AL AMAL LEARNING CENTER

PHYSICS KEY BOOK

Class 9 | Unit 1

PHYSICAL QUANTITIES AND MEASUREMENT

CHAPTER NOTES

What is inside

#	Contents
1	Student Learning Outcomes (SLOs)
2	1.1 Introduction to Physics
3	1.2 Physical and Non-Physical Quantities
4	1.3 International System of Units (SI)
5	1.4 Scientific Notation (Standard Form)
6	1.5 Prefixes (Powers of Ten)
7	1.6 Scalars and Vectors
8	1.7 Measuring Instruments
9	1.8 Errors
10	1.9 Precision and Accuracy
11	1.10 Significant Figures
12	Common Mistakes
13	Chapter Summary
14	Quick Formula Sheet

About this part

Chapter notes in simple words, with headings and difference tables (sections 1.1 to 1.10), common mistakes, a chapter summary and a quick formula sheet.

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PART CHAPTER NOTES

Student Learning Outcomes (SLOs)

After this chapter you should be able to:

- Explain what physics is and describe its branches and its role in technology and other sciences.
- Distinguish physical from non-physical quantities, and base from derived quantities.
- Name the seven SI base units and give the SI units of common derived quantities.
- Write numbers in scientific notation and use SI prefixes.
- Distinguish scalars from vectors, represent a vector, and add two perpendicular vectors.
- Use a metre rule, vernier calliper, screw gauge, physical balance, measuring cylinder and stopwatch.
- Find the least count and zero error of an instrument.
- Describe systematic and random errors, and explain precision and accuracy.
- Count significant figures and round off numbers.

1.1 Introduction to Physics

Physics is the science that studies **matter, energy** and the way they act on each other. Its laws help us understand how nature works.

Physics and other fields

Field	Role of physics
Biology	Blood flow through the heart, arteries and veins follows the physics of fluid flow
Chemistry	Why chemical reactions happen is explained by the physics of subatomic particles
Technology	Computers, smartphones, the internet, rockets, space shuttles, magnetically levitating trains, PET scans, micro-robots
Mathematics	Mathematics is the tool physics uses to describe nature

A **robot** is a machine designed to do tasks without a person helping it.

1.1.1 Branches of Physics

Branch	What it studies
Mechanics	Motion of bodies and the forces that cause or change it
Optics	Light: reflection, refraction, lenses, mirrors
Oscillations and waves	Vibrations, sound and other wave motion
Thermodynamics	Heat, temperature and how energy flows as heat
Electromagnetism	Electric charges, currents and magnets

Branch	What it studies
Astrophysics	Stars, planets, galaxies and the universe
Quantum physics	Extremely small particles and energy packets
Atomic and nuclear physics	Structure of atom and nucleus, radioactivity
Relativity	Space, time and gravity, especially at very high speeds

Do you know? The ancient Egyptians used the **cubit** (elbow to tip of the middle finger) to build the pyramids.

1.2 Physical and Non-Physical Quantities

A **physical quantity** is anything that can be measured, such as length, mass, time, density and temperature. Things that cannot be measured, such as taste, feeling and colour, are **non-physical quantities**.

Point	Physical quantity	Non-physical quantity
Measurable?	Yes	No
Unit	Has a unit	No unit
Examples	Length, mass, time, density	Taste, feeling, colour

Measurement

Measurement means comparing an unknown quantity with a **standard** (the **unit**) to see how big or small it is. Every measurement has two parts:

1. **Numerical magnitude** (the number)
2. **Unit**

Example: height $= 1.65\ \text{m}$. Magnitude is 1.65, unit is metre.

1.2.1 Base and Derived Quantities

- **Base (fundamental) quantities** are the simplest quantities, chosen so that every other quantity can be built from them.
- **Derived quantities** are obtained by multiplying or dividing base quantities.

Point	Base quantity	Derived quantity
Meaning	Simplest; not built from others	Made from base quantities by $\times$ or $\div$
Number in SI	Seven	Many
Examples	Length, mass, time, current, temperature, amount of substance, luminous intensity	Area, volume, speed, acceleration, density, force, pressure, energy
Units	Base units (m, kg, s...)	Derived units (m², m/s, N, Pa, J...)

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1.3 International System of Units (SI)

A **system of units** is a complete set of units for all physical quantities. **SI** stands for the French name *Système International d'Unités*. The BIPM (International Bureau of Weights and Measures, set up in 1875) looks after the SI standards.

1.3.1 SI Base Units

Base quantity	Symbol	SI unit	Unit symbol
Length	l	metre	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	I_v	candela	cd

Memory trick: L-M-T-I-T-A-L = **L**ength, **M**ass, **T**ime, current (**I**), **T**emperature, **A**mount, **L**ight intensity.

1.3.2 SI Derived Units

Quantity	Formula	SI unit	In base units
Area	$l \times l$	square metre (m²)	m^2
Volume	$l \times l \times l$	cubic metre (m³)	m^3
Speed / velocity	$\frac{\text{distance}}{\text{time}}$	metre per second	$\mathrm{m\,s^{-1}}$
Acceleration	$\frac{\Delta v}{t}$	metre per second squared	$\mathrm{m\,s^{-2}}$
Density	$\rho = \frac{m}{V}$	kilogram per cubic metre	$\mathrm{kg\,m^{-3}}$
Force	$F = ma$	newton (N)	$\mathrm{kg\,m\,s^{-2}}$
Pressure	$P = \frac{F}{A}$	pascal (Pa)	$\mathrm{kg\,m^{-1}s^{-2}}$
Energy	$E = Fd$	joule (J)	$\mathrm{kg\,m^2s^{-2}}$

Point	SI base unit	SI derived unit
Definition	Standard unit of a base quantity	Formed from base units by $\times$ or $\div$
Count	7	Many
Special name	Each has one	Some do (N, Pa, J); others do not (m/s)

1.4 Scientific Notation (Standard Form)

Very large and very small numbers are written compactly using powers of ten.

$$\text{number} = a \times 10^{n}, \qquad 1 \le a < 10, \quad n \text{ an integer}$$

Here a is the **mantissa** and n is the **exponent**.

How to convert

1. Move the decimal point until **one non-zero digit** is left before it. This gives a.
2. Count the places moved. - Moved **left** → exponent is **positive**. - Moved **right** → exponent is **negative**.

Quantity	Ordinary number	Scientific notation
Width of observable universe	88 followed by 25 zeros m	8.8×10^{26} m
Mass of the Earth	5 980 000… (21 zeros) kg	5.98×10^{24} kg
Diameter of hydrogen nucleus	0.0000000000000017 m	1.7×10^{-15} m

1.5 Prefixes (Powers of Ten)

A **prefix** is a name given to a power of ten. Prefixes let us write very large or small values in convenient units.

Prefix	Symbol	Multiplier	Prefix	Symbol	Sub-multiplier
exa	E	10^{18}	deci	d	10^{-1}
peta	P	10^{15}	centi	c	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	μ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto	h	10^{2}	femto	f	10^{-15}
deca	da	10^{1}	atto	a	10^{-18}

Memory trick (big to small): E P T G M k h da … d c m μ n p f a

Examples with prefixes

Quantity	Scientific notation	With prefix
Seconds in one day	8.64×10^{4} s	86.4 ks
Distance to Alpha Centauri	4.132×10^{16} m	41.32 Pm
Thickness of a page	4.0×10^{-5} m	40 μm

Quantity	Scientific notation	With prefix
Mass of a grain of salt	$1.0 \times 10^{-4}\ \text{g}$	$100\ \mu\text{g}$

Volume units

$$1\ \text{L} = 1000\ \text{mL} = 1\ \text{dm}^3 = 1000\ \text{cm}^3, \qquad 1\ \text{mL} = 1\ \text{cm}^3$$

1.6 Scalars and Vectors

1.6.1 Scalars

A **scalar** is completely described by **magnitude and unit** only. Examples: distance, speed, time, mass, energy, temperature. Scalars add by ordinary algebra: $5\ \text{s} + 20\ \text{s} = 25\ \text{s}$.

1.6.2 Vectors

A **vector** needs **magnitude, unit and direction**. Examples: displacement, velocity, acceleration, force, weight, momentum, electric field strength, gravitational field strength. Vectors follow **vector algebra**, not ordinary algebra.

Point	Scalar	Vector
Needs direction?	No	Yes
Described by	Magnitude + unit	Magnitude + unit + direction
Addition	Ordinary algebra	Head-to-tail rule
Shown by	A number with unit	An arrow ($\vec{F}$, $\vec{A}$)

Pairs students confuse

Scalar	Vector partner	Difference
Distance	**Displacement**	Total path travelled vs straight-line change of position with direction
Speed	**Velocity**	How fast vs how fast in a given direction
Mass	**Weight**	Amount of matter vs force of gravity on that mass

Coordinate system

A **coordinate system** locates a point by an ordered pair (x, y). The horizontal line is the **x-axis**, the vertical line is the **y-axis**, and they meet at the **origin O**. The system from which positions are described is the **reference frame**.

Representing a vector

- **Symbol:** a letter with an arrow above it, e.g. $\vec{F}$.
- **Graphically:** an arrow. **Length** shows magnitude (on a chosen scale), the **head** shows direction, the starting end is the **tail**.

Steps to draw a vector

1. Draw a coordinate system.
2. Choose a suitable scale (e.g. $5\ \text{km} = 1\ \text{cm}$).
3. Draw a line in the given direction, cut to length by the scale.
4. Put an arrowhead at the end.

1.6.3 Adding Vectors

Combining vectors into one vector with the same total effect is **vector addition**; the single vector is the **resultant**.

Head-to-tail rule: draw vectors to the same scale, place the tail of the second at the head of the first. The resultant joins the **tail of the first** to the **head of the last**.

For two **perpendicular** vectors A and B:

$$R = \sqrt{A^2 + B^2}, \qquad \tan\theta = \frac{B}{A}$$

where θ is the angle of R with A.

1.7 Measuring Instruments

The **least count (LC)** is the smallest value an instrument can measure. A measurement can never be finer than the least count.

1.7.1 Metre Rule and Measuring Tape

Point	Metre rule	Measuring tape
Shape	Rigid, straight	Flexible, rolls into a case
Length	1 m	A few feet to several metres
Use	Short lengths in lab	Long distances, curved or large objects
Least count	1 mm	Usually 1 mm

A metre rule has 1000 divisions of 1 mm each, so you cannot measure below **1 mm** with it.

1.7.2 Vernier Calliper

A **vernier calliper** reads a fraction of the smallest main-scale division by sliding a second scale over it. It measures thickness, diameter, width, **inner and outer diameter** of hollow cylinders, and depth.

Parts: main scale (fixed jaw), vernier scale (sliding, divisions slightly smaller than main-scale divisions), outside jaws, inside jaws, depth probe, retainer (locking screw).

$$\text{LC} = \frac{\text{smallest main-scale division}}{\text{number of vernier divisions}}$$

- $1\ \text{mm} \div 10 = 0.1\ \text{mm}$
- $1\ \text{mm} \div 20 = 0.05\ \text{mm}$
- A digital vernier calliper has $\text{LC} = 0.01\ \text{mm}$

Zero error: with jaws closed, the two zeros should coincide. If not:

- **Positive** zero error: vernier zero is to the **right** of main-scale zero.

- **Negative** zero error: vernier zero is to the **left**.

$$\text{True reading} = \text{Observed reading} - \text{Zero error}$$

(A negative error is therefore **added**.)

Taking a reading

1. Note LC and zero error.
2. Hold the object between the jaws. **MSR** = complete main-scale divisions before the vernier zero.
3. **VSR** = vernier division that coincides exactly with a main-scale division.
4. Total reading (then correct for zero error):

$$\text{Total} = \text{MSR} + (\text{VSR} \times \text{LC}) - \text{zero error}$$

1.7.3 Screw Gauge (Micrometer)

A **screw gauge** measures lengths smaller than a vernier calliper can, by rotating a **circular scale** over the linear scale.

Parts: frame, anvil (fixed), spindle (moving), sleeve with linear (main) scale and datum line, thimble with circular scale, ratchet.

Pitch is the distance moved along the main scale in one full rotation of the circular scale.

$$\text{LC} = \frac{\text{pitch}}{\text{number of circular-scale divisions}}$$

Example: pitch $0.5\ \text{mm}$, 50 divisions → $\text{LC} = 0.5 \div 50 = 0.01\ \text{mm}$.

Zero error: turn the thimble until anvil and spindle touch.

- **Positive** error: circular zero has not reached the datum line.
- **Negative** error: it has gone past the datum line.
- $\text{True reading} = \text{Observed} - \text{Zero error}$

Taking a reading (e.g. thickness of a wire)

1. Note pitch, LC and zero error.
2. Place the wire between anvil and spindle; close the gap with the **ratchet**.
3. Stop when the ratchet **clicks** (prevents too much pressure).
4. Read the linear scale reading.
5. Circular scale reading = (line on the datum) × LC.
6. Total reading (then correct for zero error):

$$\text{Total} = \text{Linear reading} + (\text{Circular reading} \times \text{LC}) - \text{zero error}$$

Vernier calliper vs screw gauge

Point	Vernier calliper	Screw gauge
Working idea	A scale slides over main scale	A circular scale rotates over linear scale
Least count	0.1 mm (digital 0.01 mm)	0.01 mm
Precision	Good	Higher
Measures	Diameter, thickness, inner/outer diameter, depth	Very small thickness, e.g. wire, paper

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Point	Vernier calliper	Screw gauge
Special parts	Jaws, depth probe	Anvil, spindle, thimble, ratchet
Pitch used?	No	Yes

Can you tell? Thickness of a page → **screw gauge**. Internal diameter of a beaker → **vernier calliper** (inside jaws).

1.7.4 Physical Balance

The **physical balance** measures **mass** and is sensitive to about a milligram.

- A vertical pillar holds a horizontal **beam** resting on a **knife edge**, with a **pan** at each end and a long **pointer** at the middle.
- **Levelling screws** level the balance; the case protects it from dust and wind.
- A **weight box** of standard weights is used.
- **Working:** body in one pan, standard weights in the other; mass is found from the weights used and the rest point of the pointer.
- Digital balances show mass on a display.

1.7.5 Measuring Cylinder

A **measuring cylinder** is a transparent tube with a vertical scale in mL (cm^3) for the volume of liquids. Its least count is usually about $1\ \mathrm{cm}^3$.

Volume of an irregular solid (e.g. a stone)

1. Pour water, read V_1.
2. Tie the stone to a thread, lower it fully, read V_2.
3. Volume of the solid:

$$V_{\text{solid}} = V_2 - V_1$$

Precautions: place on a flat surface; keep your eye **level with the liquid surface**; read at the **bottom of the meniscus**; lower the solid gently, fully immersed, no air bubbles.

1.7.6 Stopwatch

A **stopwatch** measures a **time interval**.

Point	Mechanical (analogue)	Digital
Display	Two circular dials (seconds and minutes)	Numbers on a screen
Controls	One knob: start, stop, reset	Two buttons: start/stop and reset (lap/split)
Least count (as per textbook)	1 s	0.1 s
Reading	Hands against dial	Direct from display

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Summary of least counts

Instrument	Least count	Use
Metre rule	1 mm	Length
Vernier calliper	0.1 mm (digital 0.01 mm)	Small lengths, inside/outside diameter, depth
Screw gauge	0.01 mm	Wire, paper thickness
Measuring cylinder	about $1\ \text{cm}^3$	Volume of liquids and irregular solids
Mechanical stopwatch	1 s	Time interval
Digital stopwatch	0.1 s	Time interval

1.8 Errors

Error is the uncertainty that appears during measurement. Every measurement is only approximate.

1.8.1 Systematic Errors

They push the result in the **same direction every time** (always too high or always too low).

- **Instrumental:** faulty design or calibration, **zero error**.
- **Technique or conditions:** temperature, humidity or wind that always affect the result the same way.
- **Personal:** bias, wrong set-up, careless observation.

They can be **estimated and corrected** using better instruments, better technique and less bias.

1.8.2 Random Errors

They are **unpredictable** and irregular. Causes: changing conditions, limits of the instrument, human factors such as **reaction time**.

They are **reduced** (not removed) by taking **repeated readings and finding the mean**.

Example: simple pendulum. One **oscillation** is a return to the same position with the same motion. The time for one oscillation is the **period** T. Human reaction is too slow to time one swing, so time **10 oscillations** and divide:

$$T = \frac{\text{total time}}{\text{number of oscillations}}$$

Point	Systematic error	Random error
Direction	Always the same	Sometimes high, sometimes low
Pattern	Consistent, repeatable	Irregular
Causes	Faulty instrument, zero error, bias	Changing conditions, reaction time
Correctable?	Yes	Only reduced
Reduced by	Calibration, better method	Repeating and taking the mean

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1.9 Precision and Accuracy

- **Precision:** how close repeated measurements are **to each other**.
- **Accuracy:** how close a measurement is to the **true value**.

A thermometer that always reads $2^{\circ}\mathrm{C}$ too high is **precise** (consistent) but **not accurate**.

Point	Precision	Accuracy
Meaning	Closeness of repeated readings	Closeness to true value
Shows	Consistency	Absence of systematic error
Affected by	Random errors	Systematic errors

Dartboard cases

Case	Darts
High precision, high accuracy	Tightly grouped on the bullseye
Low precision, high accuracy	Scattered but centred on the bullseye
High precision, low accuracy	Tightly grouped, away from centre
Low precision, low accuracy	Scattered and away from centre

1.10 Significant Figures

Significant figures are all the accurately known digits plus the **first doubtful digit** in a measurement. They show how reliable a measurement is and stop us from claiming more accuracy than the instrument gives.

1.10.1 Rules for Counting

Rule	Example
All **non-zero** digits are significant	23.457 → 5 s.f.
Zeros **between** non-zero digits are significant	100.8 → 4 s.f.
Zeros that only show **place** in a large number (no decimal point) are **not** significant	$29\,000$ → 2 s.f.
Use scientific notation to show exactly how many are meant	2.90×10^5 → 3 s.f.; 2.9000×10^5 → 5 s.f.
In numbers below 1, zeros **before** the first non-zero digit are place holders (not significant)	0.0029 → 2 s.f.
Zeros **after** a non-zero digit after the decimal point **are** significant	0.00290 → 3 s.f.

1.10.2 Rounding Off

1. Find the digit you want to keep.

2. Look at the digit just to its **right**.
3. If it is **less than 5**, leave the kept digit unchanged.
4. If it is **5 or more**, add 1 to the kept digit.
5. Drop the remaining digits. In whole numbers, replace them with zeros.

Common Mistakes

Mistake	Correct idea
Calling the **kilogram** a derived unit	It is an SI **base** unit
Writing $a \times 10^n$ with $a \geq 10$ or $a < 1$ (e.g. 469.3×10^5)	Mantissa must be from 1 to less than 10
Wrong sign of exponent	Decimal moved **left** → positive; **right** → negative
Confusing **milli** (10^{-3}) and **micro** (10^{-6})	micro is 1000 times smaller than milli
Mixing up **distance/displacement** and **speed/velocity**	The second of each pair needs direction
Calling **weight** a scalar	Weight is a vector (a force)
Forgetting **zero error**	Always check it; true = observed − zero error
Adding the zero error instead of subtracting	Subtract it; a negative error ends up added
Using a **pitch** for the vernier calliper	Pitch belongs to the screw gauge
Dropping **units** from answers	Always write the unit
Counting place-holder zeros (leading zeros) as significant	0.00650 has 3 s.f., not 6
Confusing **precision** and **accuracy**	Precision = consistency; accuracy = closeness to true value
Reading a measuring cylinder from above or at the edge	Eye level, bottom of the meniscus
Adding vectors like numbers ($3 + 4 = 7$ for perpendicular forces)	Use $R = \sqrt{A^2 + B^2}$

Chapter Summary

- Physics studies matter and energy; **physical quantities** are those that can be measured.
- SI has **seven base units**: metre, kilogram, second, ampere, kelvin, mole, candela. All others are derived.
- **Scientific notation:** $a \times 10^n$ with $1 \leq a < 10$. **Prefixes** name powers of ten.
- **Scalars** have magnitude only; **vectors** also have direction. For perpendicular vectors, $R = \sqrt{A^2 + B^2}$.
- **Vernier calliper** (LC 0.1 mm) and **screw gauge** (LC 0.01 mm) measure small lengths. Always check **zero error**.

- **Systematic** errors are fixed in direction and correctable; **random** errors are reduced by repeating and averaging.
- **Precision** is consistency; **accuracy** is closeness to the true value.
- **Significant figures** = certain digits + one doubtful digit.

Quick Formula Sheet

Topic	Formula
Scientific notation	$a \times 10^{n},\ 1 \le a < 10$
Vernier LC	$\dfrac{\text{smallest main-scale division}}{\text{vernier divisions}}$
Screw gauge LC	$\dfrac{\text{pitch}}{\text{circular divisions}}$
Vernier reading	$\text{MSR} + \text{VSR} \times \text{LC} - \text{zero error}$
Screw gauge reading	$\text{Linear} + \text{Circular} \times \text{LC} - \text{zero error}$
Resultant (perpendicular)	$R = \sqrt{A^2 + B^2},\ \tan\theta = \dfrac{B}{A}$
Volume of irregular solid	$V = V_2 - V_1$
Pendulum period	$T = \dfrac{\text{total time}}{\text{oscillations}}$
Force, pressure, energy in base units	$\text{kg m s}^{-2},\ \text{kg m}^{-1}\text{s}^{-2},\ \text{kg m}^{2}\text{s}^{-2}$

Exam tip

In vernier and screw gauge numericals, write the **least count first**, then MSR (or linear reading), then the scale reading, then the **total with its unit**, and state the zero error. Always write the unit, and give scientific-notation answers with **one non-zero digit before the decimal point**. For "differentiate between" questions, a **two-column table** earns full marks quickly.

Exam tip: Frequently asked topics are SI base units, scientific notation and prefix conversions, scalar vs vector, least count calculations, precision vs accuracy, systematic vs random errors, and counting significant figures.

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