Chapter 1
Physics and Measurement

Introduction:

☐ **Physics:** fundamental physical science → phenomena in Nature and Universe.
☐ Physics study natural phenomena in the Universe.

☐ Classical mechanics: motion of large objects >> size of atoms.

Move at speeds << speed of light, [e.g. planets, rockets, cars…etc.]
☐ Based on theory assumptions**, ideas, concepts** →in terms of **equations, laws, and formula** to describe natural phenomena.

☐ **Observations →Measurements and experimental observations test the validity of the theory** and check formulas used to describe the situation.

1.1 Standards of Length, Mass, and Time

Quantities are

(1) Basic quantities such as, **length, mass, time, charge.**

(2) Derived quantities: **velocity, acceleration, force**, etc⋯ derived from basic.

Physical quantities are described:

Quantitatively (كمية) by a number and qualitatively (وصفا) by a standard unit.

Quantity is given by: a number gives the a value stands before a unit of standard.

Examples: **5 meter, 10 kg, 15 Newton.**

☐ Standard systems of units

The SI system (international system of units) (Système International),

Length, ***meter, centimeter***
Mass, ***kilogram, gram***
Time **second**,

mks = meter, kilogram, second, m, kg, s

cgs: centimeter, gram, second cm, g, s

Length: in (m, cm)

- meter -- the distance traveled by light in a vacuum during a time of (1/299 792 458 s= 1/c c; being the speed of light)

Mass: kilogram (kg), gram (g)

- **BES – slug (slug)**

☐ **Standard kilogram**: platinum–iridium cylinder kept at the International Bureau of Standards at Sèvres, France

Time: Second (s) in all three systems ,

1 part of mean solar day

☐ Defined by **atomic clock** in terms of the oscillation of radiation from a cesium-133 atom
(9 192 631 700 times period of vibration of light emitted)

U.S. customary system

length in foot (ft),,

mass in slug,

time in second

Some Metric Prefixes

Tera = 10^{12}

Giga = 10^{9}

Mega = 10^{6}

Kilo = 10^{3}

milli = 10^{-3}

micro = 10^{-6}

nano = 10^{-9}

pico = 10^{-12}

femto= 10^{-15}

Table 1.4 Prefixes for Powers of Ten

Power	Prefix	Abbreviation	Power	Prefix	Abbreviation
10^{-24}	yocto	y	10^{3}	kilo	k
10^{-21}	zepto	z	10^{6}	mega	M
10^{-18}	atto	a	10^{9}	giga	G
10^{-15}	femto	f	10^{12}	tera	T
10^{-12}	pico	p	10^{15}	peta	P
10^{-9}	nano	n	10^{18}	exa	E
10^{-6}	micro	μ	10^{21}	zetta	Z
10^{-3}	milli	m	10^{24}	yotta	Y
10^{-2}	centi	c			
10^{-1}	deci	d			

EXAMPLES:

Megavolt = 10^{6} Volts

12 picoseconds = 12 x 10^{-12}sec.

1.2 Matter and Model Building

- Matter is ***made up of atoms***, the atom composed of ***electrons*** surrounding a central **nucleus**.
- The ***nucleus*** is filled with ***protons and neutrons***.
- The ***atomic number*** of the element (Z) = the number of protons.
- The ***mass number (A)*** is defined as **the number of protons plus neutrons** in a nucleus (A). ($^{A}X_{Z} = {}^{1}H_{1}, {}^{4}He_{2}, {}^{135}U_{92}$)
- Protons and neutrons are composed of quarks. The quark act as a "glue" that holds the nucleus together.

Density and Atomic Mass

The density ρ (rho) = *mass per unit volume* $\rho = \frac{m}{V}$

The atomic mass units (u): 1 u = 1.660 538 7 × 10^{-27} kg

Example: How Many Atoms in the Cube?

A solid cube of aluminum (density **2.70** g/cm³) has a volume of **0.200** cm³.
It is known that **27.0 g** of aluminum contains **6.02 × 10^{23}** atoms.
How many aluminum atoms are contained in the cube?

Solution:

(1) Find the mass of the cube of volume 0.200 cm³

$$\rho = \frac{m}{V} \Rightarrow \quad m = \rho V \ = \ 2.7 \times 0.2 = 0.54 \ \text{ g}$$

(2) The number of atoms in 0.54 g is then; no. of moles × Avogadro number

$$\text{no.of moles} = \frac{\text{mass}}{\text{Molar mass}} = \frac{0.54}{27}$$

$$N_{cube} = N_A \cdot (\text{no. of moles}) = N_A \times \frac{0.54}{27} = 6.02 \times 10^{23} \times \frac{0.54}{27.0} = 1.20 \times 10^{22} \ \text{ Atoms}$$

1.3 Dimensional Analysis

☐ In physics, **Dimension** denotes the **physical nature of a quantity**

Example: Distance has dimension of Length measured in **cm, m, or feet.**

Symbols which specify the dimensions:

Dim. Of length = **L**

Dim. Of Mass = **M**, and,

Dim. Of time = **T**,

Brackets [ ] used to denote **the dimensions** of a physical quantity. [Width] = L

☐ **Example:** Dimensions of the speed **[υ] = L/T.**

Dimensional analysis

(1) Checks if an equation is correct using Dimension

(2) used to set up an expression

☐ **Example of dimensional analysis**

d = v t **Is it dimensionally correct?**

[Distance] = [velocity]× [time]

$$L = (L/T) \times T = L$$ **[الابعاد يمينا = الابعاد يسار]**

☐ **Suppose** $X \;\alpha\; a^n t^m$

x = travel distance,

a = acceleration, and

t = time. **Find** ***n*** **and** ***m*** **using dimensional analysis**

Dimension of left is length: $[x] = L = L^1 \cdot T^0$

Dimension of right: $[a^n \cdot t^m] = (L/T^2)^n \cdot (T^m)$

$$[x] = [a^n t^m],$$

$$L^1 \cdot T^0 = \frac{L^n}{T^{2n}} \times T^m = L^n \cdot T^{m-2n} \qquad \Rightarrow n = 1$$

$$\Rightarrow m - 2n = 0,\ m = 2\times 1 = 2$$

$$\Rightarrow x \;\alpha\; a\, t^2$$

☐ **Example 1.1** **Analysis of an Equation**

$v = a \cdot t$ is it dimensionally correct?

Solution : For the speed term,

Left side $[v] = \frac{L}{T} : \frac{m}{s}$

Right side $\mathbf{[at]} = [a][t] = \frac{L}{T^2} \cdot T = \frac{L}{T}$ the expression is dimensionally correct.

☐ Example 1.2 Analysis of a Power Law

Suppose **the acceleration <u>a</u>** of a particle moving with uniform **speed v** in **a circle of radius r** is proportional to some power of **r**, say $\mathbf{r^n}$, and some power of **v**, say $\mathbf{v}^m$. Determine the values of *n* and *m* and write the simplest form of an equation for the acceleration.

Solution take *a* to be

$$a = k\, r^n v^m$$ <u>***k* is a dimensionless constant**</u>

$$[a] = [k\, r^n v^m] = [r^n][v^m] \;;\; [k] = 1$$

$$\frac{L}{T^2} = L^n \cdot \frac{L^m}{T^m} = \frac{L^{n+m}}{T^m} \Rightarrow n+m=1, \quad m=2 \quad \text{and} \quad n=-1$$

or $a = kv^2r^{-1}$, $a = k\frac{v^2}{r}$.

1.4 Conversion of Units

Converts units from one system of measurement (SI, US-customary) to another or within the same system.

☐ Examples:

1 mile = 1 609 m = 1.609 km
1 ft = 0.3048 m = 30.48 cm

1 m = 39.37 in. = 3.281 ft

1 in. = 0.0254 m = 2.54 cm (exactly)

The ratio between each pair of the above examples is 1.

☐ Examples:

15 inch = 15 inch × 2.54 cm/1 inch = 38.1 cm

10 liter water = 10 liter ×1000cm^3/ 1 liter = 10,000 cm^3

Mass of gram 10 cm^3 of water = 10 cm^3 × 1 gram/cm^3

The ratios: 1 inch/2.54 cm, 1000 cm^3/ 1 liter, 1 gram/cm^3 are conversion factors.

☐ Example 1.3 Is He Speeding?

On an interstate highway in a rural region of Wyoming, a car is traveling at a speed of **38.0 m/s**. Is this car exceeding the speed limit of **75.0 mi/h**?

(1mi = 1 mile , h = hour)

1 mi = 1609 m , $1h = 60\ \ min \times \dfrac{60s}{m} = 3600s$

$$38m/s = 38 \times \left(\frac{1}{1609}mi\right)\left(\frac{1}{(1/3600)h}\right) =$$

$$38 \times \left(\frac{1}{1609}mi\right)\left(\frac{3600}{1}\frac{1}{h}\right) = 85\,mi/h$$ Car exceeding the speed limit.

What is the speed of the car in km/h?

$$85.0\,mi/h = 85.0 \times (1.609km)/h = 137\,km/h$$

1.5 Estimates and Order-of-Magnitude Calculations

Estimated quantities can be expressed by *order of magnitude*,

→ Multiplier × 10^n → 10^{n+1} or 10^n

(1) Write value in scientific notation, *with the multiplier of the power of ten between 1 and 10 and a unit.*

(2) *Multiplier < 3.162 (the square root of 10), omit it only.*

Multiplier > 3.162, → power of 10 increased by one scientific notation.

The symbol ~ is used for "is on the order of."

☐ Examples

1- The value of a quantity **increases** by **three orders of magnitude**, means that its value increases by a factor of about $\mathbf{10^3 = 1\,000}$.

2- The order of magnitude of:

$0.0086 \approx 0.009 = 9\times10^{-3} \sim 10^{-2}$ **(9>√10 = 3.162 increment power by 1)**

$0.0021 \approx 0.002 = 2\times10^{-3} \sim 10^{-3}$ **(don't increment)**

$720 \approx 700 = 7\times10^{2} \sim 10^{3}$ **(increment 1)**

1.6 Significant Figures

☐ **measured quantities** are always **uncertain**.

This **experimental uncertainty** depend on the quality of the apparatus, the skill of the experimenter, and the number of measurements performed.

Accuracy (or uncertainty) is represented in terms of **significant figures**.

When the value obtained, **the last digit** is **uncertain (doubtful)**, the **other digits are certain**

☐ Rules for deciding the number of significant figures in a measured quantity:

- **All non-zero digits are significant digits (zero is insignificant if there is no decimal point)**

  4 , 40, 400 has **one significant digit**

  1.3 , 130 , 1300 has **two significant digits**

  4 325.334 has **seven significant digits**

- **Zeros are significant only:**

1- **If they lie between two significant digits.**

109 has **three significant digits**

3005 has **four significant digits**

40.001 has **five significant digits**

2- To right of significant only if there is a decimal point

0.10 has two significant digits (the **leading** zero is not significant, but the **trailing** zero is significant); **1.0** 2 sig. fig

0.0010 has two significant digits (the last two) ;

3.20 has three significant digits, (note: 320 has two significant figures);

320.0 has 4 significant figures

Example: measurement of the area

Accuracy of a meter stick to which we can measure lengths is ± 0.1 cm (**the smallest division**).

Length (**L**) = **6.4 cm**, the correct L lies some where between **6.4 cm** and **6.6 cm**.
Width (W) = **5.5 cm**, the actual value lies between **5.3cm and 5.4 cm.**

The measured values are written as: (best value ± uncertainty) unit

L = 6.4 ± 0.1 cm (2 sig. fig.)
W = 5.5 ± 0.1 cm (2 sig. fig.)

The last digit is uncertain, and determines the **absolute uncertainty or experimental errors**.

A mass of 15.20 g indicates an absolute **uncertainty of 0.01 g**. So we write:

m = 15.2 ± 0.01 (wrong)
m = 15.20 ± 0.01 (right)

To find the area A = W×L

A = W×L = (**5.5 ± 0.1**) × (**6.4 ± 0.1**) [Treat them as polynomials]

= [5.5×6.4] ± [5.5×0.1 + 6.4×0.1 + 0.1×0.1]

= 35.2 ± [0.55 + 0.64 + 0.01] = 35.2 ± 1.2 cm^2

Another way to find ΔA is to use $\frac{\Delta A}{A} = \frac{\Delta L}{L} + \frac{\Delta W}{W}$

$$\Delta A = A[\frac{\Delta L}{L} + \frac{\Delta W}{W}] = 35.2 \times 0.0338 = 1.20 \approx 1.2$$

Rule: In multiplication and division, the answer must *have the same number of significant figures as that in the component with the least number of significant figures.* Then,

A + ΔA = 35 ± 1 cm^2

(A = 35 has 2 sig. fig as the measured values.

Error = 1 = small unit of last digit)

For example,

3.0 × 12.60 = 37.8000≈ 38

3.0 (2 significant figures) × 12.60 (4 significant figures) = 37.8000, which should be rounded off to 38 (2 significant figures)

Zeros come after nonzero significant figure lead to misinterpretation. For example, **suppose the mass of an object is given as 1 500 g**. **This value is ambiguous** because we do not know whether the last two zeros are being used to locate the decimal point or whether they represent significant figures in the measurement.

To remove ambiguity of zeros, use scientific notation

1500 2 sig. fig

1.5×10^3 g (with two significant figures)

1.50×10^3 g (with three significant figures)

1.500×10^3 g (if there are four significant figures)

The same rule holds for numbers less than 1, so

0.000 23 = 2.3×10^{-4} (both with 2 sig. fig.)

0.000 230 = 2.30×10^{-4} (both with 3 sig. fig.)

For addition and subtraction:

When numbers are added or subtracted, the number of decimal places in the result should equal the smallest number of decimal places of any term in the sum.

As an example of this rule, consider the sum

23.2 + 5.174 = 28.374 =28.4

$$\underset{one}{23.2} + \underset{three}{5.174} = 28.374 = \underset{one\ d.d.}{28.4}$$

For example:

123 + 5.35 = 128 and not 128.35 (No Dec. places)

1.0001 + 0.0003 = 1.0004 **(4 decimal digits)**

1.002 - 0.998 = 0.004 **(3 decimal digits but only one significant)**

100 + 1.0 = 101.0 = **100** **[no decimal place]**

100 - 0.1 = **99.9 =100 [no decimal place]**

rounding off numbers: [التقريب]

(1) last digit dropped > 5, digit retained increment by 1

For example, 12.6 is rounded to 13

(2) last digit dropped < 5, digit retained kept unchanged.

For example, 12.4 is rounded to 12

(3) last digit = 5, the last remaining digit should be rounded to the nearest even number. (i.e. is increased by one if it is odd, but left as it is if even.

For example, 11.15 is rounded to 11.2 and

11.25 is rounded to 11.2

Example 1.8 Installing a Carpet

A carpet is to be installed in a room whose length is measured to be **12.71 m** and whose width is measured to be **3.64 m. find the area of the room**.

Solution

A = 12.71 × 3.46 = 43.976 6 m^2 (Answer must be rounded off so as to have only 3 sig. fig. as the measured quantity with the lowest number of significant figure)

→ A = 44.0 (3 sig. fig)