National Science and Mathematics Olympiad

First Stage- Science

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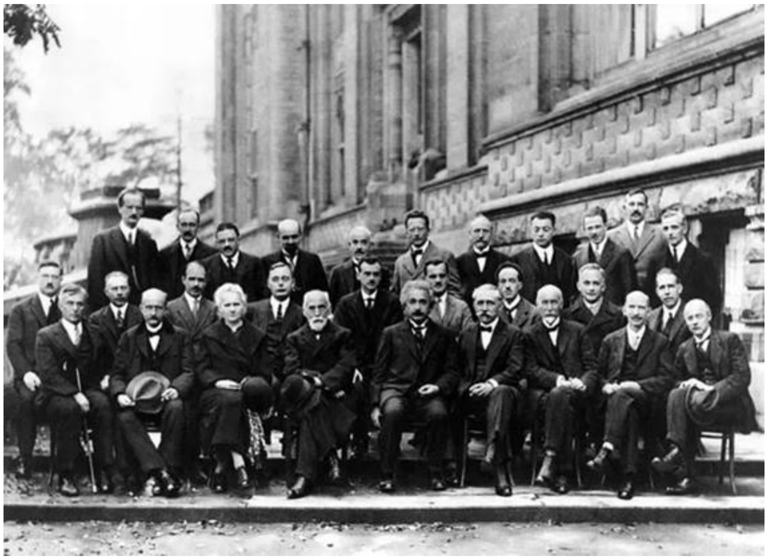
2 Physics and Its Nature

The ancient human tried early to understand and control the natural phenomena around him, such as the motion of objects and the ignition of fire, and he devised tools that help him move heavy objects and ways to ignite fire and benefit from it, and he made tools that help protect him from predators and in catching prey and in accomplishing his work and facilitate his life.

Simply put, what he did is physics in its broadest sense. In this chapter, you will learn about physics and its nature.

2.1 What is physics?

What comes to your mind when you hear the word "physics"? Perhaps you imagine a blackboard with many physical mathematical equations written on it, or you may remember pictures of famous physicists that you have heard a lot about, such as Isaac Newton or Albert Einstein, and you may think about the many technical applications developed by physics, such as the laptop computer and modern communication devices, artificial satellites and many others.



The smartest picture in history, taken at the Solvay Conference in 1927, gathered a large number of the most famous physicists, such as Einstein, Marie Curie, Dirac, Heisenberg, Pauli, Schrödinger, Bohr, Compton, and others.

In fact, what you imagined is correct to some extent and shows important aspects of physics, but physics in its broadest sense is: a branch of science concerned with the study of the natural world, matter and energy, and how they are related.

Think

What do we mean by matter, and what do we mean by energy? Give examples of them. Could you list some differences between them?

The word physics is derived from a Greek word " φύσις " (Physica), which means "nature". So, physics is one of the most important aspects of our lives. Whatever we do, there is physics. We apply the principles of physics in our everyday life activities.

2.2 Physics And Natural Phenomena

The connection of matter with energy appears in the natural phenomena around us, such as the motion of objects, lightning, thunderbolts, magnetic attraction of things, water waves, and many others. Physics is mainly aimed at:

1. Understanding and explaining these phenomena through the development of laws and theories. An example of this is what the scientist Isaac Newton did in developing equations and laws of motion, which helped us a lot in the mathematical calculation of the speed of an object after a certain period of time had passed, and in calculating the net force acting on it.

2. Utilising understanding of natural phenomena in making modern applications. Such as making cars, planes, spacecraft, lightning rods, and others.

3. Predicting natural phenomena and their future results. Example: predicting the times of eclipses, eclipses, earthquakes, the structure of the universe, and others.

Exercise: We mentioned earlier that physics studies the relationship between matter and energy. In his famous experiment, Newton studied the decomposition of the white light spectrum using a glass prism. What matter did Newton study, what energy, and how was the connection between them?

2.3 Physics And Other Sciences

For more than two thousand years, physics, chemistry, biology, and certain branches of mathematics were part of natural philosophy, but during the scientific revolution of the seventeenth century, these sciences became separated but closely linked. Physics is the basic science because it studies nature in general and provides the basis for all other sciences. It also manufactures measuring devices and invents technical applications that benefit these sciences. Be proud of your study of physics.

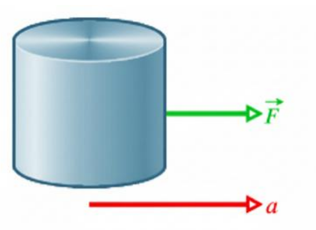
Quantum technology has become at the forefront of the most important and exciting fields that bring together sciences such as physics, biology, chemistry, engineering, and many other fields. This technology gave great hope for scientific revolutions in the near future, as it will change the direction of technology in many applications.

2.4 PHYSICS AND MATH

Physics is closely related to mathematics, and the relationship between them can be briefly described as follows: Mathematics is the language of physics in accurately expressing its description and interpretation of natural phenomena.

This Correlation appears in several forms, the most important of which are:

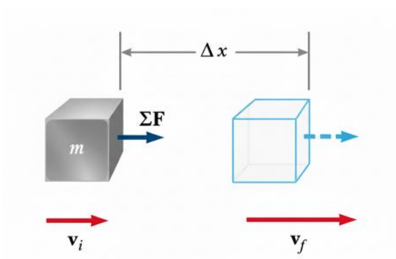
1. Physics uses mathematical equations to clarify the relationship between the physical quantities, or to calculate unknown quantities, for example:



A. $\sum \mathbf{F} = \mathrm{m}\mathbf{a}$ Newton's second law of motion

It states: the acceleration of an object is directly proportional to the net force acting on it and inversely proportional to its mass.

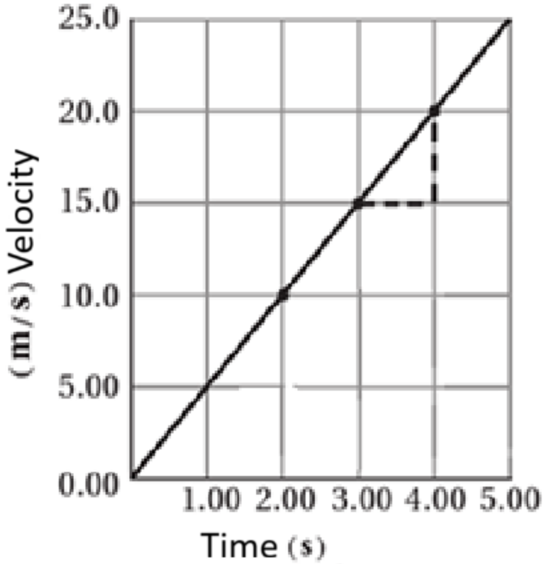
Note: acceleration means how much the velocity change in each second.



B. $\mathbf{v_f} = \mathbf{v_i} + \mathbf{a_x}\mathrm{t}$ Equation of motion in a straight line

It is an important equation that helps us to find the instantaneous velocity of an object $\boldsymbol{v_f}$ at a specific time t in terms of its initial velocity $\boldsymbol{v_i}$ and its acceleration $\boldsymbol{a_x}$.

2. Physics uses mathematical graphs a lot, in order to accurately describe some phenomena and situations, for example the corresponding graph determines how the velocity v of an object moving in a straight line changes with time t, and through the graph you can calculate the velocity of the object at each time moment shown in graph, and also conclude that the relationship between them is proportional (they increase together regularly).



2.5 Introduction to the Basics of Mathematics

One of the important skills in mathematics is solving arithmetic equations, which are used in most life applications and certainly in various sciences.

An equation is a mathematical expression in which the quantity on the left side of the equals sign (=) is the same as the quantity on the right side. One of the quantities in the equation may be unknown, usually represented by the symbol $\boldsymbol{x}$.

Let's simplify things with the following example:

$$x + 2 = 8$$

2.5.1 First-Degree Equations

Solving an equation means finding the value of the unknown variable x. To find its value, we must isolate it on one side. To keep the equation balanced, we must do the same operation on both sides. For example, if we add or subtract a value from one side, we must do the same to the other side.

Exercise:

Find the value of $\boldsymbol{x}$ in the following equations:

$$x + 2 = 8$$

$$2x + 2 = 10$$

$$2x + 2 = 10 - 2x$$

$$2x = -10$$

2.5.2 Second-Degree Equations

There is another type of equation called second-degree equations, which require a special method to solve them. The general method we will use is the discriminant (quadratic formula), whose rule is:

$$ax^2 + bx + c = 0$$

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Exercise:

Find the values of $\boldsymbol{x}$ in the following equations:

$$x^2 + 3x + 2 = 0$$

$$x^2 + 3x - 2 = 0$$

$$x^2 - 3x + 2 = 0$$

$$2x^2 - 7x - 5 = 0$$

$$3x^2 + 5x + 7 = 0$$

2.5.3 Systems of Equations

A system contains two equations, each with two unknowns, and it can be solved using one of the following methods:

- Substitution Method
- Elimination Method

Exercise:

Find the solution to the following systems of equations:

$$3x - 5y = 2 \quad ; \quad x + 2y = 3$$

$$2x - 7y = 1 \quad ; \quad 3x + 5y = -6$$

$$2x - 3y = 2 \quad ; \quad 6x - 9y = 7$$

$$3x - 5y = 7 \quad ; \quad 6x - 10y = 14$$

$$3x - 5y = 0 \quad ; \quad 6x + 10y = 14$$

2.6 Basic and Derivative Physics Quantities

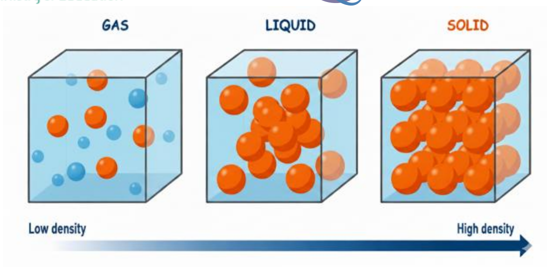
Physics studies the properties of matter, which we call "Physical Quantities".

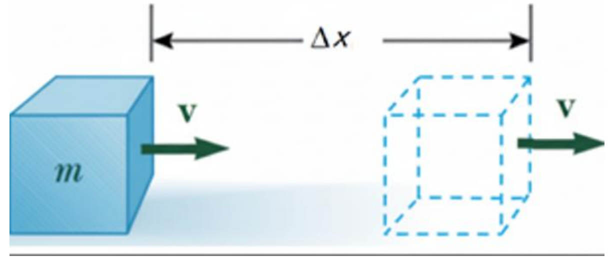
Physical quantities are of two types:

Derivative Quantities	Basic Quantities
They are the quantities defined by other basic quantities.	They are the quantities defined by themselves and are the basis for the derivation of other quantities.
Ex: velocity, density.	Ex: length (distance), mass, temperature

Exercise: Try to define velocity and density in terms of other basic quantities

Density	Velocity





2.7 Units In Physics

Suppose your friend asked you about the distance between your home and your grandfather's home, and you answered that it is 200. Is this answer sufficient to understand the distance between them accurately? Of course not, the distance could be 200 meters ($200\ m$), 200 kilometres ($200\ km$), or 200 miles ($200\ miles$). We call meters, kilometres, and miles units of measure, and they are necessary, as you noted, to accurately determine the distance. In fact, this is a fundamental difference between mathematics and physics. Mathematics deals with abstract numbers, while physics is concerned with writing the unit of the numerical value of any measurement.

It was agreed to establish an international system of measurement called "the International System of Units" with the aim of unifying units of measurement worldwide, and it was referred to by the symbol (SI). This system identified seven basic quantities in physics with the definition of their units of measurement, and these quantities are:

Basic Quantity		Basic Unit	
Name	Symbol	Name	Symbol
Length	ℓ	Meter	m
Mass	m	Kilogram	kg
Time	t	Second	s

Electric Current	I	Ampere	A
Temperature	T	Kelvin	K
Amount of Substance	n	Mole	mol
Luminous intensity	E	Candela	Cd

Note that symbols of physical quantities are written in italicised letters, and symbols of physical units are written in non-italicised letters.

Fun Fact

In A.D. 1120, the king of England decreed that the standard of length in his country would be named the yard and would be precisely equal to the distance from the tip of his nose to the end of his outstretched arm. Similarly, the original standard for the foot adopted by the French was the length of the royal foot of King Louis XIV. This standard prevailed until 1799, when the legal standard of length in France became the meter.

Non-fundamental physical quantities are derived quantities, and their units are composed of two or more basic physical units, such as velocity (ms^{-1}), acceleration (ms^{-2}), density ($\mathrm{kg} \cdot \mathrm{m}^{-3}$) and many others.

Some units of derived quantities are relatively long, and for their abbreviation they are named after the names of the scientists who contributed to their development, then the first letter of the scientist's name in the English language was taken in the capital letter to express that unit, for example, the unit of force measurement was named "Newton" relative to the scientist Newton, and it was abbreviated like this (N).

Exercise: An electric heater is used to boil water. When the switch is turned on, the electric current in the heating element produces heat energy. The temperature of the water increases steadily until it starts to boil after 15 minutes. If another heater with a greater power is used, the time taken to boil the same volume of water would be less than 15 minutes. From the above description, identify the physical quantities. Then, classify these quantities into base quantities and derived quantities.

2.7.1 Conversion of Units

The basic idea of the conversion is to multiply by the conversion factor, which is a fraction whose value is one, and is written to allow units to be shortened. Example: conversion factors between kilograms and grams, minutes and seconds:

$$1 = \frac{1000\text{g}}{1\text{kg}}\ , 1 = \frac{1\text{kg}}{1000\text{g}}$$

$$1 = \frac{1\text{ min}}{60\text{ s}}\ , 1 = \frac{60\text{ s}}{1\text{ min}}$$

Exercise: Convert the following:

500g to kg.

24 minutes to seconds.

30 ms^{-1} to km h^{-1}.

2.7.2 Prefixes

In physics, we sometimes need to write some values of quantities using prefixes, especially very large or very small values, in order to make it easier to write and understand them more clearly.

For example, 30000 m is in meters, we can write it in kilometres as follows: 30 km.

Also, 0.000001 s in the second unit, we can write it in the unit of microseconds as follows: 1 µs

The table shows some of the prefixes used in physics:

Small Prefixes		
Value	Symbol	Name
10^{-2}	c	Centi
10^{-3}	m	Milli
10^{-6}	μ	Micro
10^{-9}	n	Nano

large Prefixes		
Value	Symbol	Name
10^3	k	kilo
10^6	M	Mega
10^9	G	Giga

To write values with or without prefixes, we use the conversion factor:

1. To add the prefix: $\frac{\text{prefix that we want to write}}{\text{prefix value}}$

2. To remove the prefix: $\frac{\text{prefix value}}{\text{prefix that we want to omit}}$

Exercise:

Write 2 µs in the unit of seconds.

Write $6.7\times10^{-8}g$ in the unit of (ng).

Write 0.7ng in the unit of (kg).

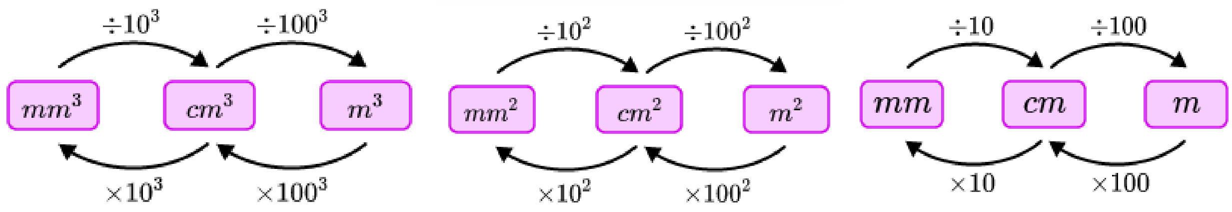
It is also useful to familiarise yourself with the rules for converting between units of length, area and volume:

Length units: $1m=10^2cm=10^3mm$

Area units: $1m^2 = 10^4cm^2 = 10^6mm^2$

Volume units: $1m^3 = 10^6cm^3 = 10^9mm^3$

The litre: $1L = 10^3 cm^3 = 10^{-3} m^3$



2.8 SIGNIFICANT DIGITS

Measurements resulting from the use of tools and devices are approximate, so they are written in the form of significant digits, and the last number on the right in the measurement result is uncertain. To clarify, "significant" digits are the numbers that are reliable in a measurement.

For example, to measure an object, a one-meter ruler gives a measurement that can be expressed as 24.5cm. However, from a more precise ruler, we can express the measurement as 24.45cm. The extra digit is not arbitrary but does have a meaning; this means that in physics $20m$ and $20.0m$ are not the same!

When multiplying or dividing multiple quantities, the result should have the same number of significant figures as the measurement with the lowest significant figures.

2.9 EXERCISES

1. A car travels at $90 kmh^{-1}$. Convert this speed to $m\ s^{-1}$.
2. Write 5L in units of mm^3
3. How many micrometres make up 1.0 km?
4. The density of water is $1\ g\ cm^{-3}$. What is this density in $kg\ m^{-3}$?
5. Write the value 0.0056 m using a suitable SI prefix.
6. Perform the calculation and round to the correct number of significant figures:

   $12.45\ m \times 3.2\ m$.

7. Perform the calculation and round to the correct number of significant figures:

   $105.4\ \mathrm{g}\ \div\ 25.2\ \mathrm{mL}$. Also, answer in $\mathrm{kg\ m^{-3}}$.

8. The area of a rectangle is found by multiplying its length by its width.

   If length $= 5.0\ \mathrm{cm}$ and width $=\ 3.00\ \mathrm{cm}$, what is the area with the correct number of significant figures?

9. If the side of a cube is $\mathbf{0.50\ m}$, what is the volume in both $\mathbf{m}^3$ and $\mathbf{L}$?

10. Earth is approximately a sphere of radius $6.37 \times 10^6\mathrm{m}$. What are (a) its circumference in kilometres, (b) its surface area in square centimetres, and (c) its volume in litres?

3 Introduction to Fluids

The crown of King Hiero: the king of Syracuse had given a craftsman a certain amount of gold to be made into an exquisite crown. When the project was completed, a rumour surfaced that the craftsman had substituted a quantity of silver for an equivalent amount of gold, thereby devaluing the crown and defrauding the king. Archimedes was tasked with determining if the crown was pure gold or not. The Roman architect Vitruvius relates the story: While Archimedes was considering the matter, he happened to go to the baths. When he went down into the bathing pool, he observed that the amount of water which flowed outside the pool was equal to the amount of his body that was immersed. Since this fact indicated the method of explaining the case, he did not linger, but moved with delight, he leapt out of the pool, and going home naked, cried aloud that he had found exactly what he was seeking. For as he ran, he shouted in Greek: Eureka! Eureka!

Archimedes came up with one of the most important fluid principles, which was named "Archimedes' principle". In this chapter, you will learn about other concepts, principles and laws in fluids.

3.1 What are Fluids?

The word fluids refers to every substance that has the property of flowing or diffusion, and thus includes: liquids and gases. The origin of the word fluid is from fluidity, which is physically: not maintaining a constant shape. The basic properties common to liquids and gases are:

1. It has no constant shape.
2. Its particles are far apart.
3. Its molecules move freely:
   a. In liquids: molecules move translationally within the volume of the liquid.
   b. In gases: molecules move freely, in any size available.

Exercise: Can you name important differences between the properties of liquids and gases?

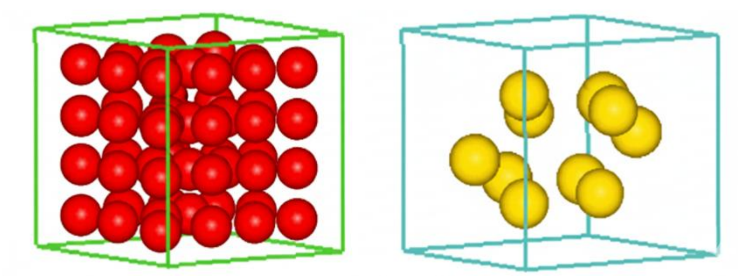
3.2 Mass, Volume, and Density

Mass, volume, and density are distinctive properties of any sample of matter, and it is very important to be aware of their meaning.

Density	Volume	Mass
Mass of a unit volume of a sample It is measured in kg/m^3	The portion of space that a sample of matter occupies. It is measured in m^3	The amount of matter in a sample of it. It is measured in kg

If the particles of a substance are closer to each other, then it is denser.

Exercise: Which of the two samples is denser?



3.2.1 Definition of Density:

Density is defined as the mass per unit of volume, which can be expressed by the equation

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

where:

m is the mass(Kg)

V is the volume (m^3)

ρ is the density $(\mathrm{kg/m}^3)$

Density is a characteristic of any pure substance; that is, each type of substance has its own density, such as iron, copper, gold, etc.

The table shows the densities of some substances at standard situations:

Substance	Density (kg/m³)	المادة
Air	1.29	الهواء
Ice	0.917×10^3	الثلج
Aluminum	2.70×10^3	الألومنيوم
Iron	7.86×10^3	الحديد
Benzene	0.879×10^3	البنزين
Lead	11.3×10^3	الرصاص
Copper	8.92×10^3	النحاس
Mercury	13.6×10^3	الزئبق
Oak	0.710×10^3	خشب البلوط
Fresh water	1.00×10^3	الماء العذب
Oxygen gas	1.43	غاز الأكسجين
Glycerin	1.26×10^3	الجلسرين
Pine	0.373×10^3	خشب الصنوبر
Gold	19.3×10^3	الذهب
Platinum	21.4×10^3	البلاتين
Helium gas	1.79×10^1	غاز الهيليوم
Seawater	1.03×10^3	ماء البحر
Hydrogen gas	8.99×10^{-2}	غاز الهيدروجين
Silver	10.5×10^3	الفضة

Exercise: What is the volume of helium (density $0.179\mathrm{kg}\cdot\mathrm{m}^{-3}$). that has the same mass as $5.0\mathrm{m}^3$of nitrogen (density $1.25\mathrm{kg}\cdot\mathrm{m}^{-3}$).

Exercise: Arrange these iron solid objects ascending a) according to their densities b) according to their masses.

a. A ball of radius r

b. A cube of side length r

c. A cylinder of height r and radius r

d. A cuboid of length r, width $2r$, and height $0.5r$

3.3 Pressure

The plane shown in the figure is standing on a runway of an airport, and the plane weight within 420 tonnes. Intuitively, this weight is distributed over the runway area, and we call the part of its weight affecting on each unit area ($1\mathrm{m}^2$) of the runway: pressure.

3.3.1 Definition of Pressure

When a force acts on a surface, we can say that the force is exerting pressure on it. In physics, pressure is defined as the perpendicular force on the surface per unit area, and it can be calculated by the equation:

$$P = \frac{F}{A} \tag{1}$$

Where:

F is the force (N)

A is the area (m^2)

P is the pressure $(\mathrm{Nm}^{-2}=\mathrm{Pa})$ (Pascal)

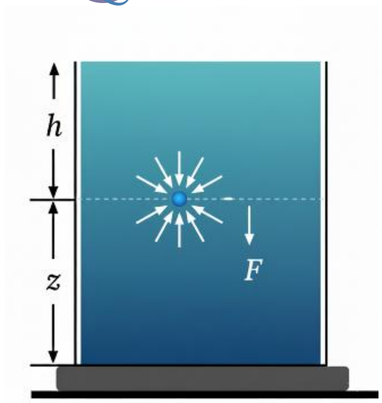
Exercise: Why do skaters use special shoes instead of regular shoes?

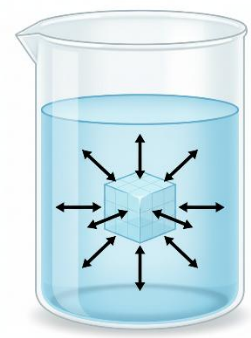
Exercise: Explain why the guy in the figure is not harmed despite being stretched out on a layer of nails.

3.3.2 Pressure in Fluids

Have you tried scuba diving? The diver feels that water exerts pressure on all parts of his body, and his feeling of pressure increases if he dives deep. This can also be witnessed when climbing a mountain, where the higher you go, the lower the pressure you feel.

In fact, all fluids (liquids and gases) exert pressure on objects immersed in them. The pressure of the fluid affects in all directions on an object that immersed in it.





Experimentally, it was found that the pressure of a fluid at a point increases with the increase of:

a. The depth of the point below the surface of the fluid h.

b. the density of the fluid ρ_f.

Therefore, the fluid pressure at a point is calculated by the equation:

$$P_f = \rho_f h g \qquad (2)$$

Where:

P_f is the pressure of fluid (Pa)

ρ_f is the density of the fluid ($\mathrm{kg{\cdot}m^{-3}}$)

h is the depth of the point below the surface (m)

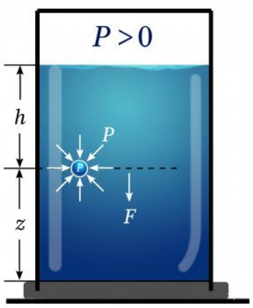
3.4 The Exposure of the Atmosphere

When the fluid is exposed to the atmosphere, then the atmosphere will exert pressure on it, this is true for all fluids too, where fluids can exert pressure on each other.

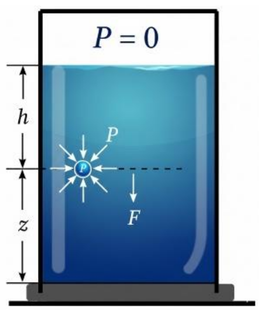
Exercise:

Calculate the total (absolute) pressure at the point P:

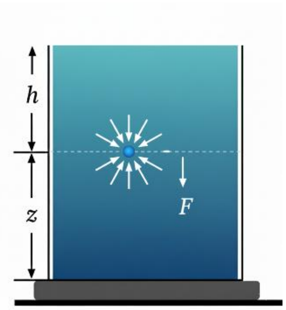
fluid is not exposed to the atmosphere and pressure above it: $P > 0$



fluid is not exposed to the atmosphere and pressure above it: $P = 0$



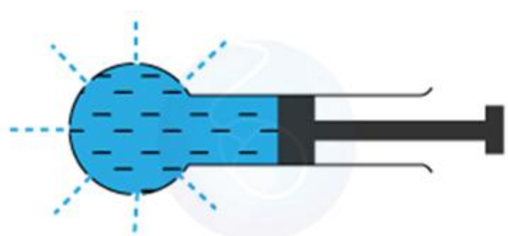
fluid exposed to the atmosphere



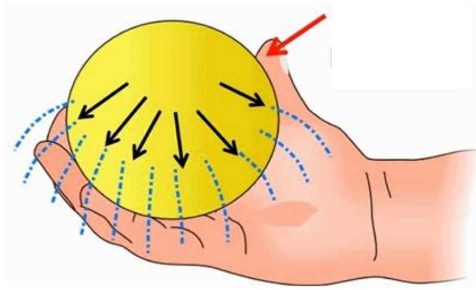
3.5 PASCAL'S PRINCIPLE

Pascal's law (also Pascal's principle or the principle of transmission of fluid-pressure) is a principle in fluid mechanics given by Blaise Pascal that states that a pressure change at any point in a confined incompressible fluid is transmitted throughout the fluid such that the same change occurs everywhere. The law was established by French mathematician Blaise Pascal in 1653 and published in 1663.

For example, when the plunger is pushed in, the water squirts equally from all the holes. This shows that the pressure applied to the plunger has been transmitted uniformly throughout the water.



Also, when you press your finger on a balloon filled with air, the pressure on the surface of the balloon increases by the same value in all directions.



3.5.1 Hydraulic Press

The hydraulic press operates according to Pascal's principle. We see it in our daily life, such as a car lift used in a service station. When a force F_1 is applied to the small piston, the piston is affected by pressure: $P = F_1/A_1$. This pressure is transmitted through the fluid in the lever and exerts the same pressure on the large piston: $P = F_2/A_2$. So:

$$F_1/A_1 = F_2/A_2 \qquad (3)$$

Then:

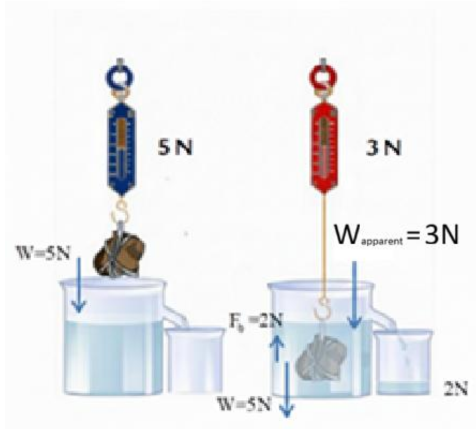
$$F_2 = F_1 \frac{A_2}{A_1} \qquad (4)$$

So, A large force is created that affects the large piston, and it is capable of lifting heavy objects such as cars. The quantity (A_2/A_1) is called: mechanical advantage or force multiplication coefficient.

3.6 ARCHIMEDES' PRINCIPLE

From our daily observations, objects appear to be lighter under water. For example, it is difficult for us to lift a heavy rock from the surface of the earth, while we can do so easily if it is submerged under water. This indicates that it is affected by an upward force that reduces its weight, called the Buoyant force and symbolised by F_B. The discovery of the principle is attributed to Archimedes (212-287) BC.

3.6.1 Experiment to verify Archimedes' Principle:



The basin is filled to the edge with water. We weigh the object in the air (reading of the scale): $W = 5N$

When the object is immersed in water, Water flows into the trough. The weight of the object inside the water (reading of the scale): $W_{apparent} = 3N$. This means that the buoyant force is:

$$F_B = W - W_{apparent} \qquad (5)$$

We can see that the weight of the displaced water is equal to the buoyant force. The volume of the displaced water is equal to the volume of the whole object. Therefore, by the displaced fluid we always mean: the weight of a volume of the fluid equal to the volume of the immersed part of the object.

Statement: Any object, totally or partially immersed in a fluid or liquid, is buoyed up by a force equal to the weight of the fluid displaced by the object.

$$F_B = \rho_{fluid} \times V_{displaced} \times g \qquad (6)$$

Where:

F_B is the buoyant force (N).

ρ_{fluid} is the density of the fluid ($kg\ m^{-3}$).

$V_{displaced}$ is the volume of fluid displaced by the object (m^3).

g is acceleration due to gravity (ms^{-2}).

3.7 EXERCISES

11. A block of wood has a mass of 120 g and a volume of $150\ \mathrm{cm}^3$. Find its density in $\mathrm{g}\cdot\mathrm{cm}^{-3}$ and $\mathrm{kg}\cdot\mathrm{m}^{-3}$. Would it float in water?
12. A force of 300 N acts on an area of $0.15\ \mathrm{m}^2$. Find its pressure.
13. The pressure at a certain point in water is $3.0\times10^5\mathrm{Pa}$. If the water density is $10^3\mathrm{kg}\cdot\mathrm{m}^{-3}$, find the depth of that point below the surface.
14. A $2\ \mathrm{m}^3$ block of wood is completely submerged in water (density = $10^3\mathrm{kg}\cdot\mathrm{m}^{-3}$). Calculate the buoyant force acting on it.
15. An object weighs 40 N in air and 35 N when completely immersed in water. Find the buoyant force and the volume of the displaced water. (Water density = $10^3\mathrm{kg}\cdot\mathrm{m}^{-3}$)
16. A hydrometer sinks deeper in oil than in water. What does this tell you about the densities of the two liquids?
17. A piece of wood immersed one-third of its volume if placed in water (the density of water is $10^3\mathrm{kg}\cdot\mathrm{m}^{-3}$) , While immersed half of its volume if put in oil, find the density of oil?
18. An object with mass 17 kg displaces 85 liters of fresh water. Find the buoyant force acting on it.
19. A solid cylinder with a density of $2.0\times10^3\mathrm{kg}\cdot\mathrm{m}^{-3}$ and a weight of 400 N in air, we immersed it in oil, so its weight became 300 N. Find the density of the oil.
20. A solid metal cylinder weighs 400 N in air, after immersing it in fresh water, its weight is $300\ N$. Calculate the volume of the cylinder. (Water density = $10^3\mathrm{kg}\cdot\mathrm{m}^{-3}$)
21. The total (absolute) pressure at the bottom of a swimming pool is $151{,}325$ Pa. If the atmospheric pressure is $101{,}325$ Pa, find the depth of the swimming pool.

22. An iceberg of density $9.2 \times 10^2 \mathrm{kg \cdot m^{-3}}$ floats in seawater of density $1.03 \times 10^3 \mathrm{kg \cdot m^{-3}}$. If the total volume of the iceberg is $2000\ \mathrm{m}^3$, find the volume of ice above the water surface.

4 MOTION IN ONE DIMENSION

To describe an event in nature, we express it using physical quantities, such as temperature, pressure, speed, and force. The effect of some of these quantities cannot be determined without knowing their direction, while others cannot be described by a direction. This distinction allows us to divide physical quantities into two types: scalar quantities and vector quantities.

4.1 SCALAR AND VECTOR QUANTITIES

Scalar quantities are physical quantities that are fully described by their magnitude (value) only, and no direction can be assigned to them. Examples include temperature and time. It makes no sense to say "the temperature is 30^o upward" or "I waited for you for two hours toward the north."

Vector quantities are quantities that require both a magnitude and a direction to be fully described, such as force and displacement. Suppose a force of 5N acts on a stationary object. Will the object move up or down? Or will it move right or left? And if another force of 5N also acts, will the object move with greater acceleration, or will the two forces balance each other so the object doesn't move? Without knowing the direction, we cannot describe the effect of these physical quantities.

Important note: Vector quantities are written with an arrow or in bold to differentiate between them and the scalar quantities, ($\vec{A}$, $\boldsymbol{A}$). The magnitude of the vector is written with the normal font $A = |\vec{A}|$.

4.2 VECTOR QUANTITIES IN THREE DIMENSIONS

We live in a three-dimensional world, which means vector quantities exist in three dimensions. Fortunately, we can describe any vector quantity as the sum of three vector quantities, each lying along one of the three dimensions (axes). We can then study each vector independently of the others. At this stage, the requirement will be to study vector quantities in one dimension, and we will leave the analysis of vectors in multiple dimensions for later stages.

4.3 Motion

The movement of objects – such as a football, a car, and even the sun and moon – is a clear part of our daily lives. The modern concept of motion became clear in the 16th and 17th centuries AD, with significant contributions from Galileo Galilei (1564-1642) and Isaac Newton (1642-1727), who helped formulate the modern understanding of motion.

The study of the motion of objects and the concepts related to force and energy includes a field called Mechanics, which is usually divided into two branches:

Kinematics	Dynamics
Describes the motion of objects in terms of position and time without considering their causes.	Describes the motion of objects by the effect of their causes, such as forces.

We will now discuss the translational motion of objects without rotation, specifically in one dimension (on a straight line).

4.3.1 Position

To describe the motion of an object well, physicists need to know several physical quantities about it, such as its position, displacement, velocity, and acceleration, which we will study successively, and we will start by knowing what we mean by position.

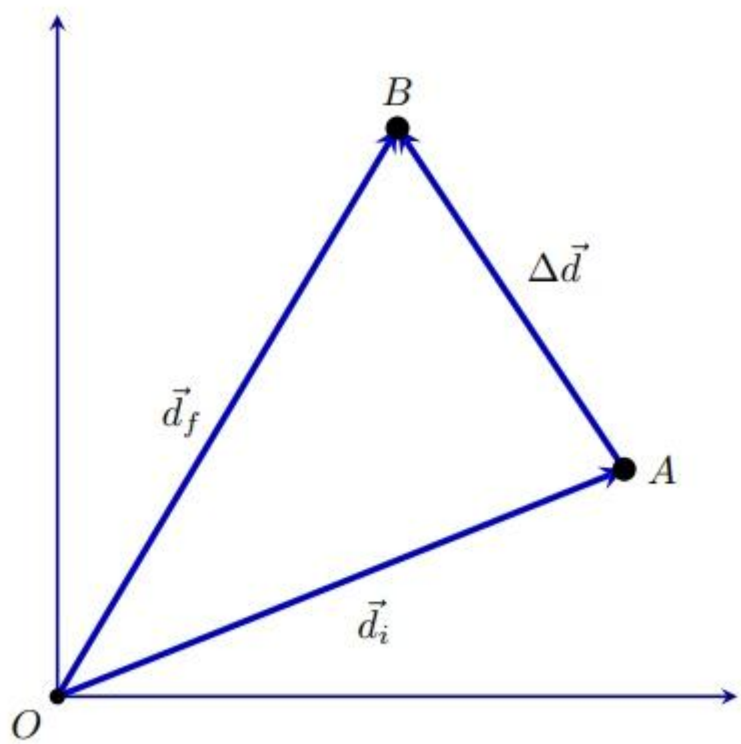
Position is defined as the location of an object at a particular moment relative to a reference point, often called the origin.

4.3.2 Distance and Displacement

	Distance	Displacement
Concept	The actual length of the path of the object's motion; it is a scalar quantity.	The change in the position of the body in a specific direction; it is a vector quantity.

Displacement is a vector connecting the endpoints of the path of an object. The displacement does not depend on the path taken, and it can be calculated by the equation:

$$\Delta\vec{d} = \vec{d_f} - \vec{d_\iota} \qquad (7)$$



Where:

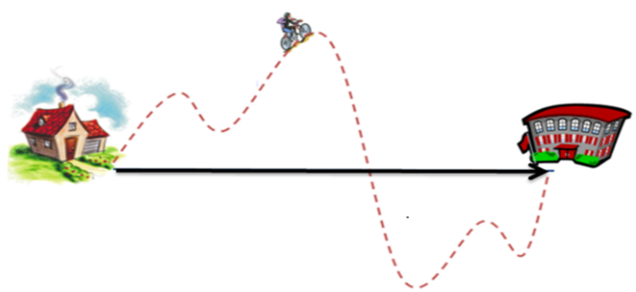
$\Delta\vec{d}$ is the displacement (m).

$\overrightarrow{d_f}$ is the final position vector (m).

$\overrightarrow{d_i}$ is the initial position vector (m).

Note that in the graph, the path wasn't taken into consideration, only the end points of the path (the start and the end points). While the distance "s" can be calculated only by calculating the length of the path taken by the object.

Exercise: A cyclist moves from his home to his school as shown in the figure. How do we distinguish between distance and displacement?



Exercise: A runner ran around a circle with a radius $r = 10.0\ m$. a) After he finished the first round, what was his displacement and distance? b) What will his displacement and distance be if he ran 10 rounds? c) What was his displacement and distance at a quarter round? d) And at half round? e) And at 3-quarters?

4.3.3 Speed and velocity

Velocity and speed measure how fast the object is moving, with the speed being a scalar quantity and velocity as a vector. So, we can define the following:

Average speed: is the rate of change of distance with respect to time. And can be calculated by the equation

$$\bar{v} = \frac{s}{t} \quad (8)$$

Where:

$\bar{v}$ is the average speed (ms^{-1}).

s is the total distance (m).

Δt is the time interval (s).

Average velocity: is the rate of change of position with respect to time. And can be calculated by the equation:

$$\vec{\bar{v}} = \frac{\Delta \vec{d}}{\Delta t} = \frac{\overrightarrow{d_f} - \overrightarrow{d_\iota}}{\Delta t} \tag{9}$$

Where:

$\vec{\bar{v}}$ is the average velocity (ms^{-1}).

d_i is the initial position (m).

d_f is the final position (m).

$\Delta\vec{d}$ is the displacement (m).

Δt is the time interval (s).

Exercise: If the runner in the last example completed the round in 12.5 s, what is his average speed and his average velocity?

4.3.4 Acceleration

Acceleration is the rate of change of velocity. It is a vector quantity, and its direction gives us insight into the object's motion. If it is in the same direction as the velocity, then the object is accelerating (speeding up), and if it is in the opposite direction, then the object is decelerating (slowing down).

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \tag{10}$$

Where:

$\vec{a}$ is the average acceleration (ms^{-2}).

$\vec{v}_i$ is the initial velocity (ms^{-1}).

$\vec{v}_f$ is the final velocity ($\mathrm{ms^{-1}}$).

$\Delta\vec{v}$ is the change of velocity ($\mathrm{ms^{-1}}$).

Δt is the time interval (s).

Exercise: A rabbit runs along the x-axis. What is the sign of its acceleration if it is moving (a) in the positive direction with increasing speed, (b) in the positive direction with decreasing speed, (c) in the negative direction with increasing speed, and (d) in the negative direction with decreasing speed?

4.4 Graphics Calculations

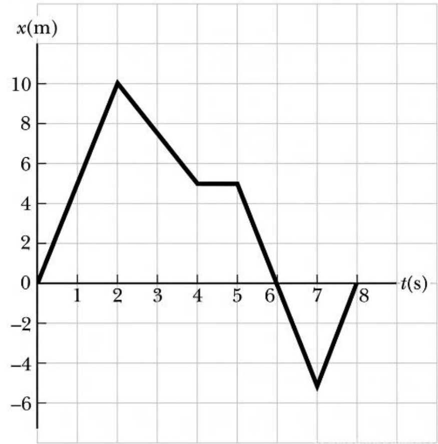
Algebraic equations are essential tools for solving problems in kinematics, yet graphical analysis offers a more intuitive and visually rich understanding of motion. By interpreting the slopes and areas of graphs, we can derive fundamental quantities such as displacement, velocity, and acceleration, and see how they relate to one another.

4.4.1 The position-time graph

This graph shows how the position of the object changes with time. From this graph, it is easy to extract the distance and displacement based on their definitions. Where the displacement only requires the endpoints, and the distance is calculated by summing all the distances travelled by the object.

Velocity is the rate of change of the position, which is the slope of the position-time graph.

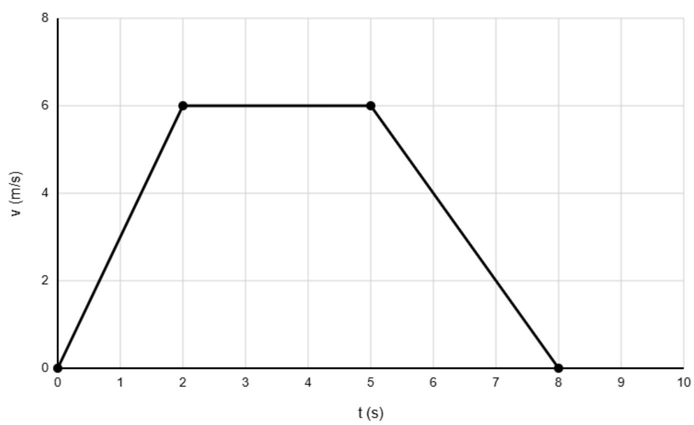
Exercise: In the following graph, a) determine the position at $\boldsymbol{t = 7.0\ s}$ b) determine the average velocity in the interval between $\boldsymbol{t = 2.0\ s}$ and $\boldsymbol{t = 4.0\ s}$. c) determine the average velocity in the interval between $\boldsymbol{t = 2.0\ s}$ and $\boldsymbol{t = 6.0\ s}$.



4.4.2 The speed-time graph

This graph shows how the speed changes with time. In this graph, the distance can be obtained by calculating the area under the graph (the area is speed times time, which is the equation to calculate distance).

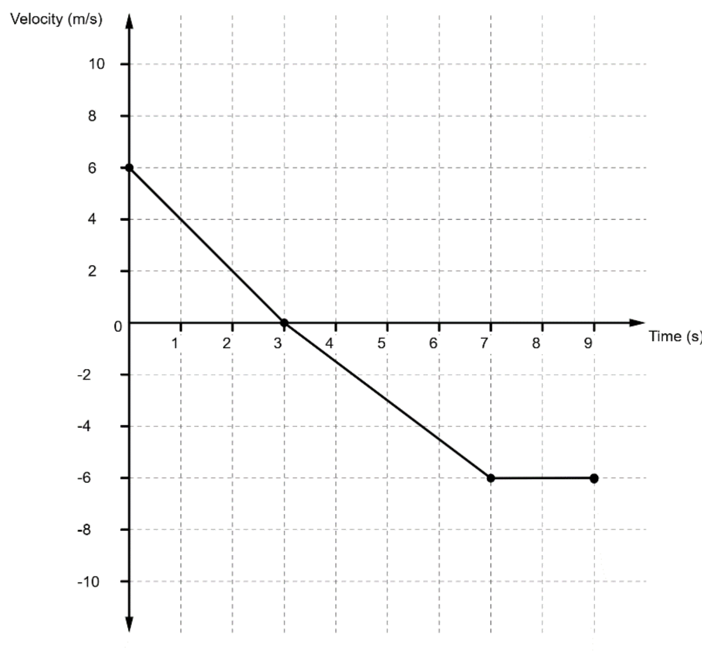
Exercise: The following graph shows the speed of an object versus time. From this graph, a) determine the speed at $t = 4.0\ s$. b) Determine the distance travelled from $t = 0.0\ s$ to $t = 8.0\ s$. c) Determine the distance travelled when the speed was constant.



4.4.3 The velocity-time graph

Similar to the speed-time graph, we can see the velocity and how it changes with time. This time, the area under the graph is the displacement. In addition, the slope of the graph is the change of velocity divided by the time interval, which is exactly the acceleration.

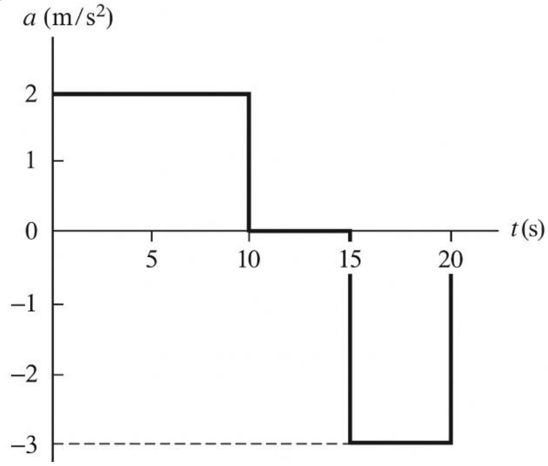
Exercise: The following graph shows the velocity of an object versus time. From this graph, a) Determine the velocity at $t = 1.0\ s$. b) At what second did the object change its direction? c) Determine the value and the direction of the average acceleration for the interval from $t = 0.0\ s$ to $t = 10.0\ s$. d) Determine the total displacement of the object for the interval from $t = 0.0s$ to $t = 7.0s$.



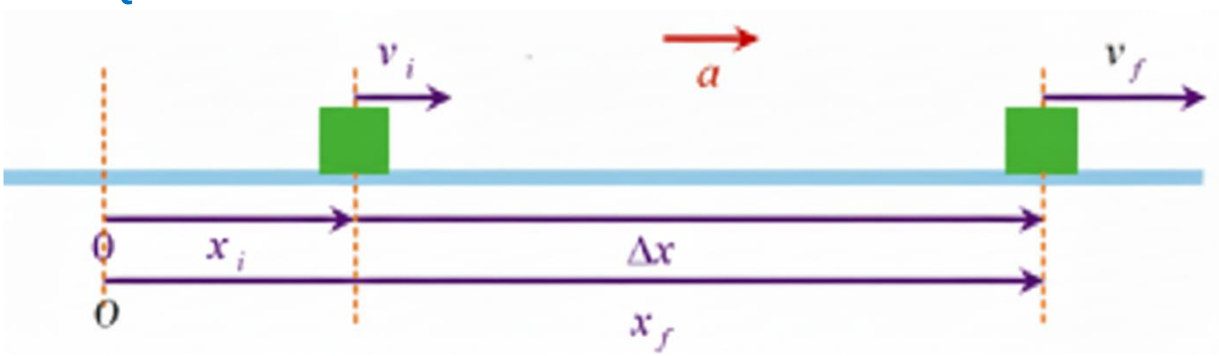
4.4.4 The acceleration-time graph

The acceleration-time graph shows how the acceleration changes with time, and the area under the curve gives the velocity difference.

Exercise: From the acceleration versus time graph, a) determine the direction and value of the acceleration at $t = 7.0\ s$. b) Calculate the change in the velocity from $t = 0.0\ s$ to $t = 20.0\ s$. c) When was the velocity constant?



4.5 Equations of Motion



How can we describe the motion of the object in the figure above, which moves in a straight line from the position on the left to the position on the right toward the axis with constant acceleration? We can describe the motion of this object using the following equations of motion.

$$v_f = v_i + at \qquad (11)$$

$$\Delta x = v_i t + \frac{1}{2}at^2 \qquad (12)$$

$$\Delta x = v_f t - \frac{1}{2}at^2 \qquad (13)$$

$$v_f{}^2 = v_i{}^2 + 2a\Delta x \qquad (14)$$

$$\Delta x = (\frac{v_f + v_i}{2})t \qquad (15)$$

Where:

O is the origin.

Δx is the displacement in the x-axis (it can be any axis) (m).

x_f is how far the object is from the origin initially (m).

x_i is how far the object is from the origin initially (m).

v_i is the initial velocity (ms^{-1}).

v_f is the final velocity (ms^{-1}).

a is the acceleration (ms^{-2})

t is the time interval (s).

4.5.1 Problem-solving skills using equations of motion

1) If the motion is in one direction: Consider it the positive direction of motion, whatever it is.
And the signs of displacement, velocity, and acceleration are positive in this direction and negative in the other direction.
2) If the motion is in more than one direction on one line: Consider one of the directions as positive (e.g., to the right or upward) and the other negative (to the left or downward).
And the signs of displacement, velocity, and acceleration are positive in the positive direction and negative in the other direction.
3) Use the appropriate equation in which all quantities are known except the quantity to be calculated. Note that you need to know 3 variables to determine the other 2.
4) If the problem contains several accelerations, apply the equations for each acceleration stage separately.
5) You need the number of equations to equal the number of unknowns.

Exercise: A truck covers $40.0\ m$ in $8.50\ s$ while smoothly slowing down to a final speed of $2.80 ms^{-1}$. (a) Find its original speed. (b) Find its acceleration.

4.6 Free Fall

Free fall is considered one of the examples of one-dimensional motion with a constant acceleration in nature, and it is defined as the motion of an object under the influence of Earth's gravity only, with the ignorance of air resistance, in a line perpendicular to the reference surface (the ground).

We usually consider the upward direction as the positive one. The value of the acceleration is: $g = 9.8\ \text{ms}^{-2}$ during ascent and descent.

The displacement and velocity of the body can be calculated at any moment during the period of ascent or descent, by utilizing the equations of motion and considering the acceleration in the equations of motion as $a = -g$:

$$v_f = v_i - gt \quad (16)$$

$$\Delta y = v_i t - \frac{1}{2} g t^2 \quad (17)$$

$$\Delta y = v_f t + \frac{1}{2} g t^2 \quad (18)$$

$$v_f{}^2 = v_i{}^2 - 2g\Delta y \quad (19)$$

$$\Delta y = \left(\frac{v_f + v_i}{2}\right) t \quad (20)$$

It is also helpful to remember that the velocity at the highest point is $v = 0$. Otherwise, it will go even higher.

Exercise: A ball was thrown next to a building, and a man in the building saw the ball from his window. After 3 seconds, he saw it again. Was the ball's speed larger in the ascending or descending? And find the velocity in both cases.

4.7 EXERCISES

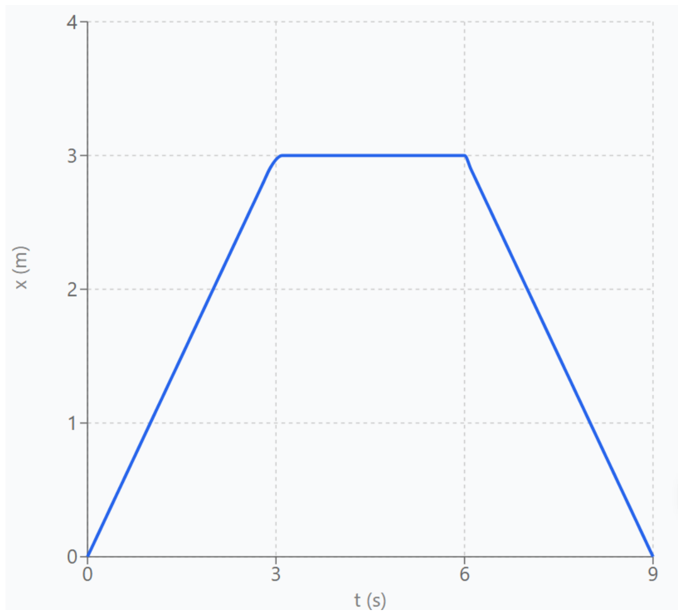
23. A person walks 4 km East, then 3 km North. Calculate the total distance travelled and the magnitude of his displacement.

24. A car travels from city A to city B with a constant speed of $100\ \text{km/hr}$ in one hour, and then back to city A with a constant speed $80\ \text{km/hr}$. Calculate its average speed and average velocity for the entire trip.

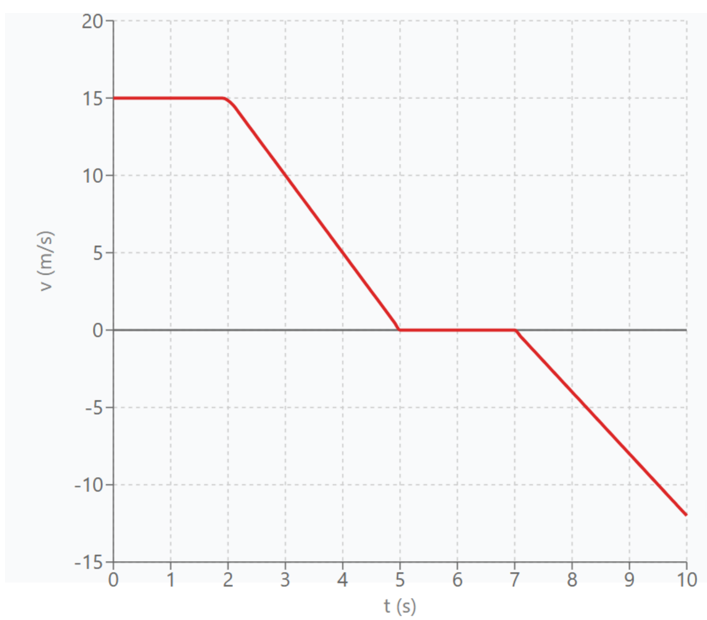
25. A car accelerates from 20ms^{-1} to 30ms^{-1} in 5 seconds. What is its acceleration? And what was its displacement?

26. A cyclist slows down from 10ms^{-1} to a stop in 4 seconds. What is his acceleration? And what was his displacement?

27. An object's motion is described by the position-time graph below. Describe its motion in words (e.g., constant speed, at rest, etc.) for each segment.



28. An object's motion is described by the velocity-time graph below. Find (a) the acceleration in each segment, and (b) the total displacement.



29. A ball is thrown vertically upward with an initial velocity of $20ms^{-1}$. How high does it go? How much time does it take to reach its maximum height?

30. A truck moving at 25ms^{-1} applies its brakes and comes to a stop in 10 seconds. What is its acceleration, and how far does it travel during this time?

31. A car accelerates uniformly from rest and covers a distance of $100\ m$ in 5 seconds. Find its acceleration and its final velocity.

32. A stone is dropped from a cliff. It hits the ground after 3 seconds. What is the height of the cliff?

33. A ball is thrown vertically upwards with a speed of 15ms^{-1} from the ground. Calculate the time it takes to return to the ground.

34. A train decelerates uniformly from 40ms^{-1} to 20ms^{-1} over a distance of 200 m. Find the acceleration and the time taken.

35. Sketch a velocity-time graph for an object that accelerates from rest, then moves at constant velocity, then decelerates to a stop.

36. On the moon, gravity is 1.6ms^{-2}. If an astronaut drops a hammer from a height of 2 m, how long does it take to hit the ground?