)
3	Time (t)	Second (s)
4	Electric Current Intensity (I)	Ampere (A)
5	Absolute Temperature (T)	Kelvin (K)
6	Amount of Substance (n)	Mole (mol)
7	Luminous Intensity (I_v)	Candela (cd)

Two additional units have been included:

- Radian: for measuring plane angles
- Steradian: for measuring solid angles

The International System of Units (SI) has been applied consistently across all scientific fields worldwide.

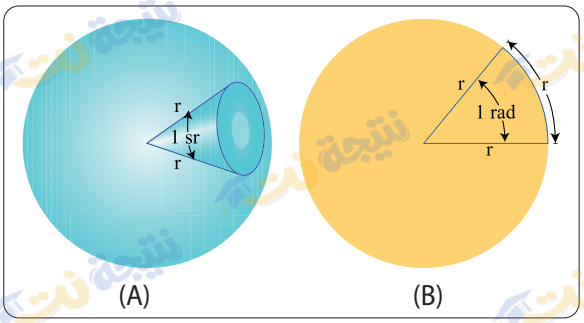
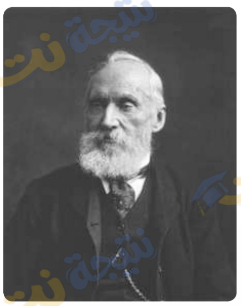


Figure (3)

(A) Solid Angle
(B) Plane Angle

Scientists Who Benefited Humanity



William Thomson (Lord Kelvin): A British scientist

He is considered one of the most prominent scientists who contributed to the development of the metric system.

He precisely defined the absolute zero point on the temperature scale, and found that it equals zero Kelvin, which corresponds to –273°C.



Ahmed Zewail: An Egyptian scientist

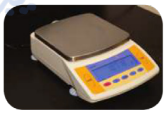
He was awarded the Nobel Prize in Chemistry in 1999 for pioneering the use of laser technology to study chemical reactions between molecules.

These reactions occur in an extremely short time frame measured in femtoseconds (10^{-15} seconds), opening a new field known as femtochemistry.

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Measurement Tools

In the past, humans used parts of their bodies and natural phenomena as tools for measurement.
They relied on the arm, hand, and foot as units of length, and used the sunrise, sunset, and moon cycles to develop a system for measuring time.
Various measurement systems emerged, differing from one country to another.
With the rise of industrial development, measuring instruments evolved significantly, helping humans describe phenomena more accurately and uncover the truths of the natural world.

Quantity	Measuring Instruments: Ancient and Modern			
Length	 Measuring Tape	 Ruler	 Vernier Caliper	 Micrometer
Mass	 Steelyard Balance	 Two-Pan Balance	 Single-Pan Balance (after calibration)	 Digital Balance (after calibration)
Time	 Hourglass	 Pendulum Clock	 Stop Watch	 Digital Clock

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Practical Experiment for Measuring Lengths Using a Vernier Caliper

- Device assembly:

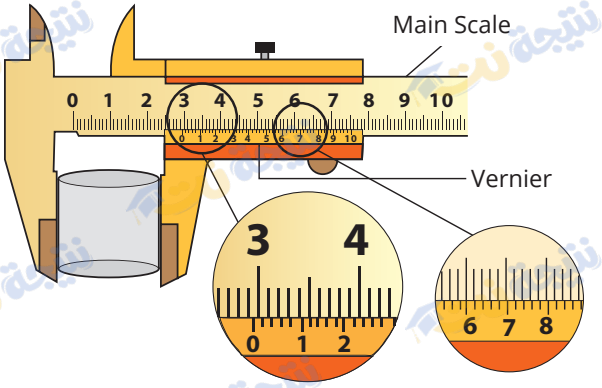


Figure (4)
Vernier Caliper

The Vernier caliper consists of a sliding scale (vernier) that moves alongside a fixed main scale. The vernier scale is divided into several divisions, each slightly smaller than the division on the fixed scale.
Since the unit is millimeter (mm), each division on the main scale equals 1 mm, while each division on the sliding vernier scale equals 0.9 mm, which is 0.1 mm less than its counterpart on the fixed scale.
Therefore, the vernier reading is calculated by multiplying the number of aligned divisions by 0.1 mm.

Procedure Steps:

1. Place the object between the caliper jaws and press gently.
2. Read the main scale value just before the zero of the vernier scale — for example: 29 mm.
3. Find the line on the vernier scale that aligns with a division on the fixed main scale — for example, the sixth line Add (6 x 0.1= 0.6mm) to the previous reading. So, the measured length becomes:

$$29\ mm + 0.6\ mm = 29.6\ mm$$

4. It is recommended to repeat the measurement several times and calculate the average of the measured values to ensure accuracy.

Standard Units

Without using units of measurement, many of the tasks we perform in our daily lives become meaningless.
For example, when we say that the mass of an object is (5) without specifying the unit of mass, it makes us wonder: is the unit grams, kilograms, or tons?
But when we say the mass is (5 kg), we have clearly and fully defined the quantity.
Scientists have long sought the most accurate definitions for standard units such as length, mass, and time.
Here are some of these definitions

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The Standard of Length (Meter)

The French were the first to use the meter as a standard unit for measuring length. The definition of the meter has changed over time in pursuit of greater precision.
The standard meter was defined as the distance between two engraved marks at the ends of a rod made of a platinum–iridium alloy, kept at zero degree Celsius at the International Bureau of Weights and Measures near Paris.



Figure (5)
The Standard Meter

Enrichment Fact

In 1960, scientists at the International Conference on Weights and Measures agreed on the possibility of replacing the previous standard meter with one based on atomic constants, according to the following definition:
The standard meter is equal to a known number (1,650,763.73) of wavelengths of the red-orange light emitted in a vacuum by atoms of the krypton-86 isotope (atomic mass 86) in an electric discharge tube containing krypton gas.

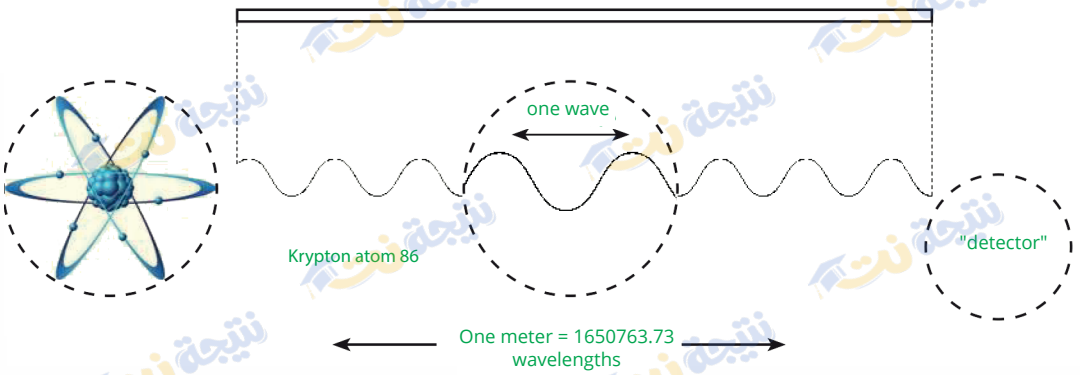


Figure (6)
The meter defined by the wavelengths of the red-orange light emitted by krypton-86 atoms

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Ideas to Stimulate Creativity

Using the information network, research the answers to the following questions:

- How can you measure the distance between the Moon and the Earth?
- How can you measure the circumference of the Earth?

The Standard of Mass (Kilogram)

The standard kilogram is the mass of a cylinder made of a platinum–iridium alloy with specific dimensions ,kept at 0 degree Celsius at the International Bureau of Weights and Measures near Paris.



Figure (7)
The standard kilogram

The Standard of Time (Second)

The second is a unit of time measurement. It was defined in ancient times, as night, day, and the full day cycle served as an excellent and simple way to establish a stable reference for measuring time, given that:

60 seconds = 1 minute

60 minutes = 1 hour

24 hours = 1 day

→ 1 day = 24 × 60 × 60 = 86,400 seconds

Based on the above, the second can be defined as equal to $\frac{1}{86{,}400}$ of the mean solar day.

Scientists have proposed using atomic clocks, such as the cesium clock, to measure time due to their extreme precision.

The use of highly accurate atomic clocks contributes to the study of many scientifically and practically important issues, such as determining the Earth's rotation period (the length of a day), improving air and ground navigation systems, and refining space missions to explore the universe and beyond.

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Enrichment Fact

Scientists have reached the following definition of the second using the cesium clock:
The standard second is equal to the time required for a cesium atom with an atomic mass of 133 to emit 9,192,631,700 waves of radiation.



8 Figure
Cesium Atomic Clock

Developing Critical Thinking

- Why isn't a length similar to the standard meter made of glass used as a reference unit for measuring length?
- In your opinion, why did scientists choose the atomic standard meter and prefer it over the international prototype meter?
- Why do scientists seek the most accurate standard for measuring physical quantities?

Dimensional Formula

Scientists have agreed on a specific definition for each physical quantity that is recognized globally.

For example: Speed is defined as the time rate of change of distance, meaning distance over time:

This definition is universally agreed upon around the world.

Each physical quantity can be expressed symbolically. For example:

- Length is represented by the symbol L
- Mass is represented by the symbol M
- Time is represented by the symbol T

When we express the definition of a physical quantity using these symbols, we obtain what is called the dimensional formula of the physical quantity. For example:

$$\text{Speed} = \frac{\text{Distance}}{\text{time}} = \frac{\text{Length}}{\text{time}} \qquad [v] = \frac{[\text{Distance}]}{[\text{Time}]} = \frac{L}{T} = LT^{-1}$$

Thus, most derived physical quantities can be expressed in terms of the dimensions of the fundamental physical quantities, which are length, mass, and time, each raised to a specific power.The resulting expression is written in the following form:

$$[A] = L^{\pm a}\, M^{\pm b}\, T^{\pm c}$$

Where A is the physical quantity , a, b, and c, are the dimensional exponents of L, M, and T, respectively.

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Unit of Measurement for a Physical Quantity:

We obtain the unit of measurement by expressing the dimensional formula using the appropriate units.

For example: Speed is measured in meters per second (m/s),

Example

Find the dimensional formula of acceleration and its unit of measurement, given that acceleration is defined as the time rate of change of velocity.

Answer

$$\text{Acceleration} = \frac{\text{velocity}}{\text{time}} \qquad [a] = \frac{[\text{Velocity}]}{[\text{Time}]} = \frac{LT^{-1}}{T} = LT^{-2}$$

As for the unit of acceleration, it is: meters per second squared (m/s^2).

Dimensional Formulas of Some Physical Quantities:

Physical Quantity	Relation to Other Quantities	Dimensional Formula	Unit of Measurement
Area (A)	Length × Width	$L \times L = L^2$	m^2
Volume (V_{ol})	Length × Width × Height	$L \times L \times L = L^3$	m^3
Density (ρ)	$\frac{\text{mass}}{\text{volume}}$	$\frac{M}{L^3} = ML^{-3}$	Kg/m^3
Velocity (v)	$\frac{\text{distance}}{\text{time}}$	$\frac{L}{T} = LT^{-1}$	m/s
Acceleration (a)	$\frac{\text{Velocity}}{\text{time}}$	$\frac{LT^{-1}}{T} = LT^{-2}$	m/s^2
Force (F)	Mass × Acceleration	$M \times LT^{-2} = MLT^{-2}$	Newton ($kg.m/s^2$)
Pressure (P)	$\frac{\text{Force}}{\text{Area}}$	$\frac{MLT^{-2}}{L^2} = ML^{-1}T^{-2}$	Pascal ($kg.\ m^{-1}.s^{-2}$)
Work (W)	Force × Displacement	$MLT^{-2} \times L = ML^2T^{-2}$	Joule ($kg.\ m^2.\ s^{-2}$)

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Pay attention

- When adding or subtracting two physical quantities, they must be of the same type—meaning they have the same dimensional formula. For example, you cannot add mass (kg) to distance (m).
- If two quantities are of the same type but have different units of measurement, one unit must be converted to match the other before the quantities can be added or subtracted.

$$1\ \text{m} + 170\ \text{cm} = 100\ \text{cm} + 170\ \text{cm} = 270\ \text{cm}$$

- Physical quantities that do not have the same dimensional formula can be multiplied or divided, and in such cases, a new physical quantity is obtained.
- For example, dividing distance by time results in speed.
- Importance of Dimensional Equations:

Dimensional equations can be used to verify the validity of physical laws. The dimensions on both sides of the equation must match, which is known as dimensional consistency or dimensional homogeneity.

Example 1

Check whether the equation is valid:

Kinetic Energy = $\frac{1}{2}$ × mass × square of speed, Given that the dimensional formula of energy is: ML^2T^{-2}

The Solution

The dimensional formula of the right-hand side is: ML^2T^{-2}

Dimensional formula of the left-hand side:

It is known that the fraction $\frac{1}{2}$ has no dimension. $M(L/T)^2 = ML^2T^{-2}$

This matches the dimensional formula of the right-hand side. So,we conclude that the relationship may be valid.

Note:The numerical values in the equation cannot be verified using dimensional formulas.

Example 2

Someone suggested that the volume of a cylinder is determined by a formula $V_{ol} = \pi rh$ involving the radius of its base (r) and the height of the cylinder (h).

Use dimensional analysis to verify whether this equation could be valid.

The Solution

The equation is written $V_{ol} = \pi rh$ It is noted that π is a constant with no units.

The dimensional formula of the left-hand side (volume) is: L^3

Dimensional formula of the right-hand side (length × length): = L^2

Result: The dimensions of both sides of the equation do not match.

Conclusion: The equation is incorrect.

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Note:

Having the same dimensional formula on both sides of an equation does not guarantee its correctness, but a mismatch in dimensions between both sides definitely indicates the equation is incorrect.

Multiples and Submultiples of Units in the International System

In the process of measurement, a physical quantity is usually described by a numerical value and a unit of measurement.

For example, the distance between stars is very large (about 100,000,000,000,000,000 meters), while the distance between atoms in solids is very small (about 0.000000001 meters).

Undoubtedly, we find it difficult to read such numbers, so it is preferable to express them using powers of 10.

In this way, the distance between stars can be written as approximately ($1 \times 110_{17}$ m) and the distance between atoms in solids as (1×10^{-9} m)

This method of expressing physical quantities is called scientific notation,and the coefficient x in the expression $10^{\pm x}$ is given specific names agreed upon by scientists. These are shown in the following table:

Coefficient	10^{-9}	10^{-6}	10^{-3}	10^{-2}	10^{3}	10^{6}	10^{9}
Designation	Nano	Micro	Milli	Centi	Kilo	Mega	Giga
Symbol	n	μ	m	c	k	M	G

Example

An electric current of 7 milliamperes (7mA), express the magnitude of this current in microamperes (μA).

Answer

From the previous table, we find that:

$$1 \text{ mA} = 10^{-3} \text{ A}$$

$$1 \text{ μA} = 10^{-6} \text{ A}$$

By dividing the two previous relations, it follows that:

$$\frac{1 \text{ mA}}{1 \text{ μA}} = 10^{3}$$

Which means:

$$1 \text{ mA} = 10^{3} \text{ μA}$$

By multiplying both sides by 7, we find that: $7 \text{ mA} = 7 \times 10^{3}$ μA.

This means that: 7 milliamperes = 7000 microamperes.

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Measurement Error

Throughout history, humans have been keen to improve measurement methods and develop their instruments, due to the clear link between the accuracy of measurement and scientific and technological progress.

It is impossible to achieve a measurement with 100% accuracy; there must always be a margin of error, however small.

For example, when measuring the length of a room, we often find a difference between the measured value and the actual value.

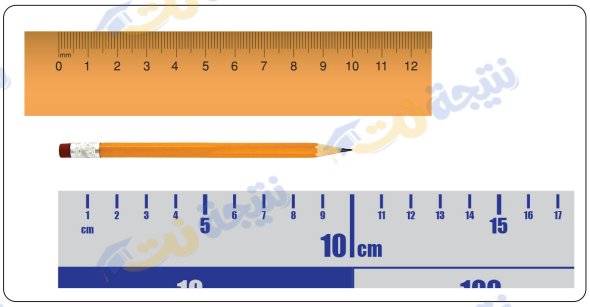
This discrepancy may be slight or significant, depending on the precision of the measurement.

Exercise

A teacher asked 5 students to measure the length of a pencil, and the results were as follows:

Student	1st	2nd	3rd	4th	5th
Measurement Result	10.1 cm	10.0 cm	9.8 cm	10.0 cm	10.0 cm

- What do you conclude from the previous table?
- Mention the possible reasons that led to errors in measurement.
- Which ruler is more accurate for measuring the pencil length, and why?



(a) A ruler graduated in 1 mm intervals.

(b) A ruler graduated in 1 cm intervals

Figure (9)

Sources of Error in Measurement

Measurement errors can arise from various sources, including:

1 Choosing an inappropriate measuring instrument:

One common mistake is selecting a tool that is not suitable for the measurement.

For example, using a regular balance instead of a sensitive one to measure the mass of a gold ring can lead to a larger error in the measurement.

2 Defects in the measuring instrument:

There may be one or more defects in the measuring device.

Examples of such defects in an ammeter include:



Figure (10)
An old ammeter device

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- The device is old, and the magnet inside has become weak.
- The pointer of the ammeter does not return to zero when the current is cut off, as shown in the diagram

③ Incorrect Measurement Technique:

Errors often arise from beginners or individuals who are not trained to perform accurate measurements. Examples of such errors include:
- Lack of knowledge in using multi-range devices, such as the multimeter.
- Viewing the pointer or scale at an angle, instead of ensuring that the line of sight is perpendicular to the scale marking that determines the reading.

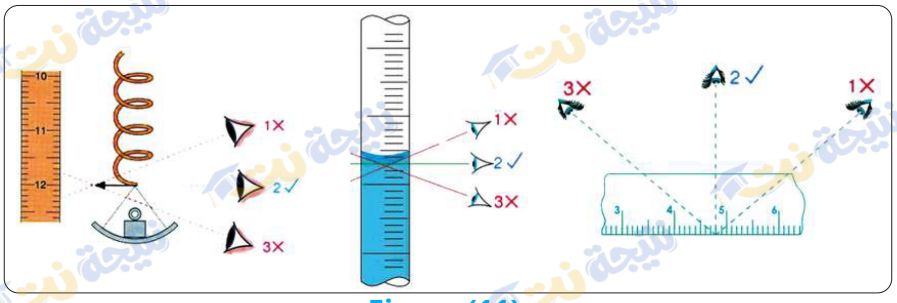


Figure (11)

The line of sight is perpendicular to the scale reading.

④ Environmental Factors :

Environmental factors such as temperature, humidity, or air currents can affect measurement accuracy.

For example, when measuring the mass of a small object using a sensitive balance, air currents may cause errors in the measurement.

To avoid this, the sensitive balance is placed inside a glass case.



Figure (12)

A sensitive balance enclosed in glass case

We can distinguish between two types of measurement:

① Direct Measurement:

This involves using a single measuring instrument.

For example, the density of a liquid can be measured using one tool known as a hydrometer.

② Indirect Measurement:

This involves using more than one measuring instrument.

For instance, density can be determined by measuring the mass with a balance and the volume with a graduated cylinder, then calculating the density by dividing the mass by the volume.



Figure (13)

Measuring Density Using a Hydrometer



Figure (14)

Measuring Density Using a Balance and a Graduated Cylinder

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Comparison of Point	Direct Measurement	Indirect Measurement
Number of Measurement Operations	Only one measurement operation is performed	More than one measurement operation is performed
Mathematical Operations	No substitution into a mathematical equation is required	Substitution into a mathematical equation is required to calculate the quantity
Errors in Measurement	There is a single error in the measurement process	Multiple errors may occur during the measurement process, leading to what is known as error accumulation
Examples	Measuring volume using a graduated cylinder	Measuring volume by multiplying length × width × height

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Summary

Definitions and Key Concepts

- Measurement: It is the process of comparing an unknown quantity with another quantity of the same kind to determine how many times the known quantity is contained in the unknown one.
- Fundamental Physical Quantities: These are physical quantities that cannot be defined in terms of other physical quantities.
- Derived Physical Quantities: These are physical quantities that are defined in terms of the fundamental physical quantities.
- Dimensional Formula Usage: Dimensional formulas are used to test the validity of physical laws. Having the same dimensional formula on both sides of an equation does not guarantee its correctness, but a mismatch confirms its error
- Sources of Error in Measurement:

1. Choosing an inappropriate measuring instrument.
2. Defects in the measuring instrument.
3. Performing the measurement incorrectly.
4. Environmental factors such as temperature, humidity, and air currents.

- Types of Measurement:

1. Direct Measurement: Involves a single measurement process without substituting into a mathematical relationship.
2. Indirect Measurement: Involves multiple measurement processes and substitution into a mathematical relationship to calculate the quantity.

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Questions & Exercises

First :Complete the Following Table

Physical Quantity	Unit of Measurement	Dimensional Formula
Speed	.....	.....
.....	m/s^2	.....
.....	.....	MLT^{-2}
Density	.....	.....

Second: Choose the correct answer

1. The derived quantity among the following is .....
A) Length B) Mass C) Time D) Speed

2. In the International System (SI), the ampere is a unit for measuring .....
A) Electric current B) Electric charge C) Length D) Luminous intensity

3. The dimensional formula of acceleration is .....
A) $L^2 T^{-1}$ B) LT^{-2} C) LT^{-1} D) LT

Third: Essay Questions

1. What is the difference between a fundamental physical quantity and a derived physical quantity?

2. Define each of the following: the standard unit of length, the standard unit of mass, and the standard unit of time.

3. Why is a glass rod of the same length as the standard meter not used as a standard unit for measuring length?

4. If you know that work = $\frac{1}{2} mv^2$, Deduce the dimensional formula of work.

5. Write the dimensional formula for each of the following: force – work – pressure (which equals force divided by area).

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6. In a physics exam, a student wrote the following equation:
(acceleration in m/s^2) × (time in s) = (velocity in m/s)
Use dimensional analysis to verify the correctness of this equation.

7. Einstein proposed his famous equation: $E=mc^2$, where (c) is the speed of light and (m) is the mass.
Use this equation to deduce the Unit in the International System (SI units) of the quantity (E).

8. Using the dimensional formulas of physical quantities, verify whether the given equation is valid.

$$P = P_a + \rho gh$$

where the total pressure at a point inside a liquid (P), The atmospheric pressure (P_a), the density of the liquid (ρ), and the acceleration due to gravity (g) and the depth of the point (h).

9. List the precautions that should be taken when using a meter ruler to measure the length of an object.

Fourth: Exercises

1. Write the following readings using scientific notation:

(A) The mass of the elephant is equal to 5000 kg $(5 \times 10^3\ kg)$

(B) The speed of light in a vacuum is approximately 300,000,000 m/s $(3 \times 10^8\ m/s)$

(C) The radius of the Earth is 6,000,000 m $(6 \times 10^6 m)$

(D) The radius of a hydrogen atom is 0.00000000005 m $(5 \times 10^{-11} m)$

2. Express the following quantities in the unit indicated, using scientific notation:

(A) 1 mg in kilogram , $(1 \times 10^{-6}\ kg)$

(B) $(3 \times 10^{-9}\ s)$ in milliseconds $(3 \times 10^{-6}\ ms)$

(C) 88 km in meter $(8.8 \times 10^4 m)$

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(D) If the diameter of a human hair is approximately 0.05 mm, calculate this diameter in meters (5×10^{-5} m)

3. The radius of Saturn is 5.85×10^{7} m and its mass is 5.68×10^{26} kg:

(A) Calculate the density of the planet material in g/cm³ (0.677 g/cm³)

(B) Calculate the surface area of the planet in m² (4.3×10^{16} m²)

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Unit Two

Linear Motion

- Chapter two: Motion in Straight Line
- Chapter three: Force and Motion



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Chapter

Two

Motion in Straight Line



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Expected learning outcomes

By the end of this chapter, you will be able to:

1- Define the concept of motion in a straight line.
2- Explain the types of motion.
3- Draw and interpret graphs that show the relationship (displacement - time) and (velocity - time).
4- Differentiate between different types of velocity and compare them.
5- Understand the concept of acceleration and its types.
6- Investigate, interpret, and analyze various graphs related to linear motion.

Key concepts

Motion - Speed - Velocity - Acceleration

Introduction

If we observe the objects around us, we find that some are stationary and some are moving. As we follow the motion of different objects, it is necessary to understand and describe that motion. In the absence of methods to describe and analyze motion, travel by ships, trains, and airplanes would become chaotic. Time and speed determine the schedules for departure and arrival of various means of transportation. Based on the above, in this chapter, we attempt to understand the concept of motion and the physical quantities necessary to describe it.



Figure (1)

What is the impact of studying motion on various means of transportation?

Motion

The adjacent figure shows a film strip marking the positions of a mouse at equal time intervals. Is the mouse moving or stationary?



Figure (2)

Motion: It is the change occurring in the position of an object over time relative to the position of another object. When the position of an object changes over a period of time, the object is said to have moved. If the motion is in one direction, i.e., follows a straight path, it is then called motion in a straight line, which represents the simplest type of motion.



Figure (3)

The motion of a train is an example of motion in a straight line. In many areas, the railway tracks do not change direction for long distances.

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Types of motion

Motion can be classified into two main types: translational motion and periodic motion.



Figure (4)
Translational motion



Figure (5)
Periodic motion

① **Translational motion:** It is a motion characterized by having a starting point and an ending point, such as motion in a straight line, projectile motion, and the motion of transportation means.

② **Periodic motion**: It is a motion that repeats itself at equal time intervals, such as circular motion and vibrational motion.

Development of scientific processes

Classify the motion of the following objects as translational or periodic:

- The motion of a clock pendulum.
- Projectile motion.
- The motion of trains.
- The motion of the prong of a tuning fork.

Aiming to integrate knowledge across subjects, the study in this unit of physics focuses on physical concepts related to force and motion, and their associated life applications, to pave the way for studying the mathematical proof of laws and computational applications in the context of mathematics and applied mathematics.

Velocity

Objects around us move; some are described as slow and others as fast, but these descriptions are not scientifically accurate. To describe the motion of an object, it must be quantified through the concept of Velocity.

Velocity: It is the displacement covered by the object in one second, or the rate of change of displacement over time, measured in (km/h) kilometers per hour or (m/s) meters per second.

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Graphical representation of the relationship between displacement and time:

Observe a moving object and record its displacement over a period of time..

The relationship between displacement (on the vertical axis) and time (on the horizontal axis) can be represented as follows:

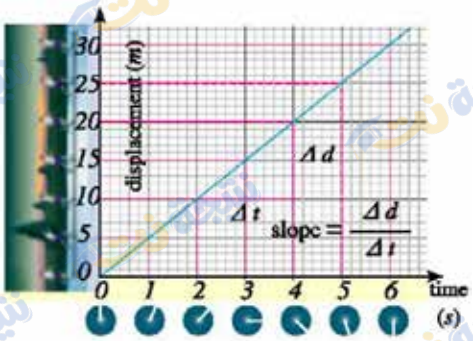


Figure (6)

- Draw a vertical line for the moments on the time axis.
- Draw a horizontal line for the corresponding displacement on the displacement axis.
- Identify the intersection point of the vertical line with the horizontal line.
- Repeat the previous steps for the other time and displacement points.
- Draw the best straight line passing through the intersection points.
- Determine the velocity by calculating the slope of the straight line.

Types of Velocity

1 Speed & Velocity

When you ride in a car, you can notice a meter in front of the driver.

Its pointer moves right and left, and this meter indicates the magnitude of velocity (e.g. 80 km/h)but does not tell us anything about the direction of the car movement. This quantity is called speed.



Fifure (7)

Does the car speedometer measure speed or velocity? And why?

Saying that a car is moving at 80 km/h is an incomplete description because we do not know in which direction the car is moving.

To fully describe the car velocity, we must specify the direction of its movement, for example, saying that the car is moving at 80 km/h toward the east. In this case, we use the term velocity.

Point of Comparison	Speed	Velocity
Definition	The distance covered by an object per unit time.	The displacement of on object per unit time
Quantity of Type	Scalar: determined by magnitude only.	Vector: determined by magnitude and direction.
Sign	Always positive	Positive when the object moves in a certain direction and negative when it moves in the opposite direction

It should be noted that the term used throughout the following texts and problems refers to velocity, not speed, because velocity is what provides a complete description of an object's motion.

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2 Uniform Velocity & Variable Velocity

When a runner moves with uniform velocity, the displacement between the positions is equal in equal time intervals. However, if the runner moves with non-uniform velocity, the displacement between positions is unequal in equal time intervals.

Uniform Velocity: The velocity at which an object covers equal displacements in equal time intervals. The object moves with constant magnitude of velocity in a straight line (constant direction).

Non- Uniform Velocity: The velocity at which an object covers unequal displacements in equal time intervals. The velocity varies in magnitude or direction.

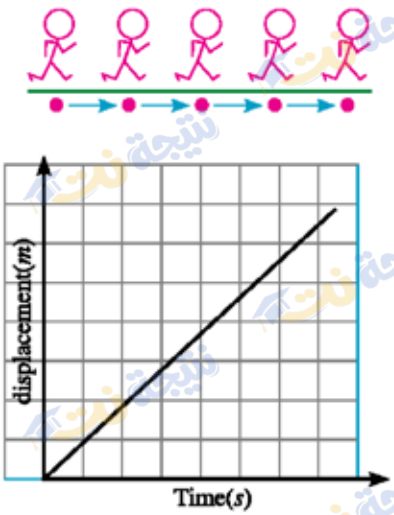


Figure (8)
Motion at uniform velocity

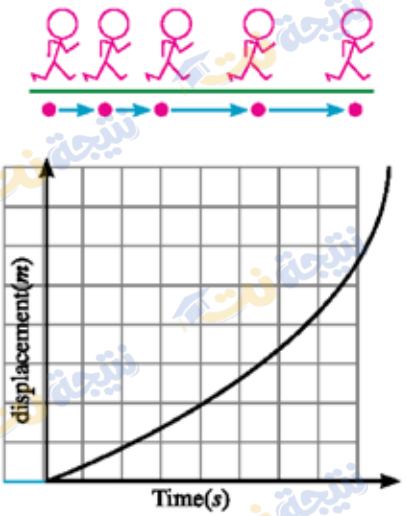


Figure (9)
Motion at variable velocity

3 Instantaneous Velocity & Average Velocity

If we observe the movement of a car on a road, we notice that its velocity is not constant but changes according to road conditions; it increases at times and decreases at others, and does not remain constant. To understand the movement of this car, we must distinguish between its instantaneous velocity and its average velocity.

Instantaneous velocity (v):

Is the velocity of the body at a specific moment, and its value can be inferred from the reading of the car speedometer at a particular moment. To determine the velocity of the car at a given moment, a tangent is drawn to the curve at the point corresponding to that moment, and the slope of the tangent represents the instantaneous velocity of the car.

Average velocity ($\bar{v}$)

Is the displacement from the starting point to the endpoint divided by the total time, and average velocity can be determined by finding the slope of the line connecting the starting point and the endpoint of the motion.

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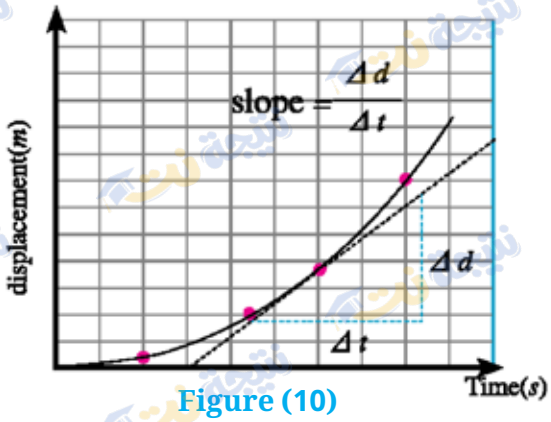


Figure (10)

Instantaneous velocity (v) = slope of the tangent to the curve at certain instant

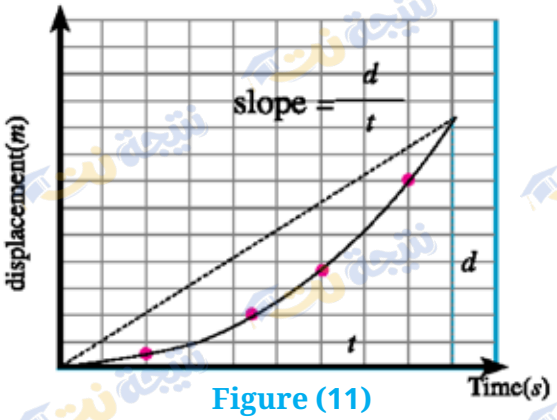


Figure (11)

$$\text{Average velocity } (\bar{V}) = \frac{\text{Total displacement } (d)}{\text{Total Time } (t)}$$

Acceleration

We have previously discussed the concept of variable velocity (in magnitude, direction, or both). Motion in which velocity changes with time is called accelerated motion, and the physical quantity that expresses the change in velocity with respect to time is called acceleration (a).



At the beginning of motion, velocity increases.



In curves, the direction of velocity changes.



By the end of motion, velocity decreases.

Figure (12)

The term acceleration is used to describe how velocity changes over time.

To understand the concept of acceleration, study the following motion diagram which shows the speedometer reading of a car starting from rest and increasing its velocity while traveling on a straight road.

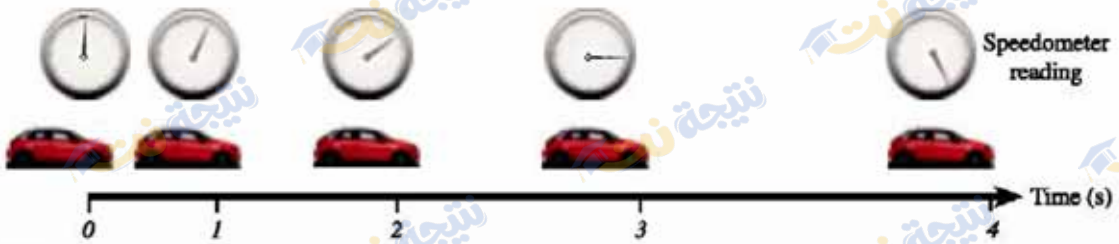


Figure (13)

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Do you know?

The readings of the car speedometer can be converted from km/h to m/s as follows:

$$1 \text{ km/h} = \frac{1 \text{ km}}{\text{h}} = \frac{1000 \text{ m}}{60 \times 60 \text{ s}} = \frac{5}{18} \text{ m/s}$$

Through studying this diagram, the relationship between velocity in (m/s) and time in (s) can be observed in the following table:

Time (s)	0	1	2	3	4
Velocity (m/s)	0	5	10	15	20

From the table, it can be concluded that the car velocity increases at a constant rate, increasing by (5 m/s) every second. This amount represents the acceleration, which is calculated from the relationship:

$$\textit{Acceleration} = \frac{\textit{Change in velocity}}{\textit{Change in time}} = \frac{(\textit{Final velocity} - \textit{Initial velocity})}{(\textit{Final time} - \textit{Initial time})}$$

$$a = \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1} \qquad (2)$$

By applying this relationship to the previous example, acceleration is calculated as follows:

$$a = \frac{\Delta v}{\Delta t} = \frac{10 - 5}{2 - 1} = 5 \text{ m/s}^2$$

Acceleration: The change in the object velocity per unit time, i.e., it is the time rate of change in velocity. Acceleration is measured in units of meters per second squared (m/s^2) or kilometers per hour squared (km/h^2).

Graphical representation of the relationship between velocity and time:

The graph (velocity-time) represents the motion of the car in the previous motion diagram. You can notice that the graph is a straight line, which means that the car's velocity increases at a uniform rate, and acceleration can be found by calculating the slope of the straight line

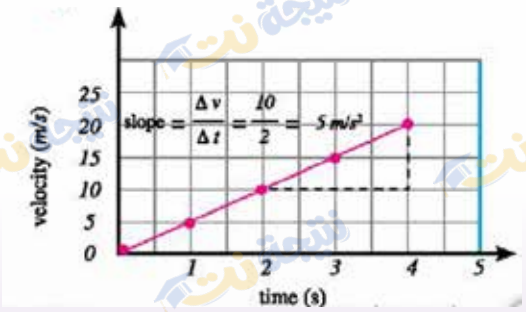
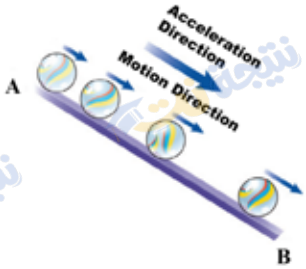


Figure (14)

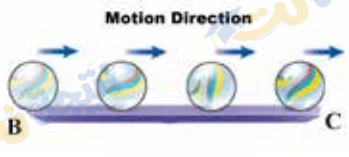
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Types of Acceleration

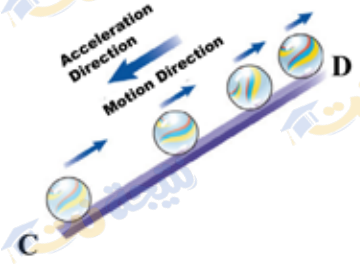
If we consider the direction of object velocity to be as a positive direction, this object may move with positive acceleration (velocity is increasing), negative acceleration (velocity is decreasing), or zero acceleration. To understand the types of acceleration, study the following motion diagram which shows the motion of a small ball on a smooth surface with variable slope.



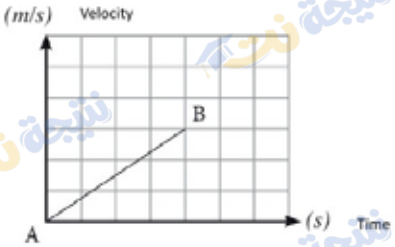
When the ball descends the inclined plane, its velocity increases with time, and therefore the acceleration is positive.



When the ball moves on a smooth horizontal surface, its velocity does not change, and therefore the acceleration equals zero.

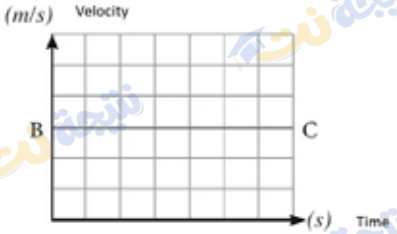


When the ball ascends the inclined plane, its velocity decreases with time, and therefore the acceleration is negative.



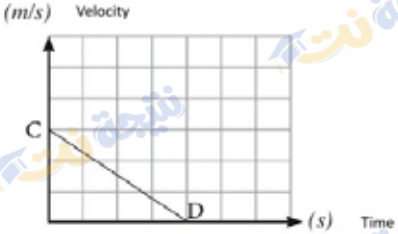
Positive acceleration

Figure (15)



Zero acceleration

Figure (16)



Negative acceleration

Figure (17)

Life applications

Inside every car, there are three tools that can be used to control the magnitude and direction of velocity : the gas pedal to increase velocity, the brake pedal to reduce velocity, and the steering wheel to change the direction of motion.

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Summary

First: Definitions and Basic Concepts

- Motion: The change that occurs in an object's position over time relative to the position of another object.
- Translational Motion: Motion characterized by having a starting point and an end point.
- Periodic Motion: Motion that repeats itself at equal time intervals.
- Velocity: The displacement of an object in one second.
- Uniform Velocity: The velocity at which an object covers equal displacements in equal time intervals.
- Variable Velocity: The velocity at which an object covers unequal displacements in equal time intervals.
- Acceleration: The change in an object's velocity per unit time.

Laws and important relations

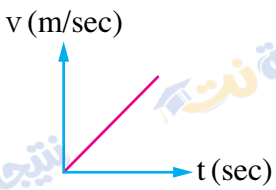
- Velocity (v): $v = \frac{\Delta d}{\Delta t}$
- Average Velocity ($\bar{v}$): $\bar{v} = \frac{Total\ displacement}{Total\ time}$
- Acceleration (a): $a = \frac{\Delta v}{\Delta t}$

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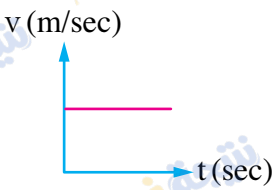
Excersice

First:Choose the correct answer

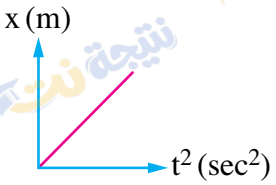
1. The graph that represents an object moving with uniform velocity.



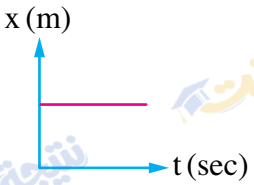
Ⓐ



Ⓑ



Ⓒ



Ⓓ

2. An object moves with uniform acceleration when .....
   - Ⓐ It covers equal distances in equal time intervals
   - Ⓑ Its velocity decreases by equal amounts in equal time intervals
   - Ⓒ Its velocity increases by equal amounts in unequal time intervals
   - Ⓓ The net force acting on the object is zero

3. The dimensional formula of acceleration .....
   - Ⓐ LT^{-1}
   - Ⓑ LT^{-2}
   - Ⓒ $L^{-1}T^{-2}$
   - Ⓓ $L^{-2}T^{-2}$

4. When the change in velocity of a sliding object is zero, ...
   - Ⓐ Its acceleration is positive
   - Ⓑ Its acceleration is negative
   - Ⓒ Its acceleration is zero
   - Ⓓ The object is at rest

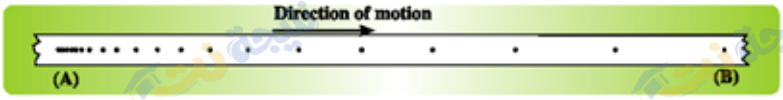
5. If both the directions of velocity and acceleration are negative, ...
   - Ⓐ The object velocity increases
   - Ⓑ The object velocity decreases
   - Ⓒ The object moves with constant velocity
   - Ⓓ The object stops moving

6. When the direction of acceleration is opposite to the direction of velocity .....
   - Ⓐ The object velocity increases at a non-constant rate
   - Ⓑ The object velocity increases at a constant rate
   - Ⓒ The object velocity remains constant
   - Ⓓ The object velocity decreases

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Second: Essay Questions

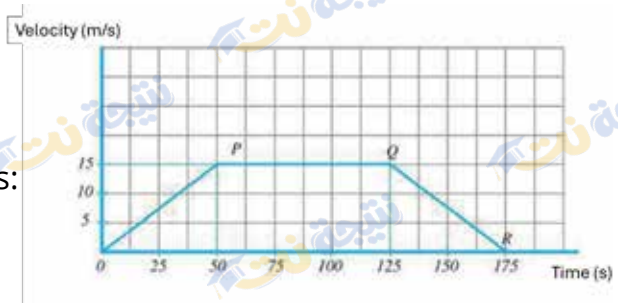
1. A student conducted an experiment to study motion using a mechanical cart and a timing bell, where he determined the cart position every second on a paper strip and obtained the strip shown in the figure:



(a) Describe the motion of the cart.

(b) Calculate the average velocity if the displacement covered from (a) to (b) equals 190 m.

2. The adjacent graph shows a journey taken by a car along a straight roed. Observe the figure, then answer the following questions:



(a) What is the maximum velocity the car reached?

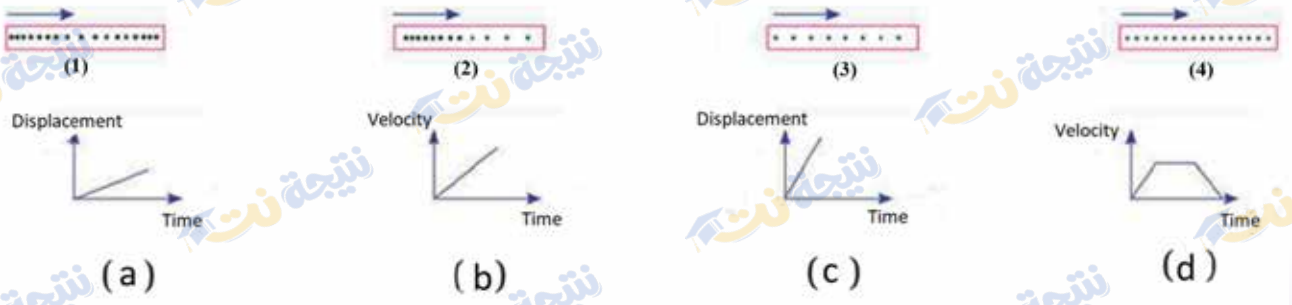
(b) Describe the car motion in part PQ.

(c) Describe the car motion in part QR.

(d) At which point P, Q, or R does the first stage where brakes were used begin?

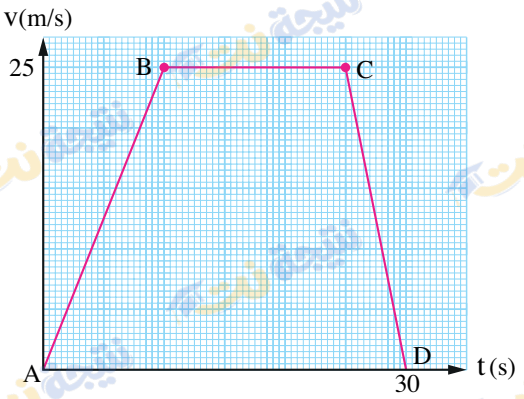
(e) Calculate the total distance covered during the journey.

3. A ball rolls when pushed, then slows down and stops. Do the ball velocity and acceleration have the same sign? And why?
4. If an object acceleration equals zero, does this mean its velocity equals zero? Give an example.
5. Match each dot diagram describing an object motion with the graph that describes the same motion:



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6. A car moved in a straight line, and its speed was recorded for 30 seconds, then represented graphically in the adjacent figure. Work with a colleague to analyze the graph that represents the car motion and extract the necessary information to complete the following table:



Car Motion Stages	Stage AB	Stage BC	Stage CD
Initial velocity v_i			
Final velocity v_f			
Change in car velocity (Δv)			
Stage duration (t)			
Acceleration value (a)			
Description of motion during the stage			

Third: Problems

7. Calculate the average velocity in (km/h) for a runner who was moving in a straight line and covered a distance of (4000 m) in (30 min), then calculate the distance he covers after (45 min) from the start of the race at the same average velocity.

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Chapter

Three

Force and Motion



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Expected learning outcomes

Expected Learning Outcomes
By the end of this chapter, you will be able to:

1- Recognize the concept of force.
2- Recognize Newton's First Law.
3- Explain the phenomenon of inertia.
4-Recognize the concept of momentum.
5-Apply the relationship between force, mass, and acceleration.
6- Explain some life phenomena using Newton's Second Law.
7- Explain the phenomenon of action and reaction.

Key concepts

- Force- Inertia- Momentum- Mass- Action- Reaction

Introduction

Previously, we covered describing motion by studying the concepts of speed and acceleration without addressing the causes of motion of objects. In this chapter, we will discuss how acceleration is generated as a result of force. During this, we will discuss Newton's three laws of motion, which are fundamentally important laws in physics.

Force



Figure (1)

What causes the movement of a child's cart?

Force is a commonly used word in our daily life. Your muscular force helps you pull things, the car engine's force helps start movement, and the brake force helps stop it.

Force is defined as: an external influence that affects an object, changing or attempting to change kinematic state or direction. It is measured using a spring scale, and its unit of measurement is the Newton (N).

Scientists Who Benefited Humanity:

Although many ancient philosophers tried to explain and interpret the causes and nature of motion, no organized theory of motion was established before the seventeenth century. The greatest credit in this regard goes to the achievements of two great scientists: Galileo and Newton.





Newton's First Law

Perhaps you have returned home after a long absence, looked around, and said with relief: "Everything remained as it was." Have you ever thought that this phrase embodies one of the most important natural laws?

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It is also known that if an object is pushed on the ground, it slides a certain distance and then slows down till it stops. The ancients believed that the nature of matter is rest, meaning that the motion of anything tends to come to rest. However, scientific experiments showed that this is due to the presence of frictional forces resisting the sliding object and working to slow it down until it stops. If these forces did not exist, the object would continue moving continuously without stopping. This is called Newton's First Law of Motion.

Newton's First Law of Motion: An object remains at rest or moves with a constant velocity in a straight line unless acted upon by a resultant force that changes its state.

The mathematical formula of the law: $\sum F = 0$ (1)

ΣF is the resultant force, as more than one force may act on the object, but some of their effects cancel each other out, and then the resultant force may be zero.



Figure (2)
Newton's First Law

Based on Newton's First Law, we conclude that when the force acting on an object equals zero (F = 0), the acceleration (a = 0), the object's velocity does not change whether it's at rest or moving . We also conclude that a force is needed to move stationary objects or stop moving ones, but no force is needed to keep them moving at a constant velocity.

Newton's First Law is closely related to the concept of inertia, which is why it is called the law of inertia.

Inertia: It is the tendency of a stationary object to remain at rest and the tendency of a moving object to continue moving uniformly at its original speed in a straight line, meaning that objects resist change to their state of rest or motion .

- It is observed that the ability to stop bodies moving under the influence of inertia depends on their mass and velocity as:
- It is difficult to stop a large truck while it is easy to stop a small bicycle, assuming they are moving at the same velocity.
- It is difficult to stop a car if its velocity is high, while it is easy to stop it if its velocity is low.
- From the previous two observations, it becomes clear that velocity and mass are linked together in an important physical quantity known as momentum.

Momentum = Mass x velocity
$P = mv$ (2)

It is a vector quantity, and its unit of measurement is kg·m/s

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Newton's Second Law

From Newton's first law, we know that an object on which no force acts does not accelerate, and this undoubtedly leads us to the object on which a resultant external force acts ($\Sigma F \neq 0$) changes its velocity and gains acceleration ($a \neq 0$).

Newton has identified the factors on which this acceleration depends through his second law.

Newton's Second Law of Motion: The resultant force acting on an object equals the time rate of change of the momentum of that object.

From Newton's second law :

$$F = \frac{\Delta mv}{\Delta t} = \frac{mv_f - mv_i}{\Delta t}$$

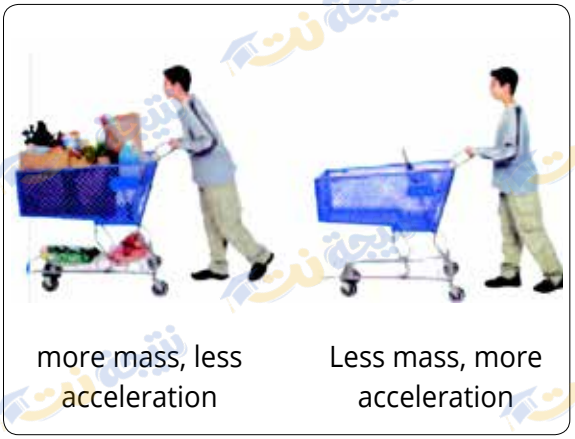
$$F = m\frac{v_f - v_i}{\Delta t} = m\frac{\Delta v}{\Delta t} \qquad \boxed{F = ma} \longrightarrow a = \frac{F}{m} \qquad (3)$$

From the previous, it can be concluded that acceleration is directly proportional to the force acting on the object and inversely proportional to its mass.



greater force, greater acceleration | less force, less acceleration

Figure (3)
Acceleration increases with increasing force, at constant mass



more mass, less acceleration | Less mass, more acceleration

Figure (4)
Acceleration decreases with increasing mass, at constant force

Accordingly, Newton's second law can be formulated as follows:

Another form of Newton's second law of motion: If a resultant force acts on an object and gives it an acceleration, this acceleration is directly proportional to the force acting on the object and inversely proportional to its mass. The mathematical formula of the law is:

$F = ma$ or $a = \frac{F}{m}$

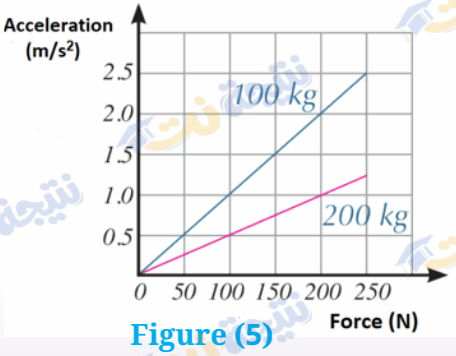


Figure (5)
Graphical relationship between force and acceleration with different masses.

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By plotting the graph between the acceleration of object and the force acting on it, we find that the acceleration of the object increases with increasing the force as well as the object of less mass. For example, an object of mass (100 kg) moves with a greater acceleration than an object of mass (200 kg) if the same force is applied to both.

From Newton's second law, the unit of the newton (N) can be redefined through this law:

Newton : It is the force that, when applied to an object with a mass of 1 kg, gives it an acceleration of 1 m/s². That means, 1 Newton = 1kg·m/s².

Critical Thinking Development

When a force of N1 is applied to a wooden cube, it gains a certain acceleration. When the same force is applied to another cube, it gains an acceleration three times greater. What do you conclude about the mass of each of these two cubes? (The relationship between mass and acceleration)

Life Applications

From studying the relation:

$$F = m \frac{\Delta v}{\Delta t} \qquad (4)$$

We can conclude that the force acting on an object increases with the increase in mass and change in velocity, and decreases with the increase in the duration of the effect. In light of the above, explain the following life phenomena:

If the change in momentum occurs over a longer time period, the impact of the collision force is less.

If the change in momentum occurs over a shorter time period, the impact of the collision force is greater.

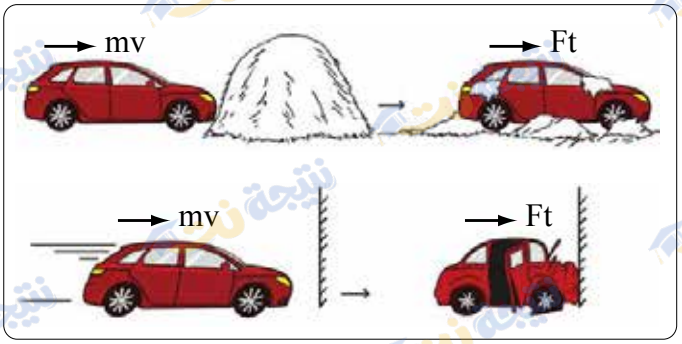


Figure (6)

- A car collision with a wall is more destructive than a collision with a pile of straw.
- If a person falls from a high place into water, he is not harmed, but if he falls on the ground, he may be harmed
- The severity of injury increases with the height from which the person falls.
- If an egg falls on a cushion, it does not break, but it breaks if it falls on the ground.
- A collision of a large truck with a wall is more destructive than the collision of a small truck.
- Airbags in cars are used to protect the driver during a collision.



Figure (7)

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Newton's Third Law



Figure (8)
If you blow up a balloon with air and then let the air escape, what happens to the balloon?



Figure (9)
If you sit on a rolling chair (with wheels) and push the wall in front of you with your feet, what happens to you?



Figure (10)
When a projectile is fired from a rifle, what happens to the rifle?

Newton found an explanation for all previous phenomena through his third law, which examines the nature of forces acting on objects, which exist in equal pairs in magnitude and opposite in direction.

Thinking Corner

When a large truck collides with a small car, on which of the two bodies is the collision force greater?



Figure (11)
The action force equals the reaction force in magnitude and is opposite in direction.

Newton's Third Law of Motion: When one object acts on another object with a force, the second object exerts a force on the first object that is equal in magnitude and opposite in direction. That is, for every action, there is an equal and opposite reaction

The mathematical formula of the law is: $F_1 = -F_2$ **(5)**



Figure (12)
The reading of the first spring scale equals the reading of the second spring scale.

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The third law includes the following:

- There is no single force in the universe; therefore, action and reaction forces arise together and disappear together.
- Action and reaction have the same nature; if the action is a gravitational force, then the reaction is also a gravitational force.
- It cannot be said that the resultant of action and reaction equals zero because they act on two different objects.

Scientific Applications

The idea behind the operation of a rocket depends on Newton's third law, where a large mass of burning gases is expelled from the bottom of the rocket, and the rocket's reaction is to thrust upward.



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Summary

First: Definitions and Basic Concepts

- Force: An external influence acting on an object that changes or attempts to change its state of motion or direction.
- Newton's First Law:

An object remains at rest or moves with a constant velocity in a straight line unless acted upon by a resultant force that changes its state.

- Inertia: The tendency of a stationary object to remain at rest and the tendency of a moving object to continue moving at its original velocity in a straight line.
- Momentum: A physical quantity equal to the product of the object's mass and its velocity.
- Newton's Second Law: The resultant force acting on an object equals the time rate of change of the momentum of that object.
- Newton's Third Law: For every action, there is a reaction equal in magnitude and opposite in direction

Second: Important Laws and Relations

- Newton's First Law $\Sigma F = 0$
- Momentum (P) $P = mv$
- Newton's Second Law $F = ma$
- Newton's Third Law : $F_1 = -F_2$

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Excersice

First :Choose the correct answer

1. A bicycle moves at a constant velocity in a straight line towards the east, when the resultant force on the bicycle is .....

   Ⓐ zero. Ⓑ negative.

   Ⓒ positive. Ⓓ in the east direction.

2. When the resultant force acting on a moving car is zero, ...

   Ⓐ the car moves with positive acceleration.

   Ⓑ the car moves with negative acceleration.

   Ⓒ the car moves at a constant velocity.

   Ⓓ the car stops.

3. Newton's third law is expressed by the mathematical relation .....

   Ⓐ $\Sigma F = 0$

   Ⓑ $\Sigma F \neq 0$

   Ⓒ $F = ma$

   Ⓓ $F_1 = -F_2$

Second: Essay Questions

1. If a train suddenly moves forward, in which direction will a small bag placed under one of the seats move?

2. It can be said that the first law of motion is a special case of the second law; explain that.

3. An astronaut throws a small object in a certain direction; what happens to the astronaut? In light of this, suggest a way for the spacecraft to change its direction outside the atmosphere.

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Unit

Three

Matter Properties

Chapter Four: Hydrodynamics.

Chapter Five: Properties of Hydrostatics



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Chapter

Four

Hydrodynamics



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Expected Learning Outcomes

By the end of this chapter, you will be able to:

1- Identify the meaning of a fluid.

2- Recognize density and some of its medical applications.

3- Identify key properties of moving fluids.

4- Compare laminar flow and turbulent flow.

5- Understand the conditions for steady flow.

6- Explain the relationship between flow rate and the continuity equation in steady flow.

7- Understand and explain the meaning of fluid viscosity.

8- Derive the viscosity coefficient mathematically.

9- Discuss some applications of viscosity.

Key Concepts

Fluid

Density

Relative Density

Laminar Flow

Turbulent Flow

Steady Flow

Viscosity

Introduction

Fluids: are materials characterized by their ability to flow. Therefore, fluids include both liquids and gases. Gases differ from liquids in that they are easily compressible, whereas liquids resist compression almost entirely. As a result, liquids are considered to exhibit incompressible laminar flow. Additionally, liquids have a definite volume, while gases occupy any space available to them.

Density

Density is a basic property of any material, it has the symbol ρ. It's defined as the mass per unit of volume, and its SI unit is kg/m^3

$$\rho = \frac{m}{V_{ol}} \qquad (1)$$

Density varies from one material to another due to the following:

(1) Difference in the atomic or molecular mass of the substance.

(2) Difference in inter-atomic or intermolecular spaces between atoms or molecules

We have already learned that objects with lower density float on liquids with higher density.

The following table illustrates examples of the densities of some common materials.

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Material	Density (kg/m^3)	Material	Density (kg/m^3)
Solids:		**Liquids:**	
Aluminum	2700	Kerosene	820
Brass	8600	Mercury	13600
Copper	8890	Glycerin	1260
Common Glass	2600	Water	1000
Gold	19300	**Gases:**	
Ice	910	Air	1.29
Iron	7900	Ammonia Gas	0.76
Lead	11400	Carbon Dioxide	1.96
Platinum	21400	Carbon Monoxide	1.25
Steel	7830	Helium	0.18
Sugar	1600	Hydrogen	0.090
Wax	1800	Nitrogen	1.25
		Oxygen	1.43
Liquids:			
Ethyl Alcohol	790		
Benzene	900		
Blood	1040		
Gasoline	690		

The ratio of the density of any material to the density of water at 4°C is called the relative density of the material.

$$\text{Relative density of a material} = \frac{\text{Density of the material at a specific temperature}}{\text{Density of water at } 4^{\circ}C} \qquad (2)$$

Since density of water at 4°C Equals 1000 kg/m^3

In general:

$$\text{Relative density of a material} = \frac{\text{Mass of a given volume of the material at a specific temperature}}{\text{Mass of the same volume of water } 4^{\circ}C}$$

Since the relative density of a substance is a ratio between two identical quantities, the relative density of a substance has no units of measurement.

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Applications of Density

Measuring density has highly importance in both scientific and practical fields, as it is considered one of the key analytical techniques.

1. Measuring the density of the electrolytic solution in a car battery; to determine the battery's charge level.

When the battery discharges, the density of the electrolytic solution (diluted sulfuric acid) decreases due to the consumption of sulfuric acid in its reaction with lead plates, forming lead sulfate. When the battery is recharged, sulfate ions are released from the lead plates and return to the solution, increasing the density of the electrolyte.

Thus, by measuring the density, we can infer the battery charge status.

2. Density applications is also used in medical science, to measure the density of blood and urine.

Blood density normally ranges between 1040 kg/m³ to 1060 kg/m³.

If the density increases, it indicates a higher concentration of blood cells.

If it decreases, it indicates a lower concentration of blood cells, which may suggest anemia.

Urine density typically is around 1020 kg/m³.

Certain diseases can lead to increase of salt excretion, which in turn causes a corresponding increase in urine density.

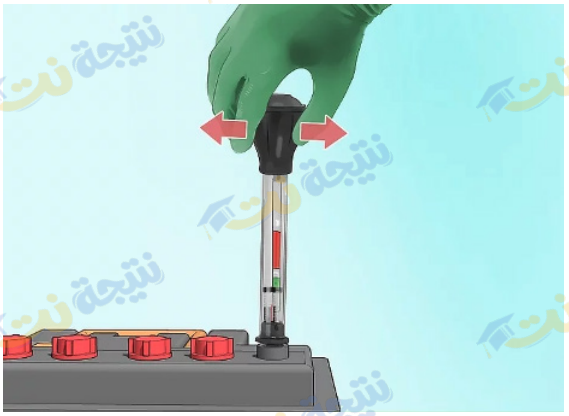


Figure (1)
Measuring the Density of the electrolytic Solution in a Car Battery

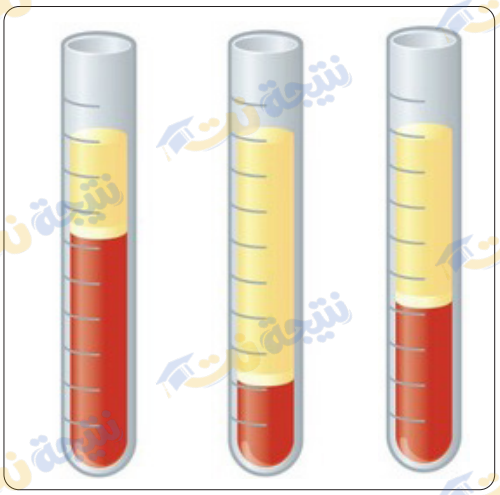


Figure (2)
Measuring Blood Density

Critical Thinking Development

Gold is one of the densest metals on Earth. Pure gold, commonly known as 24-karat gold, has a density of approximately 19.32 g/cm³. Gold also comes in alloys such as:

18-karat gold, with a density of about 15.45 g/cm³

14-karat gold, with a density of about 13.1 g/cm³

- What causes gold alloys to differ in their density?
- How can you identify the karat of gold in a piece of jewelry?



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Liquid Flow

Liquid flow can be classified into laminar flow and turbulent flow.

First Laminar Flow

When a liquid moves such that its adjacent layers slide smoothly and gently past one another, that's called **laminar flow**.

In this type of flow, each small portion of the liquid follows a continuous path called Streamline. Based on this, we can visualize the liquid motion in a real or hypothetical tube by drawing a set of streamlines, which trace the paths of different liquid particles as shown in Figure (3)

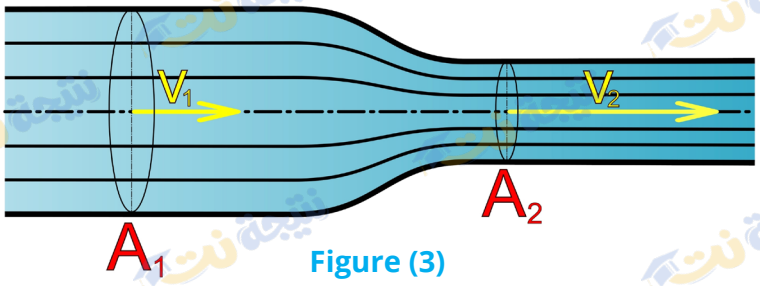


Figure (3)
Stramlines

One of the key characteristics of streamlines in laminar flow is that they do not intersect. Moreover, the tangent at any point on a streamline indicates the instantaneous velocity direction of each small quantity of liquid at that point.

The number of streamlines passing perpendicularly through a unit area at a specific point is called the Streamline Density, which determines the flow speed of the liquid at that location. Therefore, streamlines become closer together at high liquid speeds and spread apart at lower speeds.

Second Turbulent Flow

When the flow speed of a liquid exceeds a certain limit, the flow becomes turbulent.

Turbulent flow is characterized by the presence of small circular **vortices** Figure (4). The same occurs with gases as well as a result of diffusion of a gas from a small space to a larger one, or moves from high pressure to lower pressure, it moves in vortical motion Figure (5).

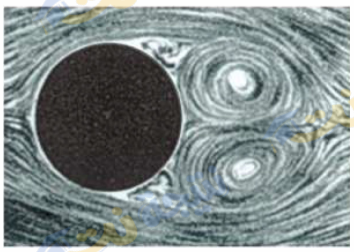


Figure (4)
Vortices resulting from violent liquid flow or the rapid motion of an object through a liquid



Figure (5)
Smoke changes from Steady Flow to Turbulent Flow

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Steady Flow

When the liquid velocity at every point along its path remains constant over time, the Laminar flow may be considered a Steady flow.

Flow Rate and Continuity Equation

When studying steady flow, we imagine a flow tube through which the liquid moves:

(1) The liquid completely fills the tube.

(2) The amount of liquid entering the tube at one end is equal to the amount exiting at the other end within the same time interval. This means the flow rate is constant along the tube's path, as the liquid is incompressible and its density does not change with distance or time.

(3) The velocity of the liquid flow at any point in the tube does not change over time.

The relation that relates the liquid flow rate to its velocity and the cross-sectional area of the tube is called the Continuity Equation.



Figure (6)

Model for Deducing the Continuity Equation

To understand what the continuity equation mean, we consider two cross-sectional planes perpendicular to the streamlines at two points in the tube as shown in Figure (6),

Let the area of the first cross-section be A_1 and the area of the second cross-section is A_2, and the volume of liquid flowing per unit time (The volumetric flow rate) (Qv) through area A_1 is:

$Q_v = A_1 v_1$ as v_1 is the liquid velocity at cross-ection A_1

And, the mass of the flowing liquid per unit time, with density ρ, is called the mass flow rate is: $Q_m = \rho Q_v = \rho A_1 v_1$ Similarly, at the second cross-section with area A_2 and velocity v_2, the mass flow rate is: $\rho Q_v = \rho A_2 v_2$

Since the mass flow rate remains constant in steady flow, we conclude that:

$$\rho A_1 v_1 = \rho A_2 v_2 \quad (3)$$

$$A_1 v_1 = A_2 v_2$$

And this is the Continuity Equation, meaning that $\frac{v_1}{v_2} = \frac{A_2}{A_1}$ (4)

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from this relationship (4), we understand that the velocity of the liquid at any point in the tube is inversely proportional to the cross-sectional area of the tube at that point. The liquid flows very slowly when the cross-sectional area is large (A_1), and flows faster when the cross-sectional area is small (A_2)—as shown in Figure (7). To better understand the continuity equation, let us imagine a liquid and we consider a small mass of the liquid, Δm, and since: $\Delta m = \rho \Delta V_{ol}$

Where ΔV_{ol} is the volume of that mass.

Let Δx_1 be the distance the fluid travels in time Δt, so:

$\Delta V_{ol} = A_1 \Delta x_1$

,and since $\Delta x_1 = v_1 \Delta t$

,then: $\Delta V_{ol} = A_1 v_1 \Delta t$

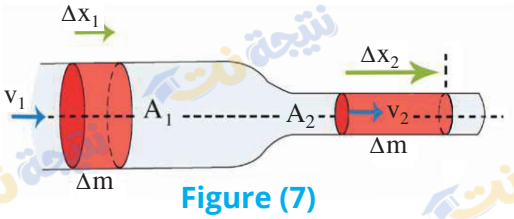


Figure (7)

Basis of the Continuity Equation

The same volume must pass through the other side of the tube, because the liquid is incompressible, that's mean:

$$A_1 v_1 \Delta t = A_2 v_2 \Delta t$$

$$\therefore \frac{v_1}{v_2} = \frac{A_2}{A_1}$$

It must be ensure here that the flow rate of the liquid is a volumetric flow rate (Q_v with units of (m^3/s), or a mass flow rate (Q_m) with units of (kg/s).Both are constant values at a given cross-sectional area, and this is based on the **Law of Conservation of Mass**, which is also known as the Continuity Equation

Enrichment Information

Bernoulli's principle describes the relationship between a fluid's pressure and its flow velocity. It states that the pressure of a fluid decreases as its velocity increases.

The airplane wing is designed with a curved upper surface and a flat lower surface, causing air to flow faster over the top than underneath. As a result, the air pressure P_1 above the wing is lower than the air pressure P_2 below it. This pressure difference generates an upward lift force on the airplane.

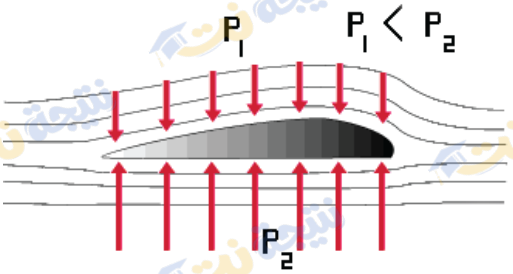


Figure (8)

The Force Resulting from the Pressure Difference Pushes the Airplane Upward.

Example 1

A water pipe with a diameter of 2 cm enters a house, and the water flows at a speed of 0.1 m/s. Then the diameter becomes 1 cm. Calculate:

(a) The speed of water in the narrow section.

(b) The amount of water (its volume and mass) that flows through any section of the pipe per minute (given that the density of water = 1000 kg/m^3).

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Answer

(a) We know that: $A_1 v_1 = A_2 v_2$

$$\pi (0.01\ m)^2 (0.1\ m/s) = \pi (0.005\ m)^2$$

$$v_2 = \frac{\pi \times 10^{-4} \times 0.1}{\pi \times 2.5 \times 10^{-5}} = 0.4\ m/s$$

(b) The volumetric rate of water is determined by the relation:

$$Q_v = A_1 v_1 \text{ OR } A_2 v_2$$

$$\pi \times 2.5 \times 10^{-5} \times 0.4 \text{ OR} = \pi \times 10^{-4} \times 0.1$$

$$= 3.14 \times 10^{-5}\ m^3/s$$

Thus, the volume of fluid flowing in one minute is:

$$\acute{V}_{ol} = Q_v \times 60 = 3.14 \times 10^{-5} \times 60 = 188.4 \times 10^{-5}\ m^3$$

Mass rate of flow (given that the density of water = 1000 kg/m³)

$$Q_m = \rho Q_v = \rho A_1 v_1 = \rho A_2 v_2$$

$$= 3.14 \times 10^{-5} \times 10^3 = 3.14 \times 10^{-2}\ kg/s$$

The mass of water flow in one minute:

$$\acute{M} = 3.14 \times 10^{-2} \times 60 = 1.884\ kg$$

Example 2

The average speed of blood flow in the Aorta (with a radius of 0.7 cm) for an adult is 0.33 m/s. From the Aorta, blood is distributed to a number of main arteries (each with a radius of 0.35 cm). If the number of main arteries is 30, calculate the blood speed in them.

Answer

* Cross-sectional area of the Aorta: $A_1 = \pi r_1^2 = \pi (0.007)^2\ m^2$

* Cross-sectional area of the thirty main arteries:

$$A_2 = \pi r_2^2 \times 30$$

$$= \pi (0.0035)^2 \times 30\ m^2$$

$$A_1 v_1 = A_2 v_2$$

$$\pi (0.007)^2 (0.33) = \pi (0.0035)^2 (30) v_2 \qquad v_2 = \frac{4 \times 0.33}{30} = 0.044\ m/s$$

That's mean, the speed of blood in the capillaries is 0.044 m/s. Therefore, the speed of blood in the capillaries is very slow, which allows for the exchange of oxygen and carbon dioxide gases in the tissues, as well as the delivery of nutrients.

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Ideas to Stimulate Creativity

Using the internet, search for answers to the following questions:

- How can the study of fluid flow be used in the design of pipeline networks and systems for water distribution and drip irrigation?



Viscosity

The meaning of viscosity can be understood from the following:

(1) We hang two identical funnels on a stand, placing an empty glass under each. We pour a specific volume of alcohol into one funnel, and an equal volume of glycerin into the other, then observe the flow rate of each liquid. We find that the flow rate of alcohol is greater than that of glycerin—in other words, alcohol has a higher ability to flow than glycerin.

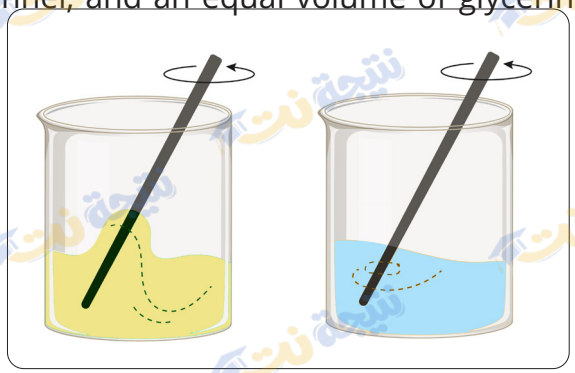


Figure (9)

The glass rod moves more easily in water than it does in honey.

(2) We take two identical glasses, one containing a specific volume of water and the other an equal volume of honey. We stir the liquid in each glass with a glass rod and observe; in which liquid the rod moves more easily. Then we remove the rod from the liquid and observe the movement of each liquid after the rod is removed. We find that:

(a) The rod moves more easily in water, indicating that water resists the movement of the glass rod less than honey does.

(b) The movement of honey stops shortly after the rod is removed, whereas the movement of water continues for a longer period.

(3) We take two identical long graduated cylinders, fill the first cylinder almost to the top with water, and the second almost to the top with glycerin. Then we take two identical metal balls (steel, for example) and gently drop one into water, measuring with a stopwatch the time it takes for the ball to reach the bottom of the cylinder. We then gently drop the other ball into glycerin and measure the time it takes to reach the bottom of the cylinder.

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We find that the time it takes for the ball to reach the bottom of the cylinder in water is less than the time it takes for a similar ball to reach the bottom in glycerin, indicating that glycerin resists the movement of the ball more than water does.

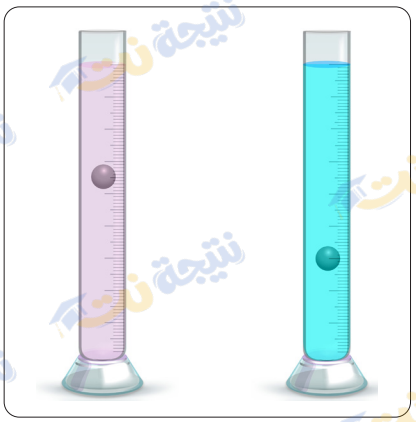


Figure (10)

The movement of the ball in water is faster than its movement in glycerin.

From the above, the following can be concluded:

(1) Some liquids, such as water and alcohol, have low viscosity, so their flowability or ease of movement is high, while their resistance to the movement of objects within them is low.

(2) Some liquids, such as honey and glycerin, have high viscosity, so their flowability or ease of movement is low, while their resistance to the movement of objects within them is high.

To explain the property of viscosity, we imagine a quantity of liquid confined between two flat plates, one stationary and the other moving at velocity v Figure (11). The layer of liquid in contact with the stationary plate is stationary, while the layer in contact with the moving plate moves at the same speed as the plate, which is v. The layers of liquid between the two plates move at velocities ranging from zero to v, increasing from the stationary plate to the moving plate, with each layer moving slower than the one above it. This relative difference in velocity is due to the following:

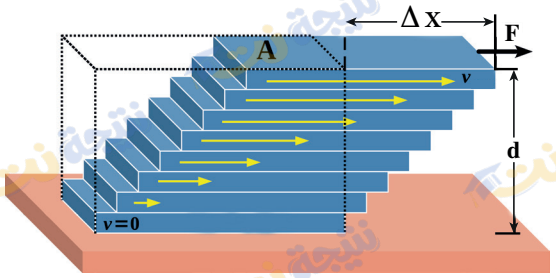


Figure (11)

a) There are frictional forces between the flat surface of the lower plate and the layer of liquid adjacent to it. These forces are attributed to the adhesion between the molecules of the solid plate surface and the molecules of the liquid directly adjacent to it, which hold them and hinder their flow, making this layer appear stationary and immobile. For the same reason, the upper layer of the liquid moves at the same velocity as the upper plate.

b) There are forces similar to frictional forces between each layer of the liquid and the layer above it, which hinder sliding of some layers over others, resulting in a relative difference in speed between each layer and the one above it.

Viscosity is the property that causes resistance or friction between the layers of the fluid, hindering their sliding over each other.

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Viscosity Coefficient

Referring to Figure 11, to keep the moving plate in the liquid at a constant Velocity (v), there must be a force (F) equal to the viscous forces. This force is directly proportional to both the velocity (v) and the area of the moving plate (A), and inversely proportional to the distance between the two plates (d).

$$F \propto \frac{Av}{d}$$

Therefore, we have:

$$F = \eta_{vs} \frac{Av}{d} \qquad (5)$$

Where η_{vs} (eta) is the proportionality constant known as the coefficient of viscosity.

$$\eta_{vs} = \frac{Fd}{Av} = \frac{F}{Av/d} \qquad (6)$$

And from this relationship, the viscosity coefficient can be defined as follows,

Viscosity coefficient of a liquid:It equals the tangential force acting on a unit area that results in a velocity difference of one unit between two liquid layers separated by a unit vertical distance. The viscosity coefficient of a pure liquid depends on its type and temperature and Its unit is N.s/m² or kg/(m.s).

Applications of viscosity

Viscosity has many applications, including:

① Lubrication and Oiling :

Metal machines should be lubricated or oiled from time to time, as lubrication leads to:

a) Reduction in the amount of heat generated due to friction.

b) Protection of machine parts from wear.

Lubrication is carried out using types of oil that are characterized by high viscosity. If we were to use water for lubrication—which is a substance with low viscosity—it would quickly flow away from the machine parts due to its weak adhesion during movement. Therefore, it is natural to use liquids that have the ability to adhere to machine parts and not flow away quickly despite the continuous motion of those parts. Hence, it is essential to use liquids with high viscosity in the lubrication process.

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② Moving Vehicles:

When a car reaches its maximum velocity, most of the total work done by the engine—derived from the consumed fuel—is used to overcome air resistance during its motion, as well as the friction between the car tires and the ground. At relatively low or moderate speeds, the air resistance encountered by moving objects—resulting from the viscosity of air—is directly proportional to their velocity. However, when the car velocity exceeds a certain limit, air resistance becomes proportional not just to the velocity, but to the square of the velocity. This means that fuel consumption increases more rapidly as velocity rises beyond that threshold. Therefore, an experienced driver tends to limit the car velocity to conserve fuel.

③ In Medicine :

Measuring Blood Precipitation Rate:

It is known that when a ball falls vertically in a liquid, it is affected by three forces:

Its weight acting downward,the buoyant force of the liquid acting upward, and the frictional force between the ball and the liquid, also acting upward, due to the liquid viscosity. By calculating the net force, it is found that the ball moves at a final velocity that increases with the ball radius.

This principle can be applied in medicine by taking a blood sample and measuring its precipitation rate. This allows the doctor to determine whether the size of red blood cells is normal or not. For example:

In cases of rheumatic fever, the precipitation rate increases beyond the normal level due to the red blood cells adhere together, which increases their size and radius—thus increasing the precipitation rate.

In cases of anemia, the precipitation rate decreases below the normal level because red blood cells break down, reducing their size and radius.



Ideas to To Spark Innovation

Imagine you are an engineer in the automotive industry:

- What factors would you rely on to determine the appropriate type of oil used in a car engine?
- What could happen if oils with unsuitable viscosity are used?

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Summary

- **First: Definitions and Key Concepts**
- **Density (ρ):** The mass of unit volume of a substance. Its unit is kg/m³.
- **Fluid:** Any substance that can flow and does not have a fixed shape of its own.
- **Steady flow in pipes requires that:**

(a) The liquid completely fills the pipe.

(b) The amount of liquid entering the pipe at one end equals the amount exiting at the other end within the same time.

(c) The flow velocity of the liquid at any point in the pipe does not change over time.

- **Viscosity:** The property that causes resistance or friction between the liquid layers, hindering their sliding over one another.
- **Coefficient of Viscosity:** Equal to the tangential force acting on a unit area, resulting in a unit difference in velocity between two layers of liquid separated by a unit vertical distance. The unit of Viscosity Coefficient is $kg.m^{-1}.s^{-1}$

Second: Important Laws and Relationships

- **Density (ρ):** $\rho = \frac{m}{V_{ol}}$
- **The volume of liquid that flows through a cylindrical tube during a specific period of time (t):** $V_{ol} = Q_v t = Avt = \pi r^2 vt$
- **The mass of the liquid that flows through a cylindrical tube during a specific period of time (t):** $M = Q_m t = Q_v \rho t = Av\rho t = \pi r^2 v\rho t$
- **The continuity equation is:** $A_1 v_1 = A_2 v_2$
- **The coefficient of viscosity of a liquid (η_{vs}) is determined from the relationship:** $\eta_{vs} = \frac{Fd}{Av}$

Where: (F) is the tangential force acting on the moving layer of the liquid, (A) is the area of the moving layer, (v) is the velocity of the moving layer and (d) is the distance between the stationary and moving layers

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Questions & Exercises

First: Define each of the following:

1- Density
2- Fluid
3- Viscosity
4- Viscosity Coefficient

Second: Essay Questions

1- Prove that the velocity of a liquid at any point in a pipe is inversely proportional to the cross-sectional area of the pipe at that point.

2- Explain the phenomenon of viscosity.

3- Explain some applications of viscosity.

Third: Exercises

1- Water flows through a horizontal pipe at a constant rate of 0.002 m^3/s. Calculate the velocity of water through the pipe if its cross-sectional area is 1 cm^2 (20 m/s)

2- Water flows through a rubber pipe with a diameter of 1.2 cm with a velocity of 3 m/s Calculate the diameter of its open if the exit velocity is 27 m/s. (0.4 cm)

3- A main artery branches into 80 capillaries, each with a radius of 0.1 mm, while the radius of the main artery is 0.035 cm. and the blood velocity in the artery is 0.044 m/s, calculate the velocity of blood flow in each capillary. (0.0067 m/s)

4- The cross-sectional area of a pipe at point A is 10 cm^2, and at point B is 2 cm^2.
If the velocity of water at point A is 12 m/s. Calculate the velocity of water at point B. (60m/s)

5- The cross-sectional area of a water pipe entering the ground floor is 4×10^{-4} m^2, and the water velocity is 2 m/s. If the pipe narrows so that its cross-sectional area on the upper floor becomes 2×10^{-4} m^2, calculate the velocity of water flow on the upper floor. (4m/s)

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Chapter 5

Properties of Hydrostatics



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Expected Learning Outcomes

By the end of this chapter, you'll be able to:

1. Measure the pressure at a point inside a liquid.
2. Determine the relative density of oil using a practical method.
3. Measure the atmospheric pressure using a practical method.
4. Identify the units of atmospheric pressure.
5. Compare the simple barometer and the manometer.
6. Discuss some applications of pressure.
7. Solve some problems related to density and pressure.
8. Explain Pascal's principle and apply it to the hydraulic press.

Key Concepts

Pressure
Atmosheric Pressure
Pascal's Principle

Overview

After studying the motion of fluids and the nature of their flow, it is now time to study static fluids (Hydrostatics), focusing on the concept of pressure and how a liquid exerts pressure at every point within it. We will also explore applications of these concepts.

Pressure

Pressure at a point: is defined as the average force acting perpendicularly to unit area surrounding that point.

Therefore, if a force (F) acts perpendicularly to a surface of area (A), the affected pressure (P) on the surface is determined by the following relation:

$$P = \frac{F}{A} \qquad (1)$$

Since Force (F) is measured in Newtons (N) and Area (A) in (m^2), the measuring unit of pressure is Newtons per square meter (N/m^2).

Enrichment Information

Which exerts more pressure: an elephant's foot or a human's heel?

Since pressure is defined as force per unit area, the pressure exerted by a pointed human heel can actually be greater than the pressure exerted by an elephant's foot on the ground because the area of the pointed heel is extremely small. Figure (1) .

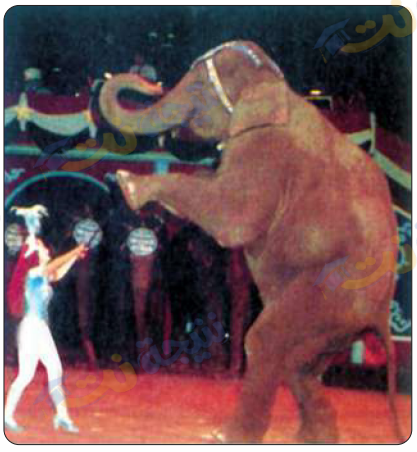


Figure (1)
Concept of Pressure

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Pressure at a Point Inside a Liquid and its Measurement

If you push a piece of cork beneath the surface of water and then release it, you'll find that the cork rises back to the surface. This demonstrates that the water exerts an upward force on the submerged cork. This force arises from the difference in water pressure acting on the piece of cork.

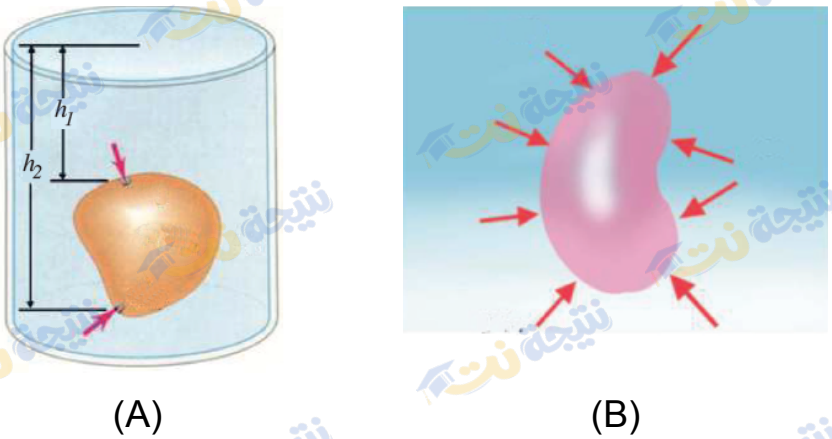


Figure (2)

(A) Pressure inside a liquid.

(B) The force arising from pressure inside a liquid is perpendicular to any surface.

At any point inside a liquid, pressure can act in any direction. The direction of the force due to pressure on a specific surface is always perpendicular to that surface. The pressure exerted on an object is the same as the pressure exerted on a volume of liquid if the object were not there. In other words, the liquid that originally occupied the space now taken by the object was subject to two forces: its weight acting downwards and the force due to the pressure difference of the surrounding liquid. And the deeper the liquid, the greater the pressure. Figure (3).

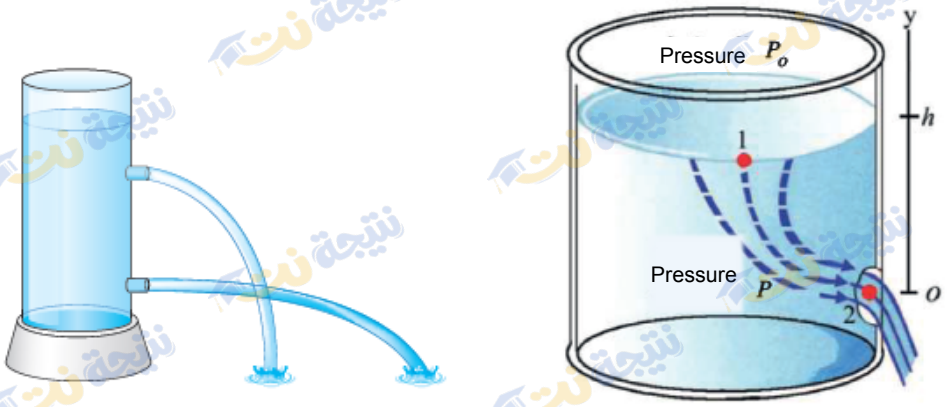


Figure (3)

Pressure increases with liquid depth

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To calculate the pressure (P), we assume a horizontal plate (X) of area (A) (m^2) at a depth h (m) beneath the surface of a liquid with density (ρ) (kg/m^3) as in Figure (4). This plate acts as the base of a column of liquid. The force exerted by the liquid colomn on the plate is equal to the weight of this liquid column whose height is (h) and cross-sectional area is (A). Since the liquid is incompressible, the force resulting from the liquid pressure equals the weight of the liquid column.

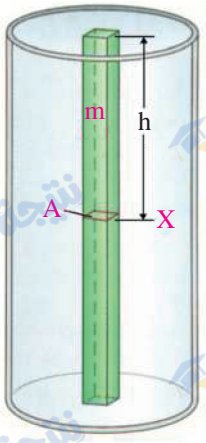


Figure (4)
Calculation of the pressure of a column of liquid

The volume of the liquid column is Ah, and the mass of the liquid column is Ahρ, Therefore, weight of the liquid (F_g) Newtons is determined by the relation:

$$F_g = Ah\rho g$$

where g (m/s^2) is the acceleration due to gravity,

The pressure of the liquid (P) on the plate (X) is determined by the relation:

$$P = \frac{F}{A} = \frac{Ah\rho g}{A}$$

$$\therefore P = h\rho g \ (N/m^2) \qquad (2)$$

And this is the value of the pressure exerted by the liquid alone at a point inside it at depth h.

If we take into consideration the free surface of the liquid is exposed to the atmospheric pressure (Pa), the total pressure at a point inside the liquid is determined via the following relation:

$$P = P_a + h\rho g \qquad (3)$$

Observations show that the liquid pressure (P) at a point beneath its surface increases as the depth (h) of that point increases beneath the surface of the same liquid Pressure also increases with increasing liquid density at the same depth.

Based on that relation, we conclude the following:

1. All points located on the same horizontal level inside a liquid have the same pressure.
2. The liquid that is in a container with multiple connected sections (connecting vessels) rises to the same level regardless of the geometric shapes, provided the base of the container is at a horizontal level Figure (5).

Thus, the sea level is the same for all interconnected seas.

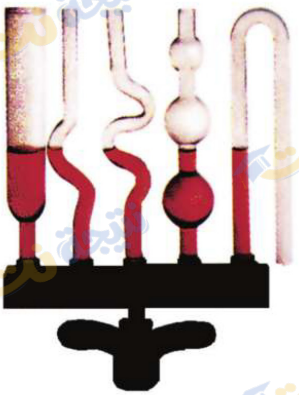


Figure (5)
Water rises to the same level in connecting vessels.

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3. Dams are designed so that their thickness increases at the base to withstand the increasing pressure with depth. Figure (6)

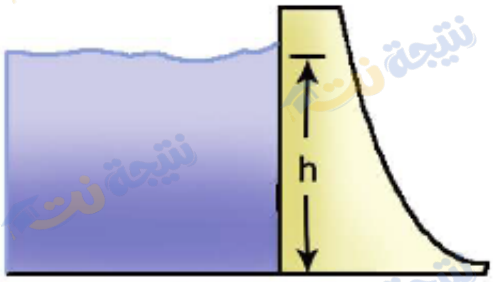


Figure (6)
The bases of dams are made thicker to bear the pressure at greater depths.

4. Divers wear diving suits and helmets to protect themselves from pressure at great depths. At shallow depths, they blow air into their sinuses to equalize the external pressure Figure (7). At great depths, the diving suit is inflated with air, and the helmet protects the diver's head from the intense pressure Figure (8).



Figure (7)
Diving at shallow depths near the surface



Figure (8)
Diving at greater depths (500 meters)

Balance of Immiscible Liquids in a U-shaped Tube

Let's take a U-shaped tube containing a suitable amount of water. We add a quantity of oil to one of the tube branches, let it be the left branch, until the oil surface reaches a certain level at C. Note that water and oil do not mix and there is a separating level between two, which is AD. Let the height of the oil above the separating surface AD between water and oil $\mathbf{h_o}$, and let the height of water in the right branch above the level AD be $\mathbf{h_w}$ Figure (9).

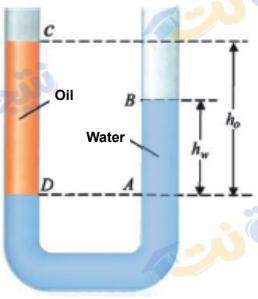


Figure (9)
Balance of Immiscible Liquids in a U-shaped Tube

Since that pressure at A equals pressure at D:

$$\therefore P_a + \rho_o g h_o = P_a + \rho_w g h_w$$

where, $\mathbf{P_a}$ is the atmospheric pressure, ρ_o is the oil density, and ρ_w is water density

$$h_o \rho_o = h_w \rho_w$$

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And the previous relation can be simplified as follows:

$$\frac{\rho_o}{\rho_w} = \frac{h_w}{h_o} \quad (4)$$

By measuring h_o ، h_w, the relative density of oil can be determined practically.
And by knowing the density of water, the density of oil can be determined.

Atmospheric Pressure

To measure the Atmospheric Pressure, Torricelli invented the mercury barometer. He took a glass tube about a meter long and filled it completely with mercury, then turned it upside down into a basin containing mercury.
He observed that the mercury surface in the tube dropped to a specific level, where its vertical height was approximately 0.76 m.
It is obvious that the space above the mercury surface in the tube is vacuum (except for a small amount of mercury vapor, whose pressure can be neglected). This space is called Torricelli vacuum.
It is clear from Figure (10) that the vertical height (h) of the mercury column inside the tube above the mercury surface level in the basin remains constant, whether the tube is in a vertical position or in a inclined position.

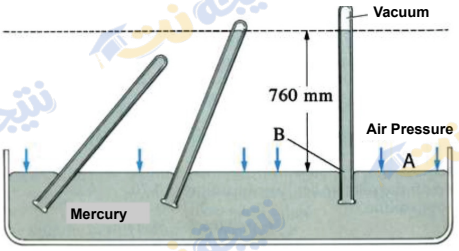


Figure (10)
Mercury height in the barometer tube is not affected by the tube inclination

And if we take the two points A and B in one horizontal level (Figure 11), such that point A is outside the tube at the mercury surface in the tank and point B is inside it, then:
Pressure at B = Pressure at A, and thus:

$$P_a = \rho g h \quad (5)$$

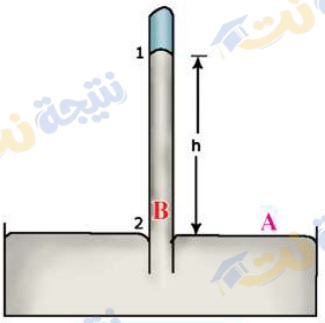


Figure (11)
The simple barometer

This means, Atmospheric Pressure is equivalent to the pressure arising from the weight of a column of mercury with a height of approximately 0.76 m and a cross-sectional area of one square meter at zero degrees Celsius (0°C).

Standered Atmospheric Pressure is the air pressure measured at sea level at zero Celsius degree , it equals 0.76 m Hg. defined as STP (Standard Temperature and Pressure) it is the pressure equal to 0.76 m Hg at 0 °C, and this term is frequently used when dealing with gas laws.

Given that the density of mercury at 0 °C is equal to 13595 kg/m^3 and the acceleration due to gravity is 9.8 m/s^2, the Standard Atmospheric Pressure is:

$$P_a = 1\text{atm} = 0.76 \times 13595 \times 9.8 = 1.013 \times 10^5 \text{ N/m}^2$$

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Enrichment Information

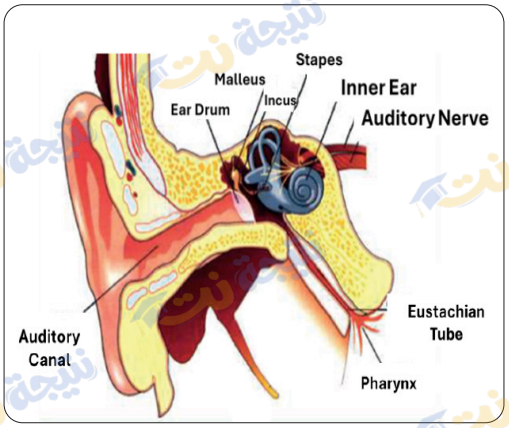


Figure (12) Model of the ear

What Happens to the Ear at Heights?
Atmospheric pressure is the weight of the air column above the Earth's surface acting on a unit area. As we going up above ground level, the height of this air column decreases, and therefore the pressure decreases.
On both sides of the eardrum, the external pressure balances with the internal pressure inside the body. So, when the external pressure drops, we feel tension in the eardrum, as the internal pressure pushes it slightly outward.
This pressure can be equalized by controlling the amount of air in the Eustachian tube, which can be done by swallowing or chewing gum, helping to relieve pressure on the eardrum Figure (12).)

Pressure at a Point Inside a Liquid and its Measurement

From the previous relationship, it is clear that the units used to measure atmospheric pressure in the International System are the same as the units for pressure, which are N/m^2.

The unit "Pascal" has been adopted to equal (N/m^2).

$$1 \text{ Pascal} = 1 \text{ N/m}^2$$

Therefore, standard atmospheric pressure becomes $P_a = 1.013 \times 10^5$ Pascal

A larger unit called "Bar" has also been adopted to equal: $1 \text{ Bar} = 10^5$ Pascal (10^5 N/m^2)

Therefore, standard atmospheric pressure becomes $P_a = 1.013$ Bar

In addition to measuring atmospheric pressure in millimeters of mercury, which is also called Torr:

$$1 \text{ Torr} = 1 \text{ mm Hg}$$

Therefore, standard atmospheric pressure becomes:

P_a (1atm) = 760 Torr = 760 mm Hg = 0.76 m Hg = 1.013 Bar

Development of Critical Thinking

Standard atmospheric pressure equals approximately 1.013×10^5 N/m^2, which is more than 10 tons per square meter.
Why don't we feel the effect of such enormous pressure on our bodies?

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Manometer

The manometer is a U-shaped tube with two branches containing an appropriate amount of liquid with known density. One of the branches is connected to the gas reservoir whose pressure is to be measured. As a result, the liquid surface in the manometer may rise in one branch and fall in the other.

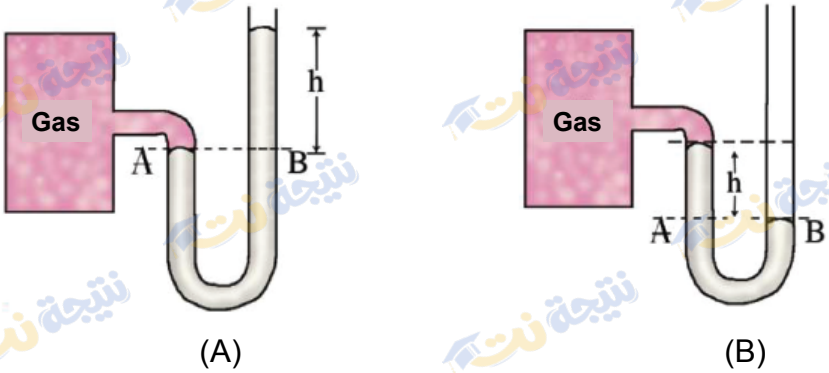


Figure (13)
The Manometer
(A) When gas pressure is greater than atmospheric pressure
(B) When gas pressure is less than atmospheric pressure

Taking two points A and B at the same horizontal level in the same fluid, as shown in Figure (13 A) so:

Pressure at B = Pressure at A

$$P = P_a + \rho gh$$

where P is the pressure of the trapped gas in the reservoir (greater than atmospheric pressure P_a and ρgh represents the pressure of the fluid in the open branch of the manometer above point B, which is the pressure difference between P and P_a.

In the case where the gas pressure P is less than atmospheric pressure as shown in Figure (13 B), then:

$$P = P_a - \rho gh$$

where the fluid surface in the open branch of the manometer is lower than the fluid surface in the branch connected to the reservoir.

In many scientific applications, it is not necessary to measure the gas pressure in the reservoir itself, but rather it is useful to measure pressure difference only as following:

$$\Delta P = P - P_a = \rho gh \quad (6)$$

Based on that relationship, by knowing the density of the manometer fluid (ρ), the difference in height (h) between the fluid surfaces in its two brunches, and the

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acceleration due to gravity (g), we can calculate the difference in pressure (Δ P) and we can also determine the gas pressure by knowing the atmospheric pressure.

Applications of Pressure

1. Blood is a viscous fluid pumped through a complex network of arteries and veins by the muscular effect of the heart. Blood flow through the body is usually steady flow.
   If the blood flow rate is turbulent flow, it's accompanied by a noise, indicating illness. This noise is easily detected by a stethoscope placed on the artery during blood pressure measurement. There are usually two values for blood pressure:
   Systolic Pressure : This is the maximum pressure in the artery, occurring when the heart muscle contracts and blood is pushed from the left ventricle into the aorta, and then into the arteries.
   Diastolic Pressure: This is the minimum pressure in the artery, occurring when the heart muscle relaxes.. For a healthy person, the Systolic Pressure is 120 Torr, and the Diastolic Pressure is 80 Torr.
2. Car Tire Pressure: When a car tire is filled with air under high pressure, the contact area with the road is as small as possible. If the tire is filled under low pressure, the contact area between the tire and the road increases, leading to greater friction and heat buildup in the tire.

Air pressure in the tire can be measured using a tire pressure gauge. Figure (14).

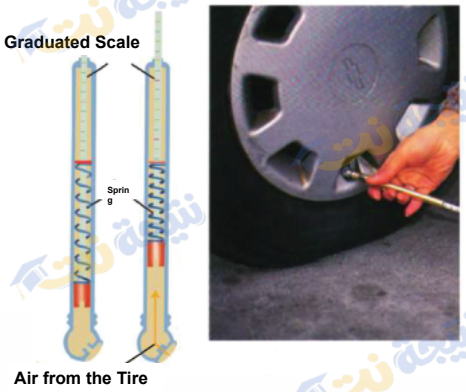


Figure (14)

Measuring air pressure in a car tire

Development of Critical Thinking

Fluid Pressure and the Scope of Medicine and Public Health:

1. When measuring blood pressure, why is the air cuff of the Blood Pressure Device placed around the upper arm in a relaxed position at the heart level?
2. Why does sitting for long periods increase the risk of leg blood clots? What advice can be given to prevent them?



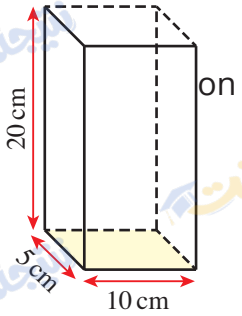
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Example 1

A solid rectangular parallelepiped with dimensions (5 cm × 10 cm × 20 cm) and material density 5000 kg/m³ is placed on a horizontal surface. Calculate the maximum and minimum pressure it exerts.
(Consider gravitational acceleration = 10 m/s²)

Answer

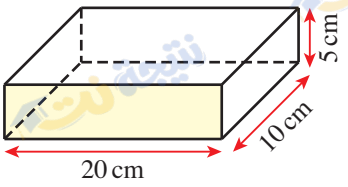
To calculate maximum pressure, the object is placed on the face with the smallest area, which is the face with dimensions (5 cm × 10 cm):



$$P = \frac{F}{A} = \frac{5 \times 10 \times 20 \times 10^{-6} \times 5000 \times 10}{5 \times 10 \times 10^{-4}}$$

$$= 10^4 \text{ N/m}^2$$

To calculate minimum pressure, the object is placed on the face with the largest area, which is the face with dimensions (10 cm × 20 cm):



$$P = \frac{F}{A} = \frac{5 \times 10 \times 20 \times 10^{-6} \times 5000 \times 10}{10 \times 20 \times 10^{-4}}$$

$$= 2500 \text{ N/m}^2$$

Example 2

Find the total pressure and the total pressing force acting on the bottom of a tank containing saltwater with density 1030 kg/m³, if the base area of the tank is 1000 cm² and the water height is one meter, and the water surface in the tank is exposed to atmospheric air, with acceleration due to gravity 10 m/s² and atmospheric pressure 1.013 × 10⁵ N/m².

Answer

Total pressure

$$P = P_a + \rho gh$$

$$= 1.013 \times 10^5 + 1030 \times 10 \times 1$$

$$= (1.013 + 0.103) \times 10^5 = 1.116 \times 10^5 \text{ N/m}^2$$

Total pressing force:

$$F = P \times A = 1.116 \times 10^5 \times 1000 \times 10^{-4}$$

$$= 1.116 \times 10^4 \text{ N}$$

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Example 3

A mercury manometer was used to measure the pressure of a gas inside a reservoir. The mercury level in the free end was 36 cm higher than the level in the side connected to the reservoir.
What is the value of the pressure of the enclosed gas in units of:
(A) cm. Hg. (B) atm. (C) N/m².

Answer

(A) In cm. Hg Unit:

$$P = P_a + h = 76 + 36 = 112 \text{ cm Hg}$$

(B) In atm Unit:

$$P = \frac{(P \text{ cm Hg})}{76} = \frac{112}{76} = 1.474 \text{ atm}$$

(C) In N/m² Unit

$$P = 1.474 \times 1.013 \times 10^5 = 1.493 \times 10^5 \text{ N/m}^2$$

Example 4

A U-shaped tube has a narrow branch cross-sectional area of 1 cm² and a wide branch cross-sectional area of 2 cm². It is partially filled with water (ρ water = 1000 kg/m³). A quantity of oil = (800 kg/m³) is poured into the narrow side until the height of the oil column reaches 5 cm. Calculate the height of the water surface above the separating surface between the water and the oil.

Answer

$$\because P = \rho_o g h_o = \rho_w g h_w$$

$$\therefore \rho_o h_o = \rho_w h_w$$

$$h_w = \frac{\rho_o h_o}{\rho_w} = \frac{800 \times 5}{1000} = 4 \text{ cm}$$

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Pascal's Principle

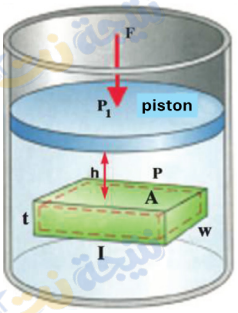


Figure (15)
Increasing weight on the piston increases pressure in the liquid

If we take a liquid in a glass container as shown in Figure (15), equipped with a piston on top, the pressure at a point A located inside the liquid at depth h is $P = P_1 + h\rho g$ Where P_1 is the pressure at the liquid surface (directly under the piston), and this pressure results from the atmospheric pressure and the pressure arising from the weight or the force of the piston.

If we increase the pressure on the piston by an amount ΔP by placing an additional weight on the piston, we observe that the piston does not move inward due to the liquid incompressibility. However, the pressure directly under the piston must increase by ΔP as well. The pressure at point A, which is at depth h under this surface, also increases by ΔP.

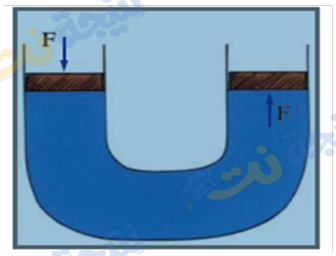
Then the pressure at this point becomes $P = P_1 + h\rho g + \Delta P$.

If the pressure increases to a certain limit, the container may break.

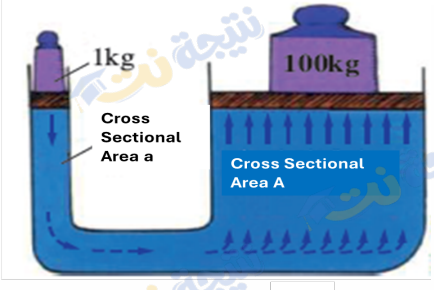
The French scientist Pascal formulated this result as follows:
"When pressure is applied on a liquid enclosed in a container, the pressure is transmitted in full to all parts of the liquid as well as to the walls of the container holding the liquid." This is known as **Pascal's Principle or Pascal's Law.**

Application of Pascal's Principle: The Hydraulic Press

There are several applications that depend on Pascal's Principle, including the hydraulic press and car brakes. The hydraulic press Figure (16), consists of: a small piston with cross-sectional area (a) and a large piston with cross-sectional area (A). The space between the two pistons is filled with a suitable liquid.



(A)



(B)

Figure (16)
The Hydraulic Press
(A) Force on the left side of the liquid is transmitted to the right side.
(B) A weight of 1 kg on the left side generates a force balanced by 100 kg on the right side if the area ratio a:A is 1:100.

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So, if the small piston is affected by pressure P, the liquid in turn is affected by the same pressure. This pressure P is transmitted completely through the liquid to the lower surface of the large piston.

And if we assume that the force acting on the small piston (f) and the force acting on the large piston (F) are as indicated, and given that the pressure acting on both pistons has the same value at equilibrium in one horizontal plane, then:

$$P = \frac{f}{a} = \frac{F}{A}$$

$$F = \frac{A}{a} f \qquad (7)$$

From the previous relation, it is clear that when a force (f) acts on the small piston, a larger force is generated on the large piston, which is the force (F). The Mechanical Advantage (η) for the hydraulic press is:

$$\eta = \frac{F}{f} = \frac{A}{a} \qquad (8)$$

Thus, the Mechanical Advantage (η) for the hydraulic press is determined by the ratio of the cross-sectional area of the large piston to the cross-sectional area of the small piston. Referring to Figure (17), it is clear that:

If the small piston moves down a vertical distance y_1 under the influence of force f, then the large piston moves up a vertical distance y_2 under the effect of force F.

Since the Work done on either of the two pistons equals The Force acting on it × its displacement, and according to the law of conservation of energy (assuming the piston is ideal and its efficiency is 100%), the Work done is the same in both cases:

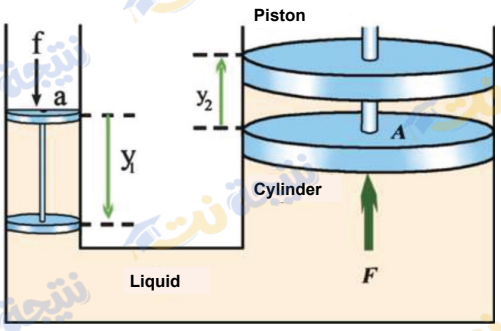


Figure (17)
Mechanical Advantage

$$f\, y_1 = F\, y_2$$

$$\frac{F}{f} = \frac{y_1}{y_2}$$

$$F = \frac{y_1}{y_2} f \qquad (9)$$

And this indicates that the Mechanical Advantage for the piston can also be expressed by the ratio $\frac{y_1}{y_2}$

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Enrichment Information

Applications of Pascal's Principle

1. Hydraulic Brake system utilizes Pascal's Principle.. The braking system uses a fluid known as Brake Fluid as an intermediary liquid. When the brake pedal is pressed with a small force over a relatively long distance, a large force is generated on the piston in the Master Brake Cylinder.

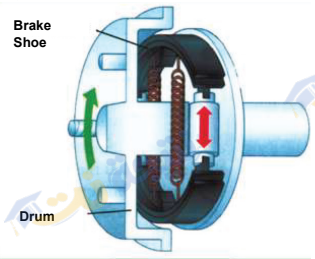


Figure (18)
Drum(Rear) Brakes

This pressure is then transmitted through the fluid to the rest of the braking line. The pressure moves the pistons of the Wheel Cylinders outward, which, in turn, pushes on the Brake Shoes. The brake shoes press against the Brake Drum, creating a large frictional force that stops the wheel and, consequently, the car.

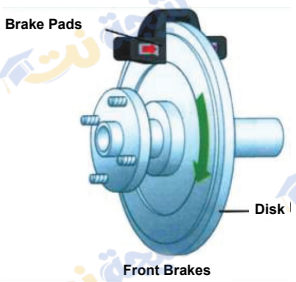


Figure (19)
Front Brakes

There are two types of Brakes: the Drum (Rear) Brake which is used for the rear brakes (Figure: 18), and the front brakes use a Disc Brake system (Figure: 19), where the forces generated during braking press Brake Pads against the disc to create the friction that stops the wheel. The distance the brake shoes or pads move in both cases is small because the transmitted force is large.

2. The Hydraulic Lift is another application of Pascal's Principle, the Hydraulic Lift uses a fluid to lift cars in gas stations (Figure: 20).

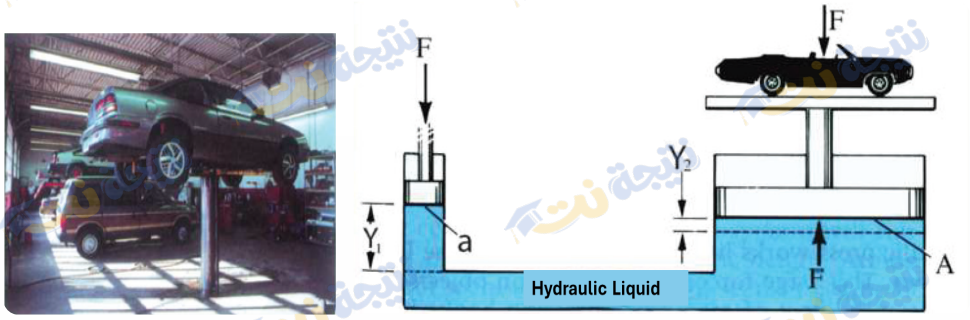


Figure (20)
The Hydraulic Lift

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3. Hydraulic Excavator (Caterpillar) relies on Pascal's Principle (Figure: 21).



Figure (21) Hydraulic Excavator

Example

A hydraulic press has a small piston cross-sectional area of 10 cm² which is acted on by a force of 100 N. The large piston cross-sectional area is 800 cm². Given that the acceleration due to gravity is 10 m/s², calculate:

(A) The largest mass that can be lifted by the large piston.

(B) The mechanical advantage (η) of the press.

(C) The distance the small piston travels for the large piston to move up by 1 cm.

Answer

The force acting on the large piston (F):

$$\frac{f}{a} = \frac{F}{A}$$

(A) The largest mass (m) that can be lifted by the large piston:

$$F = \frac{100}{10} \times 800 = 8 \times 10^3 \text{ N}$$

(B) Mechanical Advantage (η) of the piston:

$$\eta = \frac{F}{f} = \frac{A}{a} = \frac{800}{10} = 80$$

(C) The distance the small piston travels for the large piston to move 1 cm:

$$f.y_1 = F.y_2$$

$$y_1 = \frac{8000 \times 1}{100} = 80 \text{ cm}$$

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Summary

First: Definitions and Basic Concepts

- Pressure (P) at a point: The force acting perpendicularly on a unit area surrounding that point. Its unit is the Newton per square meter(N/m^2).
- All point lying on one horizontal level within a stationary fluid have the same pressure.
- Standard Atmospheric Pressure: The pressure resulting from the weight of the air column acting on a unit area at a specific point at sea level. It is equivalent to the pressure caused by a column of mercury about 0.76 m high, with a cross-sectional area of one square meter at 0°C.

  Its Units of measurement are : Pascal (N/m^2), Bar, mm Hg or Torr.
- Manometer: is a device used to measure the difference between the pressure of a confined gas and atmospheric pressure.
- Pascal's Principle: When pressure is applied to a confined fluid, the pressure is transmitted equally throughout the fluid and to the walls of the container holding the fluid.

Second: Important Laws and Relationships

- Pressure (P): $P = \frac{F}{A}$
- Pressure at a point within a fluid of density ρ exposed to air at a depth h from its surface:

$$P = P_a + \rho g h$$

Where P_a is the atmospheric pressure, and g is the acceleration due to gravity

- Equilibrium of immiscible liquids a U-Shaped tube: $\rho_1 h_1 = \rho_2 h_2$
- The Hydraulic Press: $\frac{f}{a} = \frac{F}{A}$
- Where f is the force acting on the small piston of cross-sectional area a, and F is the force acting on the large piston of cross-sectional area A.
- Mechanical Advantage (η) of the piston: $\eta = \frac{F}{f} = \frac{A}{a}$
- To determine the displacement of the large piston (y_2) in terms of the displacement of the small piston (y_1) :

$$y_2 = \frac{f\, y_1}{F}$$

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Exercises

First: Choose the correct answer:

1. The factor that does not affect the pressure at the bottom of a container filled with liquid is .....
   (a) height of the liquid in the vessel. (b) density of the liquid.
   (c) area of the vessel's base. (d) atmospheric pressure.

2. Which of the following factors has no effect on the height of the mercury column in a barometer?
   (a) The density of mercury. (b) The cross-sectional area of the tube.
   (c) The atmospheric pressure. (d) The temperature of mercury.

3. The water pressure at the bottom of the High Dam lake, which affects the dam structure, depends on .....
   (a) surface area of water in the lake (b) length of the dam structure.
   (c) depth of the water. (d) thickness of the dam wall.

4. If the ratio between the radii of the two cylindrical pistons in a hydraulic press is $\frac{2}{9}$, then the ratio between the forces on the two pistons equals:
   (a) $\frac{2}{9}$ (b) $\frac{9}{2}$ (c) $\frac{81}{4}$ (d) $\frac{4}{81}$

Second: Define Each of the Following

1. Pressure at a point
2. Pascal's Principle

Third: Essay Questions

1. Prove that the pressure P at any point within a liquid at depth h is determined by the relation: $P = P_a + \rho gh$

Where P_a is atmospheric pressure, ρ is liquid density, g is gravitational acceleration.

2. Describe the manometer and explain how it works in measuring gas pressure in a reservoir.
3. What factors determine the type of fluid used in a manometer for measuring the pressure difference between the pressure of a gas in a reservoir and atmospheric pressure?
4. What is meant by Pascal's principle? Explain one of its applications.

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Fourth: Problems

1. If the pressure on the base of a cylindrical container with oil is 1.5×10^4 N/m², calculate the total force acting on the base of the container if the base diameter is 8 m. (7.54×10^5 N)

2, A car tire requires a pressure difference of 3.039×10^5 N/m². If the atmospheric pressure is 1.013×10^5 N/m², find the required pressure inside the car tire in atm units. (4 atm)

3. A fish tank with a base area of 1000 cm² contains water weighing 4000 N. Calculate the water pressure at the base of the tank. (4×10^4 N/m²)

4. In a hydraulic press, the small and large pistons have diameters of 2 cm and 24 cm respectively. A force of 2000 N was generated on the large piston. Calculate the force acting on the small piston, as well as the mechanical advantage of the press. (13.9 N, 144)

5. If the atmospheric pressure at the water surface in a lake is 1 atm, what is the depth of the lake if the pressure at its bottom is 3 atm?
(Given: water density = 1000 kg/m³ and gravitational acceleration = 9.8 m/s²).
(20.673 m)

6. A man carries a mercury barometer whose reading at the ground floor of a building is 76 cm Hg, and at the upper floor is 74.15 cm Hg. If the building height is 200 m, calculate the average air density between these two floors, given that mercury density = 13600 kg/m³ and gravitational acceleration = 9.8 m/s².
(1.258 kg/m³)

7. A manometer containing mercury is connected to a reservoir with confined gas. If the mercury surface in the open branch is higher than the mercury surface in the branch connected to the reservoir by 25 cm, calculate the pressure difference as well as the absolute pressure of the confined air in N/m² units.
(Given: atmospheric pressure equals 1.013×10^5 N/m² and gravitational acceleration = 9.8 m/s² and mercury density = 13600 kg/m³)
(0.3332×10^5 N/m², 1.3462×10^5 N/m²)

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Unit

Four

Heat

Chapter 6: Gas Laws



Chapter

Six

Gas Laws



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Expected Learning Outcomes

By the end of this chapter, you will be able to:

1- Identify and explain the meaning of Brownian motion.
2- Explain the relationship between the volume and pressure of a gas at constant temperature (Boyle's Law).
3- Demonstrate the effect of heat on gas volume at constant pressure.
4- Prove the relationship between the volume and temperature of a gas at constant pressure (Charles's Law).
5- Explain the effect of heat on gas pressure at constant volume.
6- Prove the relationship between the pressure and temperature of a gas at constant volume (Pressure Law).
7- Deduce absolute zero from Charles's Law.
8- Deduce absolute zero from Joule's experiment.
9- Derive the Ideal Gas Law and solve problems related to it.

Key Concepts

Brownian Motion
Boyle's Law
Charles's Law
Gay - Lussac's Law
Absolute Zero
General Gas Law

Introduction

The molecules of any substance are in continuous motion, and the type of motion differs depending on the state of matter, as shown in Figure (1).

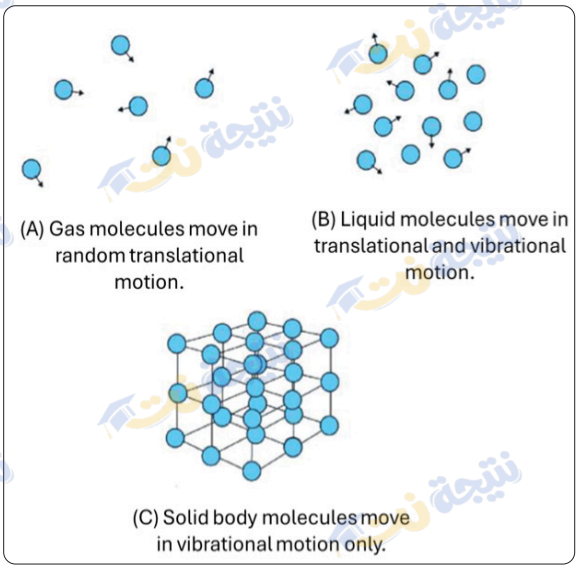


Figure (1)
The molecules in the three states of matter.

Brownian Motion

It can be understood that gas molecules are in a state of continuous random motion by studying Brownian motion, as follows:
If we examine smoke rising from a candle through a microscope, we would find that the carbon particles that make up the smoke move here and there in random motions. This motion of carbon particles is known as Brownian motion, as Brown, a Scottish botanist, was the first to discover in 1827 that pollen grains suspended in water are always in random motion.

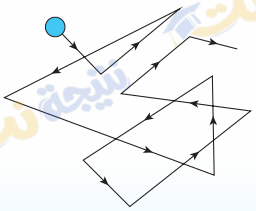


Figure (2)
Brownian Motion

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Explanation of Brownian Motion

Air (or any gas) molecules move randomly in all directions at different velocities. manner. During this movement, they collide with each other and also with the carbon particles that make up smoke. When the number of collisions at one side of a carbon particle at a certain moment is greater than the number of collisions at the opposite side, the carbon particle will move in a specific direction for a short distance. The reason for this is that gas molecules, unlike solid materials, are free to move and are constantly colliding, so they randomly change their direction due to heat. Figure (2).

From this, we can conclude the following:

Gas molecules are in a state of continuous random motion, and during their movement, they collide with each other and also with the walls of the container that holds them.

The existence of spaces between gas molecules, known as intermolecular spaces, can be understood as follows:

If we take a beaker filled with ammonia gas (NH_3) and invert it over another beaker filled with hydrogen chloride gas (HCl), we will observe the formation of a white cloud of ammonium chloride (NH_4Cl) which will grow and spread until it fills the entire space of both beakers.

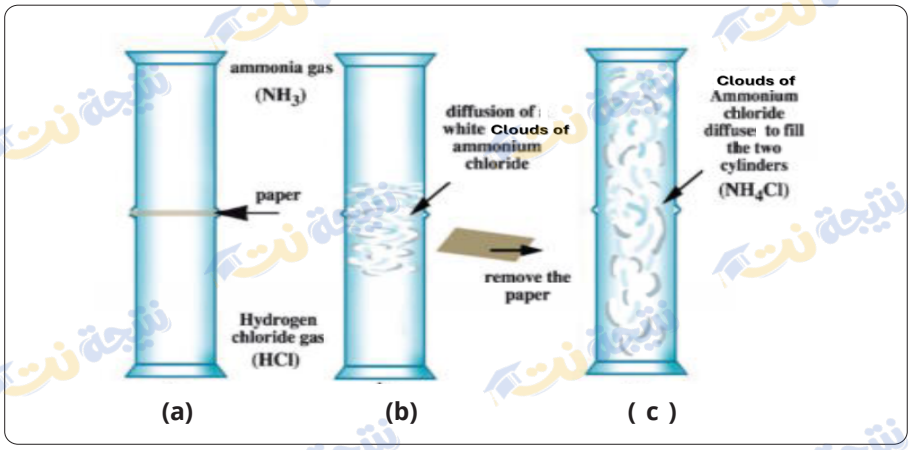


Figure (3)

Clarification of the existence of intermolecular spaces between gas molecules.

What happened is explained by the fact that hydrogen chloride gas molecules, despite being denser, diffuse upward, penetrating the spaces between ammonia gas molecules. There they combine with ammonia molecules to form ammonium chloride, whose molecules diffuse to fill the upper beaker. Similarly, ammonia molecules, despite being less dense, diffuse downward through the spaces between hydrogen chloride gas molecules. There they combine with hydrogen chloride molecules to form ammonium chloride, whose molecules diffuse to fill the lower beaker.

From the above, we conclude that gas molecules have relatively large spaces between them known as intermolecular spaces. This explains the compressibility of gases, as the relatively large intermolecular spaces allow gas molecules to get closer when subjected to pressure, which reduces the volume the gas occupies.

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Gas Laws

It has become certain that experiments to measure the thermal expansion of a gas are complex because the volume of a gas can change with changes in pressure, temperature, or both. This difficulty does not appear in the case of solids or liquids, as their compressibility is very small and can be neglected.

To conduct a complete study on the behavior of a gas, we must consider three variables: volume, pressure, and temperature. Therefore, there are three separate experiments, each used to study the relationship between only two variables while keeping the third variable constant. These experiments are:

- The relationship between the gas volume and its pressure at constant temperature (Boyle's Law).
- The relationship between the gas volume and its temperature at constant pressure (Charles's Law).
- The relationship between the gas pressure and its temperature at constant volume (Pressure Law or Gay-Lussac's Law).

We will discuss the study of each of the three relationships below.

First The Relationship Between the Gas Volume and Its Pressure at Constant Temperature (Boyle's Law)

To study the relationship between the volume and pressure of a specific amount of gas at constant temperature, the device shown in Figure (4) is used. It consists of a glass tube resembling an inverted burette whose scale starts from the top. Tube (A) is connected to another glass tube (B) through a rubber tube. Both tubes contain a suitable amount of mercury. The two tubes are held by a vertical stand fixed on a horizontal base that rests on three adjustable screws, which can be used to make the stand perfectly vertical. Tube (B) is movable along the vertical stand, up or down, and can be fixed in any position.

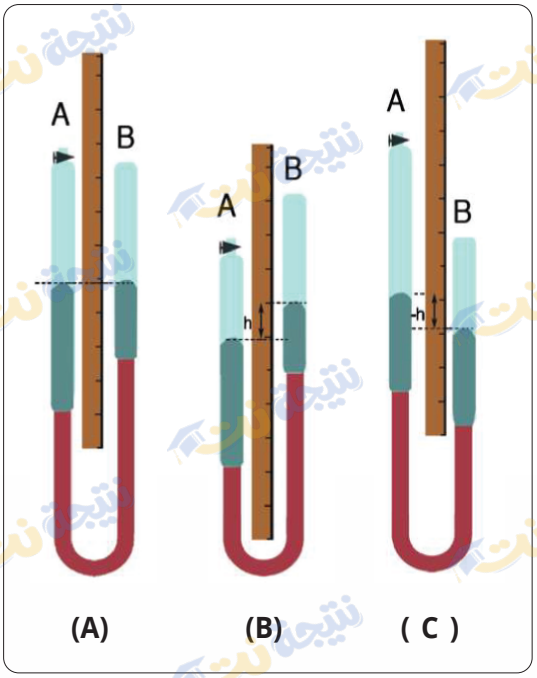


Figure (4)
Boyle's Apparatus

The following steps are followed:

1. Open the tap of tube (A) while moving tube (B) up or down until the mercury level in tube (A) is at its midpoint, as shown in Figure (4a). Since both tubes are open, the mercury levels in them will be at the same horizontal level.

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(2) We close the tap on tube (A) and measure the volume of the trapped air, let it be $(V_{01})_1$, and its pressure, let it be (P_1), which equals the atmospheric pressure (P_a cm Hg) that we determine with a barometer.

(3) We move tube (B) upward a suitable distance (several centimeters), then we measure the volume of the trapped air, let it be $(V_{01})_2$, and measure the height difference between the two mercury surfaces in the two tubes, let it be (h). Then the pressure of the trapped air will be $P_2 = P_a + h$ (Figure 4b).

(4) Repeat the previous step at least once more by moving tube (B) to another suitable upward distance and determine (P_3) and $(V_{01})_3$ in the same way.

(5) We move tube (B) downward until the mercury level in tube (B) is several centimeters lower than the mercury level in tube (A). Then we measure the volume of the trapped air, let it be $(V_{01})_4$, and its pressure (P_4) is $P_4 = P_a - h$, where (h) is the height difference between the two mercury surfaces (Figure 4c).

(6) We repeat the previous step at least once more by moving tube (B) to another downward distance and find (P_5) and $(V_{01})_5$ in the same way.

(7) We plot a graph with the gas volume (V_{01}) on the vertical axis and the inverse of the pressure $\frac{1}{P}$ on the horizontal axis. We get a straight line as in Figure (5). From this graph, we find that:

$$V_{o1} \propto \frac{1}{P}$$

From this relationship, we conclude that:
The volume of a specific quantity of gas is inversely proportional to its pressure at a constant temperature. This is the statement of Boyle's Law.

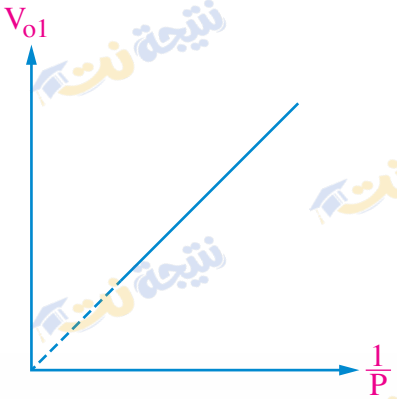


Figure (5)
The Relationship Between Gas Volume and the Inverse of Pressure at Constant Temperature

Boyle's Law can be formulated in another way where :

$$V_{01} = \frac{\text{const}}{P}$$

meaning :

$$PV_{01} = \text{const} \qquad (1)$$

At constant temperature, the product (PV_{01}) for a specific quantity of gas is a constant.

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Second : The Effect of Heat on the Volume of a Gas at Constant Pressure

We know that gases expand when heated and contract when cooled.

But do equal volumes of different gases, under constant pressure, expand by different amounts, or by equal amounts?

To understand this, we perform the following experiment:



Figure (6)
Effect of Heat on the Volume of a Gas at Constant Pressure

(1) Take two flasks of exactly equal volume, and the mouth of each is sealed with a stopper through which a glass tube bent at a right angle passes. This tube contains a thread of mercury, 2 cm or 3 cm long. Let one flask be filled with oxygen and the other with air or carbon dioxide, then submerge them in a basin of water, as in Figure (6).

(2) Add a little hot water to the basin and observe the distance the mercury thread moves in each of the flasks. We observe that the two mercury threads move equal distances, which indicates that equal volumes of different gases expand by equal amounts if their temperature increases by the same amount while their pressure remains constant. Therefore, we expect that their volume expansion coefficient will be the same.

Coefficient of Expansion for a Gas at Constant Pressure: It is the amount of increase in a unit volume of gas at 0°C if its temperature increases by one degree Celsius while its pressure remains constant. It is symbolized as (α_V).

The Relationship Between the Gas Volume and Its Temperature at Constant Pressure (Charles's Law)

To study the relationship between the gas volume and its temperature at constant pressure, Charles's apparatus, shown in Figure (7), is used. It consists of a glass tube about 30 cm long and 1 mm in diameter, which is closed at one end and contains a drop of mercury trapping a certain amount of air inside the tube. The tube is fixed along with a thermometer to a graduated ruler inside a cylindrical glass vessel.

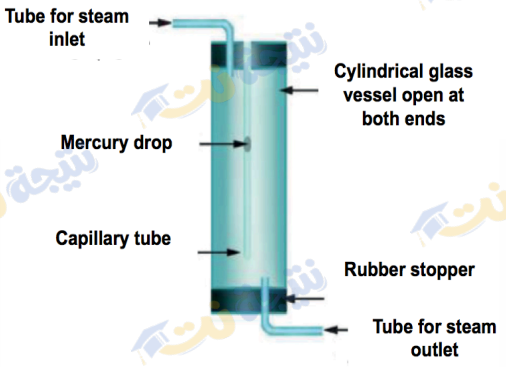


Figure (7)
Charles's Apparatus

The following steps are followed:

(1) The apparatus is placed inside a glass jacket, and the jacket is filled with crushed ice that is beginning to melt. It is left for a suitable period until the air inside the tube cools to 0 °C.

(2) The length of the trapped air column is measured, which is used as a measure of its volume $(V_{01})_{0°C}$, since the tube has a uniform cross-section.

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3 The jacket is emptied of ice and water, then steam is passed through the jacket from top to bottom. After waiting a suitable period until the temperature of the trapped air becomes 100°C, the length of the trapped air column is measured, which is used as a measure of its volume, let it be $(V_{01})_{100°C}$.

4 A relationship is plotted between the volume (V_{ol}) and the temperature (t) (Figure 8). We find that this relationship is a straight line, and if we extend this line, it intersects the horizontal axis at a value of (–273°C)

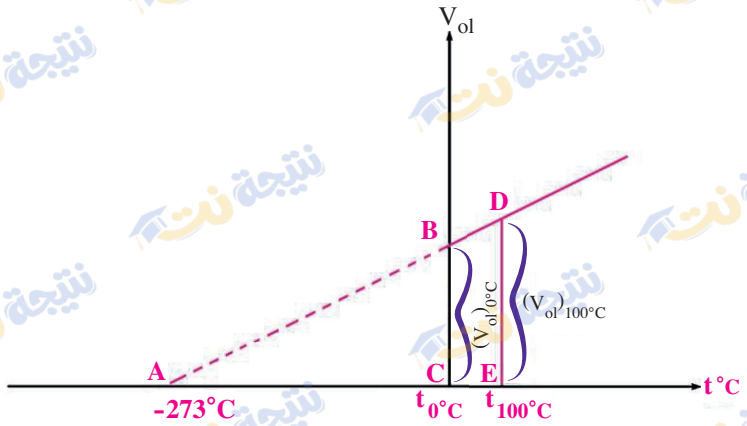


Figure (8)
Charles's Law

The Relationship Between Volume and Temperature at Constant Pressure

5 The volume expansion coefficient of air at constant pressure is determined by the relation:

$$\alpha_V = \frac{(V_{o1})_{100°C} - (V_{o1})_{0°C}}{(V_{o1})_{0°C} \times 100°C} \quad (2)$$

- It was found experimentally that the volume expansion coefficient of air at constant pressure is equal to $\frac{1}{273}$ per degree Celsius. And since equal volumes of different gases expand by equal amounts under constant pressure, the volume expansion coefficient for different gases has the same value. This result was formulated by Charles as follows:

Charles's Law:

The volume of a quantity of gas at constant pressure increases by $\frac{1}{273}$ of its original volume at 0°C for every one-degree Celsius increase in temperature. This value does not differ from one gas to another.

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Third : Effect of Heat on the Pressure of a Gas at a Constant Volume

(1) To study the effect of heat on the pressure of a gas at a constant volume, we take a glass flask sealed with a stopper through which a U-shaped tube (A), (B) passes, as shown in Figure (9). We observe that the tube contains a suitable amount of mercury, whose surfaces in the two arms (A), (B) rest at the same horizontal level at (x), (y). Therefore, the pressure of the trapped air in the flask is equal to the atmospheric pressure. Then, we determine the temperature of the air, let it be t_1 °C (Figure 9a)

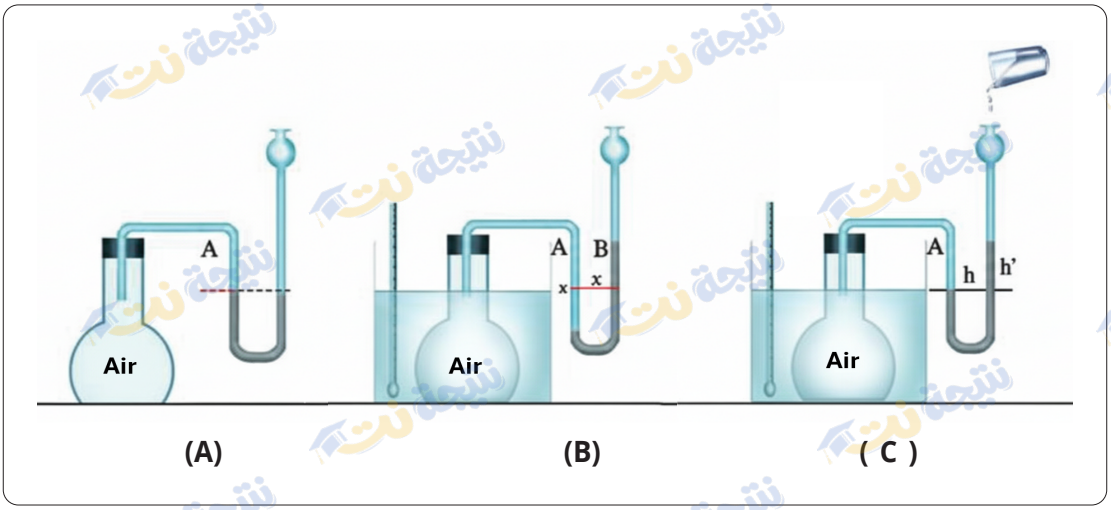


Figure (9)
Effect of Heat on Pressure at a Constant Volume

(2) We immerse the flask in a basin of warm water with a temperature of t_2 °C. Note that the mercury level begins to drop in arm (A) while rising in arm (B), as in Figure (9b).

(3) We pour mercury into the funnel until the mercury level in arm (A) returns to the mark (x) so that the volume of the trapped air in the flask at t_2 °C becomes equal to its volume at t_1 °C.

(4) We observe that the mercury level in arm (B) is higher than the level in arm (A) by a certain amount, let it be h (cm), which indicates that the pressure of the trapped air has increased due to the temperature rising from t_1 °C to t_2 °C by an amount equal to h (cmHg), as in Figure (9c).

(5) If we repeat the previous experiment several times, each time filling the flask with a different gas and measuring the increase in gas pressure with a constant volume as the temperature rises by the same amount, we will find the following:

(a) When the volume of a gas is constant, its pressure increases as the temperature rises.

(b) When the volume is constant, equal pressures of different gases increase by the same amount if their temperatures increase by equal amounts.

Coefficient of Pressure Increase: It is the amount of increase in a unit pressure measured at 0°C if its temperature is increased by one degree Celsius at a constant volume.

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The Relationship Between the Gas Pressure and Its Temperature at Constant Volume (The Pressure Law)

It has been found experimentally that the increase in the pressure of a quantity of gas at constant volume is directly proportional to the original pressure ($P_{0°C}$) measured at 0°C and also to the amount of its temperature increase (Δt°C).

This is expressed as follows:

Where β_P is a constant quantity, which is the coefficient of pressure increase of the gas with its temperature at constant volume.

$$\Delta P \propto P_{0°C}\, \Delta t$$

$$\Delta P = \beta_P\, P_{0°C}\, \Delta t$$

$$\beta_P = \frac{\Delta P}{P_{0°C}\, \Delta t} \qquad (3)$$

To determine the coefficient of pressure increase of a gas at constant volume, Jolly's apparatus, shown in Figure (10), is used. It is composed of a spherical bulb (A) made of thin-walled glass, which is connected to a long capillary tube (B) bent at two right angles. This is fixed on a vertical board, which in turn is fixed to a horizontal base resting on three threaded screws. The end of the capillary tube (B) is connected by a rubber tube to a somewhat wide tube (C). The tube (C) is movable up or down on the vertical board.
A graduated ruler is also fixed to this board.

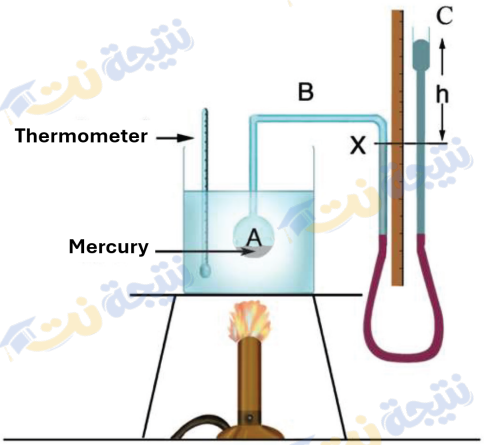


Figure (10) Jolly's apparatus

The following work steps are conducted:

(1) We determine the atmospheric pressure at the time of the experiment using a barometer.

(2) A volume of mercury is introduced into the bulb (A) ($\frac{1}{7}$ of its volume) so that the volume of the remaining part remains constant at all temperatures. This is because the volume expansion coefficient of mercury is seven times that of glass.

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(3) We immerse the bulb (A) in a beaker of water. We then pour mercury into the pure arm (C) until its surface in the other branch rises to a specific mark (X).

(4) We heat the water in the beaker until it boils and wait for a suitable period until the temperature stabilizes and the decrease of the mercury surface in the branch connected to the bulb stops.

(5) We move the pure arm (C) upward until the mercury level in the other arm rises to the same mark (X). From this, we determine the pressure of the trapped air, let it be P, which is equal to the atmospheric pressure (P_a) added to the height difference h (cm Hg). Then we measure the difference in height between the two mercury surfaces in the two arms, let it be h.

(6) We move the arm (C) downward, then stop the heating and allow the bulb to cool to about 90°C. We then move arm (C) upward until the mercury level in the branch connected to the bulb rises to the mark (X). Then we determine the temperature and the height difference between the two mercury surfaces in the two arms. From this, we calculate the pressure of the trapped air in this case.

(7) We repeat the previous work several times at different temperatures, and each time, we calculate the pressure of the trapped air in the same way as before.

(8) We plot a graph of temperature on the horizontal axis and pressure on the vertical axis. We find that the relationship is a straight line. Then, we calculate the coefficient of pressure increase for the gas at a constant volume from the relationship:

$$\beta_P = \frac{P_{100°C} - P_{0°C}}{P_{0°C} \times 100} \qquad (4)$$

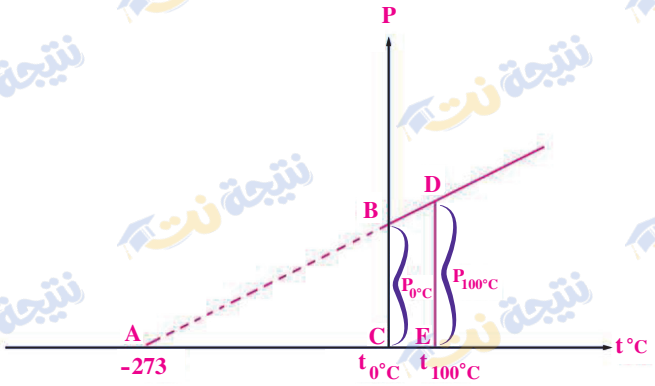


Figure (11)
The Pressure Law
The Relationship Between Pressure and Temperature at Constant Volume

It has been found experimentally that the coefficient of pressure increase of air at constant volume is equal to $\frac{1}{273}$ for every one-degree Celsius rise in temperature. It has also been found that the coefficient of pressure increase for different gases at constant volume has the same value.

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From the results of the previous experiment, we can reach the following:

At a constant volume, the pressure of a specific quantity of gas increases by an amount equal to $\frac{1}{273}$ of its pressure at zero degree Celsius for every one-degree Celsius increase in temperature. This is the Pressure Law.

Absolute Zero (Zero Kelvin)

From the graph in Figure (12) showing the relationship between volume on the vertical axis and temperature on Celsius scale on the horizontal axis, we obtain a straight line. When we extend this straight line, we find that it intersects the temperature axis at (–273°C)

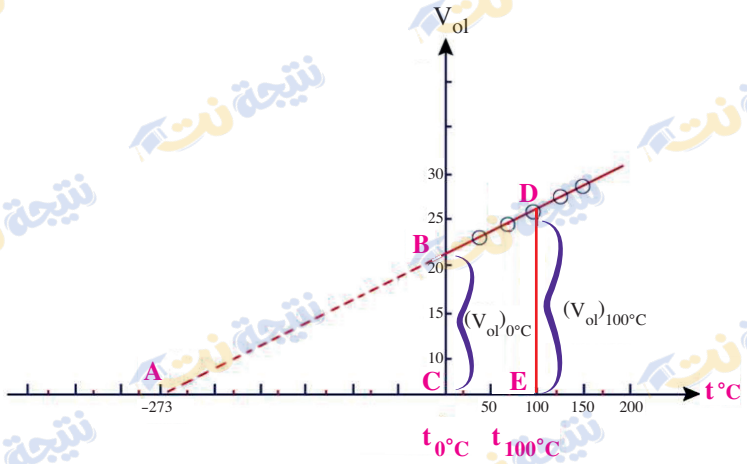


Figure (12)

Deducing Absolute Zero (0 Kelvin) from Charles's Law.

We can also use the results obtained from Jolly's apparatus experiment and represent these results graphically. Where pressure is represented on the vertical axis and temperature, measured on the Celsius scale, is represented on the horizontal axis, a straight line is obtained, as shown in Figure (13). When this straight line is extended, it is observed that it also intersects the temperature axis at (–273°C).

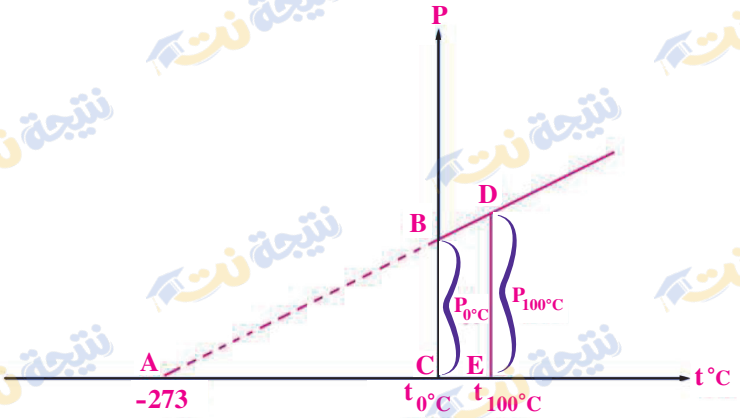


Figure (13)

Deducing Absolute Zero (0 Kelvin) from Jolly's experiment.

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From Figures (12) and (13), the lowest theoretically achievable temperature is −273°C. This temperature corresponds to what is called Absolute Zero or Zero Kelvin. It is the temperature at which the volume of an ideal gas becomes zero at constant pressure, or the pressure of an ideal gas becomes zero at constant volume. Temperature on Kelvin scale is always a positive value, while Celsius degrees (°C) vary between positive and negative.

Change in Gas Volume and Pressure with Change in Absolute Temperature

Figures (12) and (13) can be redrawn such that the horizontal axis is the absolute temperature. We then have Figure (14) and Figure (15). It is observed that at zero Kelvin, the volume (V_{ol}=0) and the pressure (P=0). However, in reality, with extreme cooling, matter does not remain in its gaseous state; rather, it transforms into a liquid and sometimes a solid, and therefore does not obey the gas laws. Thus, the definition of an ideal gas is the gas whose volume vanishes at constant pressure or whose pressure vanishes at constant volume at the absolute zero.

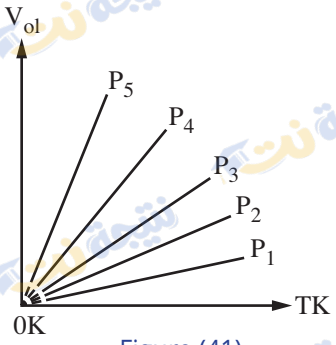


Figure (41)
Relationship between Volume and Absolute Temperature at Constant Pressure

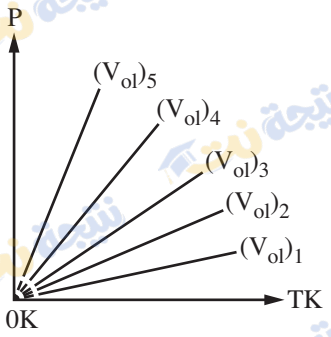


Figure (51)
Relationship between Pressure and Absolute Temperature at Constant Volume

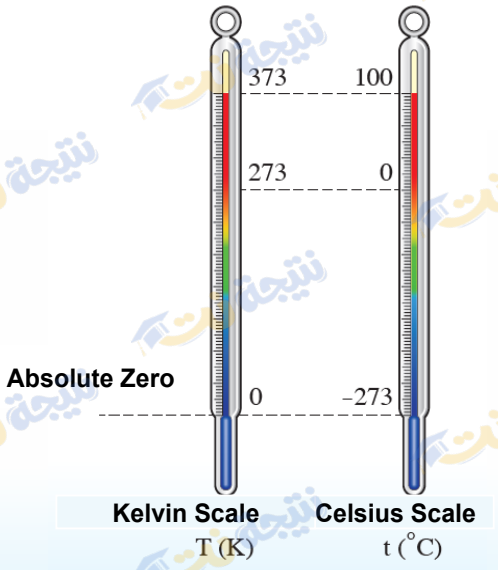
To find the relationship between the Celsius scale and the Kelvin scale, we take the following into consideration:

−273°C corresponds to 0K

0°C corresponds to 273K

100°C corresponds to 373K

So, $T(K) = 273 + t\ (°C)$ **(5)**



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Other Forms of Charles's and the Pressure Laws

(1) We can use Figure (8) to derive another form of Charles's Law, from the similarity of triangles ABC and ADE, where:

$$BC = (V_{0l})_1$$

$$DE = (V_{0l})_2$$

$$AC = T_1$$

$$AE = T_2$$

$$\therefore \frac{(V_{ol})_1}{T_1} = \frac{(V_{ol})_2}{T_2} \qquad (6)$$

So, $$\frac{V_{ol}}{T} = \text{const}$$

Therefore, $$V_{ol} \propto T$$

At constant pressure, the volume of a specific quantity of gas is directly proportional to its absolute temperature (on Kelvin scale). This is another form of Charles's Law.

(2) Using Figure (11) and the same method of similar triangles, you can obtain the relationship:

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad (7)$$

So, $$\frac{P}{T} = \text{const.}$$

And therefore $P \propto T$

At constant volume, the pressure of a specific quantity of gas is directly proportional to its absolute temperature (on Kelvin scale). This is another form of the Pressure Law.

General Gas Law

As previously mentioned, the behavior of a gas can be described by three variables: volume, pressure, and temperature. The relationship that connects these three variables is represented by the General Gas Law.

The General Gas Law for a specific quantity of gas can be deduced as follows:

From Boyle's Law: $V_{01} \propto \frac{1}{P}$ (at constant temperature)

From Charles's Law: $V_{01} \propto T$ (at constant pressure)

From this, we find that: $V_{01} \propto \frac{T}{P}$

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From this relationship $V_{ol} = const \times \frac{T}{P}$

Therefore $\frac{PV_{ol}}{T} = const \therefore$

For comparing these variables for a quantity of gas:

$$\frac{P_1(V_{ol})_1}{T_1} = \frac{P_2(V_{ol})_2}{T_2} \quad (8)$$

Enrichment Information

In general, the General Gas Law is:

$$PV_{ol} = nRT \quad (9)$$

Where: (n): number of moles of the gas quantity, (P): pressure of the gas quantity, (V_{01}): volume of the gas quantity, (T): temperature of the gas on Kelvin scale, and (R): the universal gas constant, equal to 8.31 J/(mol.K)

The mole: It is the amount of a substance that has a mass in grams equivalent to its molecular mass.

For example: The mass of one mole of oxygen (O_2) is 32 g., of nitrogen ($N_{2)}$ is 28 g. and of carbon dioxide (CO_2) is 44 g.

Developing critical thinking

A balloon filled with helium rises when it's released.
What happens to the volume of the balloon as it rises in the sky?
What is your explanation in light of your study of gas behavior?



Example 1

Assuming the volume of a certain amount of gas at 0°C is 450 cm³, what will its volume be at 91°C, given that its pressure remains constant?

Answer

$$\frac{(V_{ol})_1}{(V_{ol})_2} = \frac{T_1}{T_2}$$

$$\frac{450}{(V_{ol})_2} = \frac{273}{273 + 91}$$

$$(V_{ol})_2 = \frac{450 \times 364}{273} = 600 \text{ cm}^3$$

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Example 2

You heated half a liter of hydrogen from 10°C to 293°C. What is its new volume, assuming its pressure remains constant?

Answer

$$\frac{(V_{ol})_1}{(V_{ol})_2} = \frac{T_1}{T_2}$$

$$\frac{500}{(V_{ol})_2} = \frac{273 + 10}{273 + 293}$$

$$(V_{ol})_2 = \frac{500 \times 566}{283} = 1000 \text{ cm}^3 = 1 \text{ liter}$$

Example 3

A quantity of gas has a pressure of 26 cmHg at 59.8°C. What is its pressure at 130°C, knowing that its volume is constant?

Answer

$$\frac{P_1}{P_2} = \frac{T_1}{T_2}$$

$$\frac{59.8}{P_2} = \frac{273 + 26}{273 + 130}$$

$$P_2 = \frac{59.8 \times 403}{299} = 80.6 \text{ cm Hg}$$

Example 4

A quantity of gas occupies a volume of 380 cm³ at 30°C and under a pressure of 27 cmHg. What will its volume be at Standard Temperature and Pressure (STP)?

Answer

What is meant by (STP) is that the quantity of gas is under a pressure of 76 cmHg and at a temperature of 0°C or 273 K.

$$\frac{P_1 (V_{ol})_1}{T_1} = \frac{P_2 (V_{ol})_2}{T_2}$$

$$\frac{60 \times 380}{300} = \frac{76 \times (V_{ol})_2}{273}$$

$$(V_{ol})_2 = \frac{60 \times 380 \times 273}{76 \times 300} = 273 \text{ cm}^3$$

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Example 5

A quantity of nitrogen gas has a volume of 15 liters when the pressure on it is 12 cmHg. A quantity of oxygen gas has a volume of 10 liters when the pressure on it is 50 cmHg. Both were placed in a sealed container with a capacity of 5 liters. If the temperature of the two gases remained constant during mixing, find the pressure of their mixture.

Answer

Since the gases are mixed, each gas will now occupy the entire volume of the container, which is 5 liters. To find the pressure of the nitrogen gas after mixing, we apply the law:

$$PV_{ol} = P_1 (V_{ol})_1$$

$$\therefore 12 \times 15 = P_1 \times 5$$

$$P_1 = 36 \text{ cm Hg}$$

To find the pressure of the oxygen gas, we apply the relationship:

$$PV_{ol} = P_2 (V_{ol})_2$$

$$P_2 = \frac{10 \times 50}{5} = 100 \text{ cm Hg}$$

And since the pressure of a mixture of two gases is equal to the sum of their partial pressures, the pressure of the gas mixture is:

$$P = P_1 + P_2 = 36 + 100 = 136 \text{ cm Hg}$$

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Summary

First: Definitions and Basic Concepts

- Gas molecules are in a state of continuous random motion, colliding with each other as well as with the walls of the container that holds them.
- There are spaces between gas molecules known as intermolecular spaces.
- Boyle's Law: At constant temperature, the volume of a specific quantity of gas is inversely proportional to its pressure.
- Charles's Law: At constant pressure, the volume of a specific quantity of gas increases by an amount equal to $\frac{1}{273}$ of its original volume at 0°C for every one-degree Celsius rise in temperature.

Or, the volume of a fixed quantity of gas is directly proportional to its absolute temperature under constant pressure.

- The Pressure Law (Gay-Lussac's Law): At constant volume, the pressure of a specific quantity of gas increases by an amount equal to $\frac{1}{273}$ of its original pressure at 0°C for every one-degree Celsius rise in temperature.

Or, the pressure of a fixed quantity of gas is directly proportional to its absolute temperature at constant volume.

- The coefficient of pressure increase with temperature at constant volume = The coefficient of volume increase with temperature at constant pressure = $\frac{1}{273}$ per Kelvin, and it is a constant value for all gases.
- Absolute temperature (on Kelvin scale) is equal to the temperature on Celsius scale plus 273.

Second: Important Laws and Relationships

If the volume of a specific quantity of gas is V_{ol}, its pressure is P, and its temperature on the Kelvin scale is T, then:

- Boyle's Law: $(PV_{ol} = \text{const.})$ at constant temperature.
- Charles's Law: $(\frac{V_{ol}}{T} = \text{const.})$ at constant pressure.
- The Pressure Law: $(\frac{P}{T} = \text{const.})$ at constant volume.
- The General Gas Law: $\frac{P_1(V_{ol})_1}{T_1} = \frac{P_2(V_{ol})_2}{T_2}$

•Coefficient of volume increase with temperature at constant pressure:

$$\alpha_v = \frac{V_{t°C} - V_{0°C}}{V_{0°C} \times \Delta t°C} = \frac{1}{273} K^{-1}$$

- Coefficient of pressure increase with temperature at constant volume: $\beta_P = \frac{P_{t°C} - P_{0°C}}{P_{0°C} \times \Delta t°C} = \frac{1}{273} K^{-1}$

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Questions and Exercises

First: Complete

Which of the following phrases completes the sentences below?

(a) Increases by a small amount. (b) Decreases by a small amount.

(c) Remains constant. (d) Doubles.

(e) Decreases by half.

1. If the pressure of a specific quantity of gas doubles while the temperature is constant, its volume .....

2. If the pressure of a gas is constant and its temperature on Kelvin scale is halved, its volume .....

Second: Choose the Correct Answer

1. The following are some statements a student recorded about what happens when the temperature of a car tire filled with air increases:

(I) The pressure of the air inside the tire increases.

(II) The volume of the air inside the tire increases.

(III) The surface area of the part of the tire touching the road decreases.

Which of these statements agrees with what you have studied?

(a) All statements are correct. (b) Statements (I) and (II) are correct.

(c) Statements (I) and (III) are correct. (d) Only statement (III) is correct.

2. The temperature of the human body on Kelvin temperature scale is approximately .....

(a) 310 K (b) 37 K

(c) 100 K (d) 373 K

3. The volume of a specific quantity of gas is proportional to .....

(a) Inversely proportional to its temperature at constant pressure.

(b) Inversely proportional to its pressure at constant temperature.

(c) Directly proportional to its pressure at constant temperature.

(d) Directly proportional to its temperature when the pressure changes.

4. The pressure of a quantity of gas at 10°C will double if the gas is heated at a constant volume to .....

(a) 20°C (b) 80°C (c) 410°C (d) 293°C

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5. If a quantity of gas is slowly compressed to half of its original volume at constant temperature, then .....

(a) The mass of the gas will double.

(b) The density of the gas will decrease to half its value.

(c) The pressure of the gas will become half.

(d) The pressure of the gas will double.

Third: Essay Questions

1. How do you show experimentally that the coefficient of volume expansion for all gases is the same at constant pressure?
2. Describe a method to find the coefficient of pressure of a gas at constant volume and show that it is constant for all gases.
3. How can Boyle's Law be verified experimentally?
4. How do you show experimentally that the pressure of a quantity of gas increases with a rise in temperature at constant volume?
5. How can you determine the absolute zero (0 Kelvin)?
6. Explain the meaning of the absolute zero, and what is the relationship between temperature on Kelvin scale and temperature on Celsius scale?
7. Derive the General Gas Law.

Fourth: Exercises

1. A liter of gas at 10°C had its temperature raised while its pressure was constant. Find its volume at 293°C. (2 Liters)
2. A sealed container with air is at 0^{o}C, and cooled to (-91°C), its pressure became 40 cmHg. What is the pressure of the air at 0°C? (60 cmHg)
3. A quantity of oxygen occupies a volume of 760 cm^3 at 91°C and under a pressure of 84 cmHg. What will its volume be at 0°C temperature and 76 cmHg pressure (STP)? (630 cm^3)
4. A flask containing air is heated from 15°C to 87°C. What is the percentage of the air that escaped compared to the initial amount? (25%)
5. A car tire has air with a pressure of 1.5 atm on a day when the temperature is 3°C. Calculate the pressure of the air in the tire when the temperature rises to 51°C, assuming the volume remains constant. (1.8 atm)
6. An air bubble has a volume of 28 cm^3 at a depth of 10.13 m under the surface of fresh water. Calculate its volume just before it reaches the surface, assuming the water temperature at the mentioned depth is 7°C and at the surface is 27°C. The atmospheric pressure is 1.013×10^5 N/m^2 and the density of water is 1000 kg/m^3. (60 cm^3)

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