1 Scientific Study

The scientific study includes scientific facts, theories, models, experiments and physical situations. It studies various objects in nature in a planned and organized way. It also logically investigates the various phenomena based on the scientific method and empirical or measurable evidence. Various causative factors have a role in different events and phenomena that have occurred in nature. The causative factor, characteristic, or trait that has a direct or indirect relationship with an event or a phenomenonis known as a variable.

1.1 Variables of scientific research

When we see a phenomenon or change, we are curious to know why it happens, what factors areinvolved, and how they have affected that event or phenomenon. Such curiosity helps us to predict the result of an action correctly. For instance, if we see a wilted potted plant in the garden, we want to know why is it wilted.Is it because of lack of water, overexposure to bright sun, or someother reasons? To find out the answer, we try to find the effects of keeping the plant in theshade or watering it or doingsome other things. With the help of knowledge and experience obtained fromsuch curiosity or interest, we can easily guess what could be the condition of the plant if we forget to water it or keep it in the shade on a hot day.Then we can take the necessary measures to save it.

For each incident or change, there is always cause and effect. In the aforementioned example, either lack of water or excessive heat of the sun is the causative factor whereas wilting is the effect. The effect depends on the causal factors. For example, the rigidity of the stem of a plant depends on the amount of water in it. Therefore, for the right estimation, it is essential to know the

relationship between the magnitude of the causative factor and the magnitude of the effect.

This relation can be established through experiments. The task of a scientist is to set up a relationship between various physical quantities and ultimately find out how nature works.

Activity 1.1

Title: Making catapult from a rubber band

Materials required: rubber band (about 5 cm long), a 15 cm long ruler, small pieces of paper (about 2cm length and 2 cm breadth) and measuring tape

Method

1. Wrap the pieces of paper into a cylinder-like form and fold them in the middle. It functions as a projectile or bullet for a catapult.
2. Hook the rubber band into two fingers of one hand (e.g., thumb and forefinger), as shown in the figure.

Figure 1.1

3. Hold the paper bullet within two segments of the rubber band and stretch the rubber band.
4. Ask your friend to measure the extension of the rubber band (distance from the fingers to the paper bullet). Make the distance 4 cm.
5. Release the paper bullet. It will fly away from the catapult. Measure the distance covered by the paper bullet.
6. Note down the extension of the rubber band and the distance travelled by the paper bullet.

7. Now, stretch the rubber band 6 cm and launch the paper bullet. Measure the distance travelled by the bullet. Repeat this for the extension of 8 cm and 10 cm.

S.N.	Extension of rubber band(cm)	Distance travelled by the paper bullet (cm)
1.	4	
2.	6	
3.	8	
4.	10	

Scientific research involves changing the magnitude of one physical quantity and observing how this change brings changes in another physical quantity. For example: in the above experiment, we studied how the extension (stretch) of the rubber band affects the distance travelled by the paper bullet. Here, the extension of the rubber band and the distance covered by the bullet are both physical quantities and their magnitude are different in each experiment. Such physical quantities are called variables because their value or magnitude varies each time. The elements (physical quantities) that change or may change in an experiment are called variables of the experiment or research. In the above experiment stretching of the rubber band and the distance covered by the paper bullet are the variables of that experiment. The thickness of the rubber band and the size of the paper bullet could also have been changed in that experiment. Therefore, these are also the variable of the research.

Each variable has a name and is represented by a symbol for ease of writing. The relation between variables is expressed interms of a mathematical formula. For example: If the extension or stretch of rubber is denoted by 'e'and the distance travelled by the paper piece is denoted by 'x', the relation between them is $x \propto e$.

Types of variables

Usually, variables are classified into three types: independent variable, dependent variable and controlled variable.

a. Independent variable

During a scientific experiment or research, the researcher manipulates or changes a variable in a particular amount and measures the changes in another variable. The change made by the experimenter or researcher is the causative factor and subsequent change in another variable is the effect.

In the experiment above, stretched rubber band throws the paper bullet. The extension of the rubber band is the causative factor and the distance travelled by the paper is the effect. The researcher or experimenter is free to decide the degree of extension of the rubber band. The variable which can be manipulated by a researcher is called the independent variable. In activity 1.1, the extensionof the rubber band is the independent variable.

Causative factors related to the experiment are independent variables. For example, the amount of fertilizer, sunlight and water can be the independent variables for the growth of a plant.

b. Dependent variable

In experiment 1.1, the researcher cannot tell the distance covered by the piece of paper directly because it depends on the amount of stretching of the rubber band. Such a variable is called a dependent variable. So dependent variable is the variable whose value depends upon the value of anothervariable and the experimenter cannot predict or determine its value directly.For example,in activity 1.1 the distance covered by the paper bullet is the dependent variable. Similarly, while observing the effect of sunlight on the growth and development of the plant, the amount of sunlight is the independent variable and the height or growth of the plant is the dependent variable.

c. Controlled variable

In some experiments or research, there may be more than two variables. Each variable influences the result of an experiment or research. Thus, it isnot possible to determine which variable is responsible for the change in the results or findings. In such a situation, it is difficult to draw conclusion. The conclusion might even not be valid or

reliable. Therefore, to make the finding of the experiment valid, reliable and accurate, variables other than the specified independent variable and dependent variable should be controlled so that they do not affect the result. Such variables which are taken into control throughout the experiment or research are known as the controlled variables.

In activity 1.1, the thickness of the rubber band and the size of the paper bullet should be kept the same throughout the experiment.

If different rubber band sare used at each activity, the result will not be valid. Hence, for this experiment, the thickness of the rubber band and the size of the paper bullet are the controlled variables. Similarly, while we are observing the effect of light on plant growth, all plants should be of uniform size at the beginning of the experiment. Air, water and manure supplied to these plants should also be kept uniform throughout the experiment. So,the initial size of plants, air, water, and manure supplied to them are the controlled variables. In the same way, if we are studying the rate of a chemical reaction between the surface area of limestone and acid, the acid used each time should have the same concentration and the quantity and weight of limestone should also be kept the same. In this experiment, surface area is the independent variable, the rate of reaction is the dependent variable and the concentration of acid, quantity and weight of limestone are the controlled variables. Controlling such variables requires special arrangements while formulating the design of the experiment.

In Activity 1.1

Independent variable : extensionof rubber band

Dependent variable : distance travelled by paper bullet

Controlled variable : thickness of rubber band and size of the paper bullet

Other examples of thevariable types mentioned above are listed in the table below:

S.N.	Subject of research	Independent variable (what I can change)	Dependent variable (What I observe)	Controlled variable (what I keep the same
1.	Relation of a rotating knob of a tap and the rate of flow of the water	Magnitude of rotation of knob (in degree)	Amount of the water flow per minute (in litre)	water pressure
2.	Relation of electricity and magnetism in a solenoid	Amount of electric current (in ampere)	Number of pinsattracted by the electromagnet	Number of turns in the solenoid, size of the pin
3.	Effect of heat on the solubility of sugar	Temperature of water (in degree celsius)	Amount of completely dissolved sugar in water (in grams)	Amount of water (always 100 grams)
4.	The immediate effect of physical exercise on the heartbeat	Duration of physical exercise (in minutes)	Number of heartbeats	Type of physical exercise, the interval between the end of exercise, and count of heartbeats

Things to be considered about variables

1. There should be only one independent variable in research or an experiment.
2. There should be only one dependent variable in research or an experiment.
3. Except for the specified independent variable and dependent variable, other variables should be controlled.

4. While expressing the relation between variables in an equation, usually, the dependent variable is written on the left side of the equation and the independent variable is written on the right side. Hence, the independent variable is sometimes called a right variable and the dependent variable is called the left variable. For example,if we study how the distance covered by a moving object varies with time, then the mathematical equation of their relationship will be s =vt. Where distance travelled (s) is the dependent variable, time (t) is the independent variable and speed (v) is the controlled variable.

5. While plotting the relationship of variables in a graph, the dependent variable is always plotted on the y-axis or the vertical line and the independent variable is plotted on the horizontal line or the x-axis.Therefore, the dependent variable is sometimes called the vertical variable or the y-variable and the independent variable is called the horizontal variable or the x-variable. Graph presentation always depicts how the change in the independent variable brings the change in the dependent variable.

1.2 Types of units

Physical quantities are measured in units. The units of all physical quantities can be divided into two types:

1. Fundamental unit

2. Derived unit

Fundamental unit

The unit of measurement which has its independent existence or does not depend upon the other units and cannot be resolved into any simpler forms is called the fundamental unit. For example, the fundamental unit of mass is kilogram, the fundamental unit of time is second, and the fundamental unit of length is metre. In the SI system, there are 7 fundamental units and they are listed below:

S.N.	Physical quantity	Fundamental unit	Symbol
1.	length	meter	m
2.	mass	kilogram	kg
3.	time	second	s
4.	temperature	kelvin	K
5.	luminous intensity	candela	cd
6.	electric current	ampere	A
7.	amount of substance	mole	mol

Derived unit

The unit of measurement which has no independent existence and is composed of two or more fundamental units is called a derived unit. For example, the unit of density is kg/m^3. It consists of two fundamental units; kilogram and meter. Similarly, the unit of force is $kgms^{-2}$, where kilogram (kg), metre (m) and second (s) are the three fundamental units involved in it. It is difficult to say $kgms^{-2}$ in daily use andhence, this combined form of units is given a simpler name, newton (N). Therefore, $N = Kgms^{-2}$. Likewise, the unit of pressure is pascal (Pa). This unit is equal to $kgm\ -^1s^{-2}$. In this way, units of many derived quantities are given a specific name.But in the case of some physical quantities, the combination of fundamental units in itself is in use, for example, unit of density is kgm^{-3}.There is no simpler name for it.

Quantity	Formula	Combination of base units according to the formula	Fundamental Units involved	Derived Unit)
area	$l \times b$	meter × meter	m^2	m^2
volume	$l \times b \times h$	meter × meter × meter	m^3	m^3
density	$\frac{\text{mass}}{\text{volume}}$	$\frac{\text{kilogram}}{\text{meter}^3}$	kg/m^3	kg/m^3
velocity	$\frac{\text{displacement}}{\text{time}}$	$\frac{\text{meter}}{\text{second}}$	m/s	m/s

acceleration	$\frac{\text{velocity}}{\text{time}}$	$\frac{\text{meter}}{\text{second} \times \text{second}}$	m/s^2	m/s^2
force	mass × acceleration	$\frac{\text{kilogram} \times \text{meter}}{\text{second} \times \text{second}}$	kgm/s^2	Newton (N)
pressure	$\frac{\text{force}}{\text{area}}$	$(kgm/s^2)/meter^2$	kg/ms^2	Pascal (Pa)
work	force × distance	$kgm/s^2 \times$ meter	kgm^2/s^2	joule (J)
power	$\frac{\text{work}}{\text{time}}$	$\frac{kgm^2/s^2}{\text{second}}$	kgm^2/s^3	watt (W)
moment	force × distance	$(kgm/s^2) \times$ meter	kgm^2/s^2	Nm
frequency	$\frac{1}{\text{time}}$	$\frac{1}{s}$	s^{-1}	Hz

To find out the composition of derived unit which includes the fundamental units, analysis can be done based on the definition of the physical quantity. For example:

a) The unit of area is square metre

Analysis: Area = length × breadth

$= m \times m$

$= m^2$

Therefore, the unit of area is m^2. This unit is formed from two fundamental units.

b) The unit of force is Newton (N)

Analysis: According to the definition of force, F = ma

The unit of mass (m) is kg and the unit of acceleration (a) is ms^{-2}.

Therefore, N = $kgms^{-2}$. Hence kilogram, meter and second are the fundamental units and they are combined to form the unit of force which is called newton.

Activity 1.2

Find out the various units used to measure different kinds of physical quantities in your daily life. Classify these units into two groups; fundamental and derived units and fill up the table as given below in your note copy.

Fundamental units	Derived units

The difference between the fundamental unit and the derived unit is mentioned below:

Fundamental unit		Derived unit	
a)	It doesnot depend upon other units.	a)	It depends upon the fundamental units.
b)	There are seven fundamental units used till now.	b)	Many derived units are formed from seven fundamental units.

Analysis of unitwise equation

Various formulae and equations are obtained from the conclusion of scientific studies. The validity and uniformity of such formulae and equations can be checked by the analysis of units involved in such physical quantities. For the validation of an equation, units on both sides of an equation must be the same. Example: While performing the unit analysis of the equation: $s=v\times t$, the fundamental unit of the quantity onthe left-hand side of the equation is m and the fundamental unit of the quantity on the right-hand side of the equation is also $ms^{-1} \times s = m$. Therefore, this equation is valid.

But, if someone claims $s = v/t$, then by performing the unit analysis, the fundamental unit of the quantity on the left-hand side is m but the fundamental unit of the quantity on the right-hand side is ms^{-1}/s or ms^{-2}. Hence the unit of physical quantity on the left-hand side of

the equation is not equal with the unit of physical quantity on the right-hand side. So, the equation s = v/t is invalid or wrong.

Addition and subtraction of physical quantities are possible if they have the same composition of fundamental units. Example: u+v is possible because both of them have the same unit, ms^{-1}. Similarly, $s - at^2$ is also possible because the fundamental unit of s is m and the fundamental unit of at^2 is also m; when simplified. But, s+at is not possible because the unit of s (distance covered) is m and the fundamental unit of atis ms^{-1}. Thus, they cannot be added due to dissimilarity in the composition of fundamental units.

Example: Test the validity of the equation given below by unit analysis.

(i) $v^2 = u^2+2as$

(i) $s = ut+ \frac{1}{2} a^2t$

Now,

(i) $v^2 = u^2+2as$

$$m^2s^{-2} = m^2s^{-2} + m^2s^{-2}$$

In the above equation, there is uniformity in the unit of physical quantity oneither side. So, this is a valid equation.

(ii) $s = ut+ \frac{1}{2} a^2t$

$$m = ms^{-1} \times s + (ms^{-2})^2 \times s$$

$$m = m + m^2s^{-3}$$

In the equation given above, there is no similarity in the base units of the physical quantities on either side. So, this equation is not valid.

Analysis of units is required to prove the accuracy of an equation, to find out the inter-relation of physical quantities and for the conversion of units of various measurement systems.

Exercise

1. Choose the correct options for the following questions.

a. Which of the following is a fundamental unit?

i. newton ii. pascal

iii. kilogram iv. joule

b. Which of the following physical quantities has the unit ms^{-1}?

i. acceleration ii. velocity

iii. force iv. density

c. Which of the following is a derived unit?

i. candela ii. ampere

iii. joule iv. kelvin

d. Which of the following units denote newton?

i. $kgms^{-2}$ ii. kgm^2s^{-2}

iii. $kgm^{-2}s^{-2}$ iv. $kgms^{-1}$

2. Give reason:

a. Joule is the derived unit of work.

b. Some variables should be controlled while performing an experiment.

c. $v^2 = ut$ is not a valid relation.

3. Differentiate between:

a. Independent variable and dependent variable

b. Fundamental unit and derived unit

4. Answer the following questions:

a. What is a unit?

b. Write the SI units of mass, temperature, energy, and density.

c. How is the validity of an equation checked? Write an example.

d. Mention the fundamental units involved in the unit of pressure.

e. Find out the fundamental units involved in the given derived unit.

i.	newton (N)	ii.	watt (W)
iii.	joule (J)	iv.	pascal (Pa)

f. Niva claimed that an alternative formula for power is $P=mv^2$ and the formula of pressure; $P=mv/A$. Check the validity of given formulae by the analysis of units.

g. Describe the independent variable, dependent variable and controlled variable with a suitable example of each.

h. Karma connected a dry cell to a bulb using a few pieces of wire and lit the bulb. He was curious to know how the thickness of the used wire affects the life span of a dry cell. In this test or experiment, find out the independent variable, dependent variable and controlled variable.

i. Chandani wanted to investigate the effects of substances mixed with the soil on plant growth. She decided to mix lime, urea fertilizer, common salt, and compost manure in the soil. Then she brought a bucket of soil from a nearby field and sieved it. She put that soil equally into 12 uniform-sized pots. Then she mixed two spoons of salt in every three pots, two spoons of urea fertilizer in each of the next three pots, two spoons of table salt in each of the next three pots, and finally, two spoons of compost fertilizer in each of the remaining three pots.She then planted similar seeds of the same plant in every pot and placed them all in a sunny place in the house. She watered all the pots every day. After the plants grew, she measured the height of each plant daily and kept a record.

i. Identify the independent variable, dependent variable and controlled variable in Chandani's experiment.

ii. Why did Chandani use 3 pots for each experiment?

j. Subodh wanted to find out how the colour of an object affects its ability to hold heat. For that, he took four conical flasks and coated the first flask with black coloured enamel, the second with white enamel, the third with green enamel and the fourth with red enamel. Then, he filled all the flasks with water, closed the mouth of each flask tightly with cork and then kept them in the sun. After some time he measured the temperature of water in each flask with the help of a thermometer and noted the readings.

Identify the independent variable and dependent variable in Subodh's experiment. Which variables should be controlled by Subodh?

k. Manisha wanted to test the eating habits of her dog. She decided to study how the amount of food and the time of giving food affects the speed at which the dog ate. What is wrong with the design of Manisha's experiment and how can she correct it?

l. Prove that: Unit of electric resistance ohm (Ω) = $kgm^2s^{-3}A^{-2}$