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FSc Part-I Physics — Punjab Board

CHAPTER 1

Measurements

Key Concepts · Definitions · Short & Long Questions · MCQs · Diagrams · Exam Tips

This chapter covers Measurements from the 1st Year (FSc Part-I) Physics syllabus of the Punjab Curriculum and Textbook Board (PTB/PCTB). Physics is an experimental science based on measurement, so this chapter builds the tools every physicist needs: physical quantities and units, the International System of Units (SI), errors and uncertainties, significant figures, and dimensional analysis. These notes are prepared by freebooks.pk.

Once you can measure carefully, record results with the right number of significant figures, estimate the uncertainty, and check an equation by its dimensions, you are ready for the rest of the course. This chapter is short but forms the foundation of all practical and numerical work in Physics.

Learning Objectives

- Distinguish base and derived physical quantities and state the seven SI base units.
- Express quantities in scientific notation and use unit prefixes.
- Explain errors and uncertainties and how to reduce them.
- Apply the rules of significant figures in recording and calculating results.
- Distinguish precision and accuracy and find the least count of an instrument.
- Assess the total uncertainty in a final result.
- Find the dimensions of physical quantities and use dimensional analysis to check and derive equations.

Key Concepts

Physical Quantities: Base and Derived

A physical quantity is any quantity that can be measured, such as length, time or force. Physical quantities are of two kinds. Base (fundamental) quantities are chosen by convention and are independent of one another; there are seven of them. Derived quantities are obtained by combining base quantities through multiplication or division, for example speed (length/time), force (mass x acceleration) and density (mass/volume).

The International System of Units (SI)

To measure a quantity we compare it with a standard called a unit. The internationally agreed system is the SI, which has seven base units: the metre (m) for length, the kilogram (kg) for mass, the second (s) for time, the ampere (A) for electric current, the kelvin (K) for temperature, the mole (mol) for amount of substance and the candela (cd) for luminous intensity. All other units are derived from these, for example the newton ($N = kg\ m\ s^{-2}$) and the joule ($J = N\ m$).

Very large or very small quantities are written in scientific notation (a number between 1 and 10 multiplied by a power of ten) and are given standard prefixes such as kilo (10^3), milli (10^{-3}), micro (10^{-6}) and nano (10^{-9}).

Errors and Uncertainties

No measurement is perfectly exact; every measurement has some uncertainty. Errors are of two main types. A random error causes readings to scatter above and below the true value; it can be reduced by taking several readings and using their mean. A systematic error shifts every reading in the same direction (for example a zero error in an instrument or a wrongly calibrated scale); it is reduced by correcting or replacing the instrument.

Significant Figures

The significant figures of a measurement are the digits that are reasonably reliable, that is all the certain digits plus the first uncertain digit. The main rules are: all non-zero digits are significant; zeros between non-zero digits are significant; trailing zeros after a decimal point are significant; and in a calculation the result should not have more significant figures than the least precise measurement used. In addition and subtraction the answer is rounded to the least number of decimal places; in multiplication and division it is rounded to the least number of significant figures.

Precision and Accuracy

Precision and accuracy are different ideas. Precision refers to how finely a measurement is made and is linked to the least count of the instrument (the smallest reading it can take); a smaller least count means greater precision, shown by a smaller absolute uncertainty. Accuracy refers to how close a measurement is to the true value and is linked to the fractional or percentage uncertainty. A measurement can be precise without being accurate, and vice versa.

The least count of vernier callipers is 0.1 mm and that of a micrometer screw gauge is 0.01 mm, so the screw gauge is the more precise of the two.

Assessment of Total Uncertainty

The uncertainty in a final result is found from the uncertainties in the measured quantities using simple rules. For addition and subtraction, add the absolute uncertainties. For multiplication and division, add the percentage (fractional) uncertainties. For a power, multiply the percentage uncertainty by the power. For a mean of several readings, the uncertainty is the mean of the deviations. For a timing experiment, the uncertainty is the least count of the timer divided by the number of oscillations.

Dimensions and Dimensional Analysis

The dimensions of a physical quantity show how it is related to the base quantities mass (M), length (L) and time (T). For example, the dimensions of velocity are [LT^-1], of acceleration [LT^-2] and of force [MLT^-2]. Dimensional analysis has two main uses: to check whether an equation is correct (both sides must have the same dimensions, the principle of homogeneity) and to derive the possible form of a relationship between quantities. Its limitation is that it cannot find dimensionless constants (such as the number 2 or the factor 2 pi) and cannot be used when a quantity depends on more than three others.

Important Definitions

Term	Definition
Physical quantity	Any quantity that can be measured, such as length, time or force.
Base quantity	A fundamental quantity chosen by convention and independent of others; there are seven.
Derived quantity	A quantity obtained by combining base quantities, such as speed, force or density.
SI units	The International System of Units, with seven base units (m, kg, s, A, K, mol, cd).
Significant figures	The reliable digits in a measurement: all certain digits plus the first uncertain one.
Least count	The smallest reading that an instrument can measure.
Precision	How finely a measurement is made; linked to the least count and the absolute uncertainty.
Accuracy	How close a measurement is to the true value; linked to the fractional or percentage uncertainty.
Dimensions	The powers to which the base quantities M, L and T are raised in a physical quantity.

Formulas & Rules

Item	Fact
SI base units	metre (m), kilogram (kg), second (s), ampere (A), kelvin (K), mole (mol), candela (cd)
Least count (vernier)	smallest main-scale division / number of vernier divisions = 1 mm / 10 = 0.1 mm
Least count (micrometer)	pitch / number of circular-scale divisions = 0.5 mm / 50 = 0.01 mm
Addition / subtraction	add the absolute uncertainties
Multiplication / division	add the percentage uncertainties
Power	multiply the percentage uncertainty by the power
Dimensions of force	[MLT^-2]
Dimensions of energy / work	[ML^2T^-2]

Diagrams & Illustrations

SI base quantities and units: a table of the seven SI base quantities with their units and symbols (length/metre/m, mass/kilogram/kg, time/second/s, electric current/ampere/A, temperature/kelvin/K, amount of substance/mole/mol, luminous intensity/candela/cd).

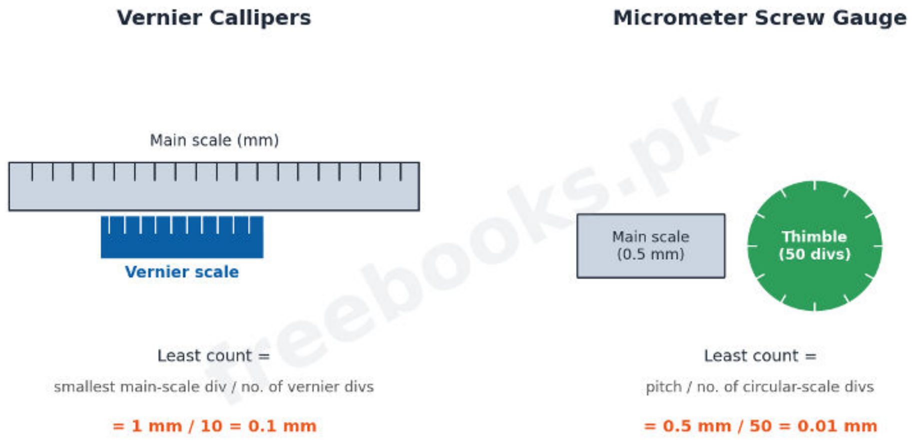
SI Base Quantities and Units

Base Quantity	Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

All physical quantities are derived from these seven base units.

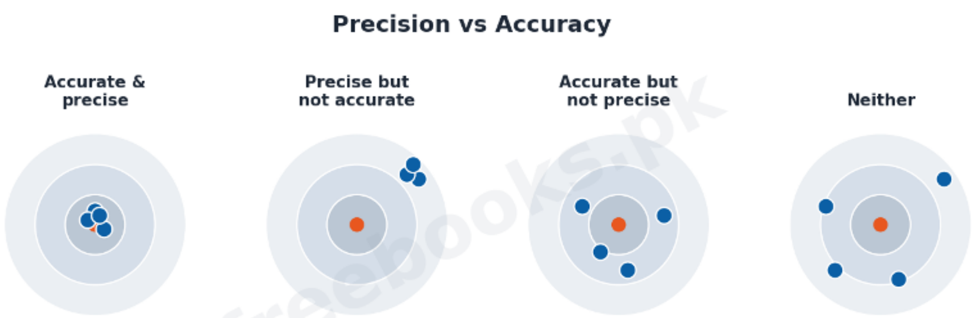
SI base quantities and units

Measuring instruments: schematic diagrams of vernier callipers (least count 0.1 mm) and a micrometer screw gauge (least count 0.01 mm), showing how the least count is calculated.



Measuring instruments

Precision versus accuracy: four target diagrams showing accurate-and-precise, precise-but-not-accurate, accurate-but-not-precise, and neither.



Solved Examples & Numericals

Significant figures

Round 3.4567 to three significant figures. Counting from the first non-zero digit, the first three significant figures are 3, 4 and 5; the next digit (6) rounds the 5 up, giving 3.46.

Uncertainty in addition

Two lengths are measured as 12.5 +/- 0.1 cm and 8.3 +/- 0.1 cm. Their sum is 20.8 cm, and because we add absolute uncertainties, the uncertainty is 0.1 + 0.1 = 0.2 cm, so the result is 20.8 +/- 0.2 cm.

Dimensional check

Check the equation v = u + at. The dimensions of v and u are [LT^-1]; the dimensions of at are [LT^-2][T] = [LT^-1]. Since every term has the dimensions [LT^-1], the equation is dimensionally correct (homogeneous).

Least count reading

A micrometer screw gauge has a pitch of 0.5 mm and 50 divisions on its circular scale. Its least count is 0.5 mm / 50 = 0.01 mm, so it can measure to the nearest hundredth of a millimetre.

Short Questions & Answers

Q1. Differentiate between base and derived quantities.
Ans. Base quantities are fundamental and independent (there are seven), while derived quantities are obtained by combining base quantities, such as speed or force.

Q2. Why is the mean of several readings taken?
Ans. To reduce random error; averaging readings that scatter above and below the true value gives a value closer to the true one.

Q3. Differentiate between random and systematic errors.
Ans. A random error scatters readings both ways and is reduced by averaging; a systematic error shifts all readings the same way and is reduced by correcting the instrument.

Q4. Differentiate between precision and accuracy.
Ans. Precision is how finely a measurement is made (linked to least count), while accuracy is how close it is to the true value (linked to fractional uncertainty).

Q5. What is the least count of a micrometer screw gauge?
Ans. 0.01 mm (pitch 0.5 mm divided by 50 circular-scale divisions).

Q6. State two uses of dimensional analysis.

Ans. To check whether an equation is dimensionally correct, and to derive the possible form of a relationship between physical quantities.

Long Questions & Answers

Q1: Explain base and derived quantities and the SI system of units.

A physical quantity is anything that can be measured, and physical quantities are of two kinds. Base or fundamental quantities are chosen by convention and are independent of one another; there are seven of them, and the SI assigns each a base unit: length (metre), mass (kilogram), time (second), electric current (ampere), temperature (kelvin), amount of substance (mole) and luminous intensity (candela). Derived quantities are formed by multiplying or dividing base quantities, for example speed is length divided by time and force is mass times acceleration; their units are derived units such as the newton and the joule. Using one agreed system (the SI) means measurements made anywhere in the world can be compared, which is why it is used in all scientific and technical work.

Q2: Explain errors and uncertainties, and state the rules for assessing the total uncertainty in a result.

No measurement is perfectly exact, so every measurement carries an uncertainty. Errors are of two types: random errors, which scatter readings above and below the true value and are reduced by taking the mean of several readings, and systematic errors, which shift every reading in the same direction (for example a zero error) and are reduced by correcting or replacing the instrument. When measured quantities are combined, the uncertainty in the final result is assessed by simple rules: for addition and subtraction the absolute uncertainties are added; for multiplication and division the percentage uncertainties are added; for a power the percentage uncertainty is multiplied by the power; for a mean the uncertainty is the mean of the deviations; and for a timing experiment the uncertainty is the least count of the timer divided by the number of oscillations. Recording the result with the correct significant figures then reflects this uncertainty honestly.

Q3: What is dimensional analysis? Give its uses and limitations with an example.

The dimensions of a physical quantity express it in terms of the base quantities mass (M), length (L) and time (T); for example force has the dimensions [MLT^-2]. Dimensional analysis uses these to work with equations. Its first use is to check the correctness of an equation: by the principle of homogeneity, every term on both sides must have the same dimensions, so an equation like v = u + at is confirmed because each term has the dimensions [LT^-1]. Its second use is to derive the possible form of a relationship; for instance the time period of a simple pendulum can be shown to depend on the square root of length divided by g, giving T proportional to the square root of (l/g). Its limitations are that it cannot find dimensionless constants (such as the factor 2 pi in the pendulum formula) and cannot handle a quantity that depends on more than three other quantities.

MCQs with Answers

1. The number of SI base units is:

(a) five   (b) six   (c) seven   (d) eight

Correct Answer: (c) seven. There are seven SI base units.

2. The SI unit of amount of substance is the:

(a) mole   (b) candela   (c) kelvin   (d) ampere

Correct Answer: (a) mole. The mole (mol) measures amount of substance.

3. Which is a derived quantity?

(a) length   (b) mass   (c) time   (d) force

Correct Answer: (d) force. Force is derived from mass and acceleration.

4. A zero error in an instrument is an example of a:

(a) random error   (b) systematic error   (c) personal error   (d) no error

Correct Answer: (b) systematic error. A zero error shifts every reading the same way, so it is systematic.

5. The least count of vernier callipers is:

(a) 1 mm   (b) 0.5 mm   (c) 0.1 mm   (d) 0.01 mm

Correct Answer: (c) 0.1 mm. 1 mm divided by 10 vernier divisions = 0.1 mm.

6. The number of significant figures in 0.00580 is:

(a) two   (b) three   (c) four   (d) five

Correct Answer: (b) three. 5, 8 and the trailing 0 are significant, giving three.

7. The dimensions of force are:

(a) $[MLT^{-1}]$ (b) $[MLT^{-2}]$ (c) $[ML^{2}T^{-2}]$ (d) $[ML^{-1}T^{-2}]$

Correct Answer: (b) $[MLT^{-2}]$. Force = mass x acceleration = $[M][LT^{-2}]$ = $[MLT^{-2}]$.

8. In multiplication and division, uncertainties are combined by adding the:

(a) absolute uncertainties   (b) percentage uncertainties   (c) squares   (d) least counts

Correct Answer: (b) percentage uncertainties. Add the percentage (fractional) uncertainties.

9. Random error can be reduced by:

(a) using a better zero   (b) taking the mean of several readings   (c) a single careful reading   (d) changing units

Correct Answer: (b) taking the mean of several readings. Averaging several readings reduces random scatter.

10. Dimensional analysis cannot find:

(a) dimensions of force   (b) dimensionless constants   (c) unit of energy   (d) homogeneity

Correct Answer: (b) dimensionless constants. It cannot determine dimensionless constants such as 2 pi.

Quick Revision Summary

- Physical quantities are base (seven) or derived; SI base units are m, kg, s, A, K, mol, cd.
- Random errors scatter readings (reduce by averaging); systematic errors shift them (reduce by correcting the instrument).
- Significant figures: keep certain digits plus the first uncertain one; round to the least precise measurement.
- Precision is linked to least count (absolute uncertainty); accuracy to fractional/ percentage uncertainty.
- Least count: vernier 0.1 mm, micrometer 0.01 mm.
- Uncertainty: add absolute (sum/difference), add percentage (product/quotient), multiply percentage by power.
- Dimensions: force [MLT^-2], energy [ML^2T^-2]; use for checking and deriving equations. Notes by freebooks.pk.

Exam Tips

- Learn the seven SI base units and their symbols by heart; a guaranteed MCQ.
- State BOTH the type of error and how to reduce it in error questions.
- For significant-figure questions, apply the addition rule (decimal places) and the multiplication rule (significant figures) correctly.
- Remember least counts: vernier 0.1 mm, micrometer 0.01 mm.
- Practise dimensional checks ($v = u + at$) and the pendulum derivation.
- Do not confuse precision (least count) with accuracy (closeness to the true value).