Applied Physics 1

Physical Quantities & Units

1. Physical Quantities

A physical quantity is any quantity that can be measured and expressed in terms of a numerical value along with an appropriate unit. In physics, every measurement consists of two essential parts — a magnitude (numerical value) and a unit. For example, when we say the length of a rod is 5 metres, "5" is the magnitude and "metre" is the unit.

Physical quantities form the foundation of all scientific measurement and are broadly classified into two categories:

- Fundamental (Base) Physical Quantities
- Derived Physical Quantities

1.1 Fundamental (Base) Physical Quantities

Fundamental physical quantities are those quantities which are independent of one another and cannot be expressed in terms of any other physical quantity. They form the basic building blocks from which all other quantities are derived. There are seven fundamental quantities recognised internationally under the SI system.

The seven fundamental quantities along with their SI units are given below:

Physical Quantity	SI Unit	Symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Electric Current	ampere	A
Thermodynamic Temperature	kelvin	K
Amount of Substance	mole	mol
Luminous Intensity	candela	cd

Key points about fundamental quantities:

- They are independent and cannot be broken down further.

- They are chosen by international agreement to form a consistent basis for measurement.
- All other physical quantities can be expressed as combinations of these seven quantities.
- Two supplementary quantities — plane angle (radian) and solid angle (steradian) — are also used alongside the seven base quantities.

1.2 Derived Physical Quantities

Derived physical quantities are those quantities which are obtained by combining two or more fundamental quantities through multiplication, division, or other mathematical operations. Their units are therefore called derived units, since they are derived from the base units.

Examples of common derived quantities:

- Area = Length × Length → unit: square metre (m^2)
- Volume = Length × Length × Length → unit: cubic metre (m^3)
- Velocity = Displacement / Time → unit: metre per second (m/s)
- Acceleration = Velocity / Time → unit: metre per second squared (m/s^2)
- Force = Mass × Acceleration → unit: newton (N) = $kg \cdot m/s^2$
- Density = Mass / Volume → unit: kilogram per cubic metre (kg/m^3)
- Work/Energy = Force × Displacement → unit: joule (J)
- Pressure = Force / Area → unit: pascal (Pa) = N/m^2

Since nearly every physical phenomenon studied in mechanics, heat, electricity, and other branches of physics can be expressed using such combinations, the number of derived quantities is virtually unlimited, while the number of fundamental quantities remains fixed at seven.

2. Units and Systems of Units

A unit is a standard or reference quantity used to express and compare measurements of a physical quantity. Without a defined unit, a numerical value alone has no physical meaning. For instance, saying a table is “2 long” is meaningless unless we specify whether it is 2 metres, 2 feet, or 2 some other unit.

A good unit should possess the following characteristics:

1. It should be well-defined, without any ambiguity.
2. It should be of a convenient and suitable size for practical use.
3. It should be reproducible so it can be recreated anywhere in the world.
4. It should not change with time, place, or physical conditions such as temperature and pressure.
5. It should be internationally accepted for uniformity in scientific communication.

2.1 Need for a System of Units

Since a physical quantity can be measured using different units (for example, length can be measured in metres, feet, or inches), it becomes necessary to adopt a standard system of units. A system of units provides a complete and consistent set of units for all physical quantities, ensuring that scientists and engineers across the world can communicate measurements without confusion.

2.2 Types of Systems of Units

Historically, several systems of units have been developed. The most important ones are:

- CGS System — based on centimetre, gram, and second.
- FPS System — based on foot, pound, and second.
- MKS System — based on metre, kilogram, and second.
- SI System — the International System of Units, an extended and modernised form of the MKS system, now used universally in science and engineering.

2.3 CGS System of Units

The CGS (Centimetre–Gram–Second) system was one of the earliest systems used in scientific work, particularly in the field of electromagnetism. In this system:

- Length is measured in centimetres (cm)
- Mass is measured in grams (g)
- Time is measured in seconds (s)

The CGS units of some derived quantities are shown below, compared with their SI equivalents:

Quantity	CGS Unit	SI Unit
Length	centimetre (cm)	metre (m)

Mass	gram (g)	kilogram (kg)
Time	second (s)	second (s)
Force	dyne	newton (N)
Energy/Work	erg	joule (J)

Although the CGS system is still occasionally used in certain branches of physics such as electrodynamics and astronomy, it has largely been replaced by the SI system for general scientific and engineering purposes.

2.4 SI System of Units (International System of Units)

The SI system, adopted internationally in 1960, is the most widely used and universally accepted system of units today. It is a coherent and rationalised system built upon the seven fundamental quantities discussed earlier, along with two supplementary units for plane angle (radian) and solid angle (steradian).

Advantages of the SI system:

- It is a coherent system — derived units are obtained directly from base units without conversion factors.
- It is a rational system — only one unit is used for each physical quantity.
- It is a metric system — multiples and submultiples are in powers of 10, making calculations simple.
- It is internationally accepted, enabling uniformity in scientific research, industry, and trade across the world.
- It absorbs the CGS, FPS, and MKS systems into a single comprehensive system.

Because of these advantages, the SI system is now the standard system used in engineering education, scientific research, and industrial applications throughout the world.

3. Multiple Choice Questions (MCQs)

Answer the following questions by selecting the most appropriate option.

1. Which of the following is a fundamental physical quantity?

A) Velocity
B) Mass
C) Force
D) Momentum

2. How many fundamental (base) quantities are there in the SI system?

A) 5

B) 6

C) 7

D) 9

3. The SI unit of electric current is:

A) Volt

B) Ohm

C) Ampere

D) Coulomb

4. Which of the following is a derived physical quantity?

A) Mass

B) Length

C) Force

D) Time

5. The CGS unit of force is:

A) Newton

B) Dyne

C) Pascal

D) Joule

6. 1 Newton is equal to how many dynes?

A) 10^2 dyne

B) 10^3 dyne

C) 10^5 dyne

D) 10^7 dyne

7. The SI unit of luminous intensity is:

A) Lumen

B) Lux

C) Candela

D) Watt

8. Which system of units uses centimetre, gram, and second as base units?

A) SI

B) FPS

C) MKS

D) CGS

9. The SI unit of thermodynamic temperature is:

A) Celsius

B) Fahrenheit

C) Kelvin
D) Rankine

10. Which of these is NOT a derived quantity?
A) Pressure
B) Density
C) Time
D) Work

11. The unit of energy in the CGS system is:
A) Joule
B) Erg
C) Calorie
D) Watt

12. The SI unit of the amount of substance is:
A) Mole
B) Gram
C) Kilogram
D) Litre

13. Which unit system is internationally accepted for scientific use today?
A) CGS
B) FPS
C) SI
D) MKS

14. Density is a derived quantity obtained from:
A) Mass and Time
B) Mass and Volume
C) Length and Time
D) Force and Area

15. The SI base unit of mass is:
A) Gram
B) Pound
C) Kilogram
D) Tonne

Answer Key

1. B) Mass | 2. C) 7 | 3. C) Ampere | 4. C) Force | 5. B) Dyne | 6. C) 10^5 dyne | 7. C) Candela | 8. D) CGS | 9. C) Kelvin | 10. C) Time | 11. B) Erg | 12. A) Mole | 13. C) SI | 14. B) Mass and Volume | 15. C) Kilogram

4. Broad / Long Answer Questions

1. Define physical quantity. Explain the difference between fundamental and derived physical quantities with suitable examples.

2. What is a unit? Explain the need for a standard system of units in physics and engineering.

3. List the seven fundamental quantities of the SI system along with their names and symbols of units.

4. Explain the CGS system of units. Give the CGS units of length, mass, time, force, and energy.

5. Compare the CGS and SI systems of units, highlighting their advantages and disadvantages.

6. Derive the dimensional formula for force and show how it is expressed as a derived quantity.

7. Explain why the SI system is preferred over other systems of units in modern science and engineering.

8. Define derived physical quantities. Give five examples along with their SI units.

9. Explain the term 'supplementary units' with examples, and state how they differ from base units.

10. Discuss the characteristics of an ideal unit. Why must a unit be well-defined, reproducible, and invariable?