Chapter 1

Measurement

القياس

Measuring Things

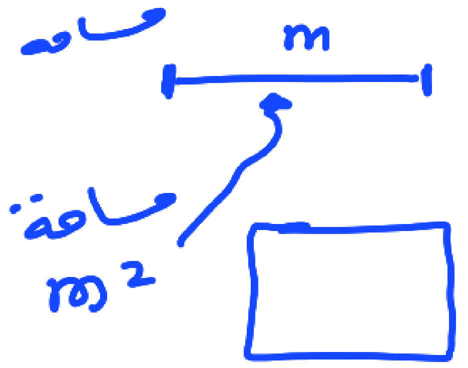
- To measure any physics quantity, we need magnitude and unit
- For example: the full day is 24 hours
- Each unit must be compared to a standard
- There are 3 *Base Quantities* (Length, Time, Mass).
- We then define all other physical quantities in terms of these *base quantities* and their standards (called *base standards*).
- For example: volume is length × length × length, density is the ratio of mass to volume (volume is length × length × length) …
- Base standards must be both accessible and invariable

Table 1-1 Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

Volume = $l \times l \times l$

$$\text{density} = \frac{m}{V} = \frac{kg}{m^3}$$



The Physical Quantities

نوعين من الوحدات الاساسية

There are two types of Physical Quantities

1 — كميات اصلية

Basic Physical Quantity

2 — كميات مشتقة

Derived Physical Quantity

- كتلة — Mass denoted as M (kg)
- طول — Length denoted as L (m)
- زمن — Time denoted as T (s)

It is any quantity that can be expressed by the basic quantity, such as area, volume, density, force, velocity, etc.

اي وحدة يمكن كتابتها باستخدام الوحدات الاساسية

There are three common systems of units

1. International system of units (SI units) → النظام العالمي للمقاييس SI unit
2. British system of units (UK units) → النظام البريطاني (UK unit)
3. Gaussian system of units (*cgs* units) → النظام الغاوسي (مصغر) (cgs unit)

حفظ ١٠٠

Quantity (كميات)	System: SI	System: British	System: CGS
Length	Meter (m)	Foot (ft) قدم	Centimetre (cm)
Time	second (s)	Second	second
Mass	Kilogram (kg)	Pound_mass (lbm)	Gram (g)
Force (القوه)	Newton (N)	Pound_force (lbf)	Dyne

The International System of Units (SI Units)

- The *International System* of units (abbreviated as SI units) has only seven quantities that are chosen internationally as *base quantities*. These units are used to *derive* any other unit in science.
- In this course we need only these three base quantities: length, time, mass to derive all other units we will study.

length	meter	m
mass	kilogram	kg
time	second	s
electric current (تيار كهربائي)	ampere	A
thermodynamic temperature (درجة الحرارة)	kelvin	K
amount of substance (كمية المادة)	mole	mol
luminous intensity (شدة الإضاءة)	candela	cd

For example:

$$\text{Speed} = \frac{\text{Length}}{\text{Time}}$$

السرعة = المسافة / الزمن

speed = m/s

Derived quantity — Speed

base quantities — Length, Time

Table 1-1 Units for Three SI Base Quantities

Quantity	Unit Name	Unit Symbol
Length	meter	m
Time	second	s
Mass	kilogram	kg

$$\therefore \text{Unit of speed} = \frac{\text{unit of length}}{\text{unit of time}} = \frac{m}{s}$$

Prefixes for SI Units

- To express the very large and very small quantities we often run into in physics, we use *scientific notation*, which employs powers of 10. In this notation,

$$3\,560\,000\,000 \text{ m} = 3.56 \times 10^9 \text{ m}$$

$$0.000\,000\,492 \text{ s} = 4.92 \times 10^{-7} \text{ s} = 492 \times 10^{-9} \text{ s}$$

- When dealing with very large or very small measurements, we use the prefixes listed in Table 1-2, For example:

$$1.27 \times 10^9 \text{ meter} = 1.27 \text{ gigameter} = 1.27 \text{ Gm}$$

$$2.35 \times 10^{-9} \text{ s} = 2.35 \text{ nanoseconds} = 2.35 \text{ ns}$$

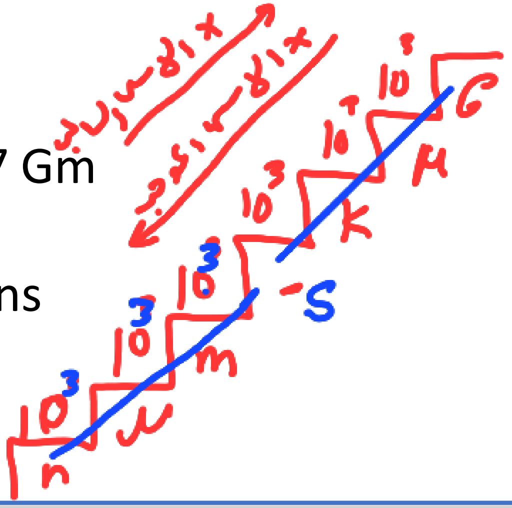


Table 1-2 Prefixes for SI Units

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

Changing Units

- We often need to change the units in which a physical quantity is expressed.
- We multiply the original measurement by a **conversion factor** (معامل التحويل)
- For example, because 1 min and 60 s are identical time intervals, we have:

$$1\ \text{min} = 60\ \text{s}$$ ← *Conversion factor between min and s*

1 min = 60 s

1 yd = 0.91 m

- If we need to convert 2 min to seconds:

$$2\ \text{min}\left(\frac{60\ s}{1\ min}\right) = \frac{2\ \text{min}\times 60\ s}{1\ min} = 120\ \text{s}$$

$$2\ min \times \left(\frac{60\ s}{1\ min}\right) = 120\ s$$

- Another example: we need to change the quantity 15 m/s to its equivalent in cm/min:

Conversion factors are: 1 min = 60 s and 1 m = 100 cm, so,

$$\frac{15\ m}{1\ s} \rightarrow \frac{15\times100}{\frac{1}{60}}\ \frac{cm}{min}$$

$$15\ \frac{m}{s}\left(\frac{100\ cm}{1\ m}\right)\left(\frac{60\ s}{1\ min}\right) = \frac{15\ m\times100\ cm\times60\ s}{1\ s\times1\ m\times1\ min} = 90000\ \text{cm/min}$$

$$= 90000\ cm/min$$

- By using this method, we can convert any unit to any other unit (even if we are not familiar with these units)

لو كان عنا وحده مركبه من بسط ومقام نحول البسط وحده والمقام وحده

<u>Example 1</u>: The speed of a car is 35 m/s. What was this speed in km/h?

<u>Solution:</u>

Conversion factor:

1 km = 1000 m and 1 h = 3600 s

The speed is $v = 35\ \frac{m}{s} = 35\ \frac{m}{s} \times \left(\frac{1km}{1000\ m}\right) \times \left(\frac{3600s}{1h}\right)$

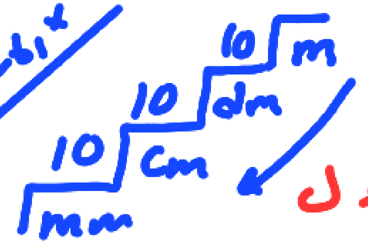
$$= \frac{35 \times 1 \times 3600}{1000 \times 1}\ \frac{km}{h} = 126\ km/h$$

$$\frac{35\ m}{1\ s} = \frac{35 \times 10^{-3}}{\frac{1}{3600}}\ \frac{km}{hr}$$

$$= 35 \times 10^{-3} \times 3600 = 126\ km/hr$$

Notes on unit conversion:

If there is a power in the unit, you must use the same power for the conversion factor.



$1\ m = 100\ cm$

$1\ m^2 = (100)^2\ cm^2 \Longrightarrow 1\ m^2 = (10\ 000)\ cm^2$

$1\ m^3 = (100)^3\ cm^3 \Longrightarrow 1\ m^3 = (1\ 000\ 000)\ cm^3$

For example, converting 5.3 m² to cm² unit will be:

$$5.3\ m^2 \times \left(\frac{10000\ cm^2}{1\ m^2}\right) = 53000\ cm^2$$

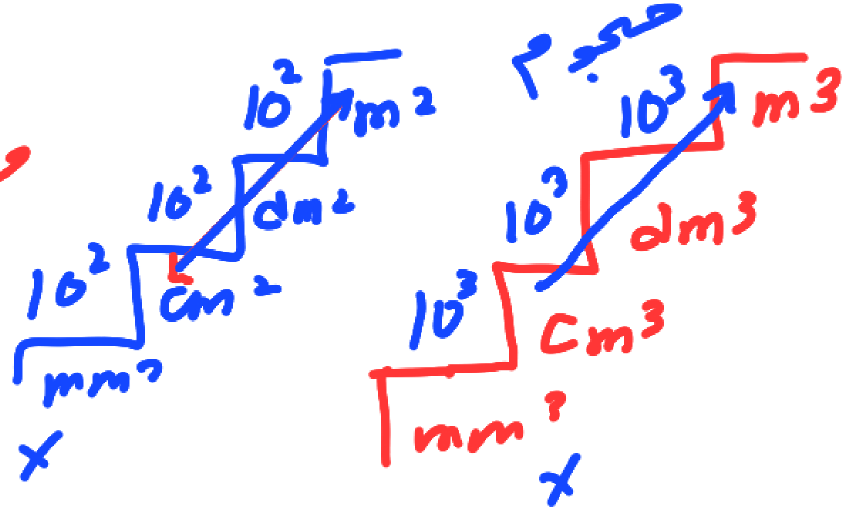
$1\ cm = 10^{-2}\ m$

$1\ cm^2 = (10^{-2})^2\ m^2 \Longrightarrow 1\ cm^2 = (10^{-4})\ m^2$

$1\ cm^3 = (10^{-2})^3\ m^3 \Longrightarrow 1\ cm^3 = (10^{-6})\ m^3$

For example, converting 5.3 cm² to m² unit will be:

$$5.3\ cm^2 \times \left(\frac{10^{-4}\ m^2}{1\ cm^2}\right) = 5.3\times10^{-4}\ m^2 = 0.00053\ m^2$$



$5.3\ m^2 \rightarrow 5.3\times10^{4}\ cm^2 = 53000\ cm^2$

$5.3\ cm^2 \rightarrow 5.3\times10^{-4}\ m^2 = 0.00053\ m^2$

الطول

Length

- In 1792, the meter (m) was selected to be the standard unit of length.

التعريف القديم لـ m

- The old definition of the meter: the meter, defined to be one ten-millionth of the distance from the north pole to the equator.

تعريف m

- Later, the meter was defined as the distance between two fine lines engraved near the ends of a platinum–iridium bar, the **standard meter bar**, which was kept at the International Bureau of Weights and Measures near Paris.

تعريف حديث لـ m

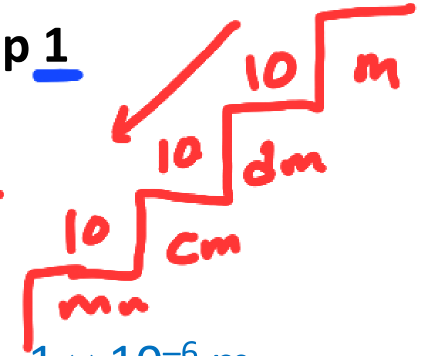
- New definition of the meter: The meter is the length of the path traveled by light in a vacuum during a time interval of 1/299 792 458 of a second.

المسار الذي يقطعه الضوء في الفراغ خلال فترة زمنية $\frac{1}{299792458}$ ثانية

The standard meter

It is a bar of Platinum-Iridium kept at a constant temperature The meter is defined as the distance between the two scratch marks

Example: The micrometer (1 μm) is often called the *micron.* (a) How many microns make up 1 km? (b) What fraction of a centimeter equals 1 μm? (c) How many microns are in 1 yd?



Solution:

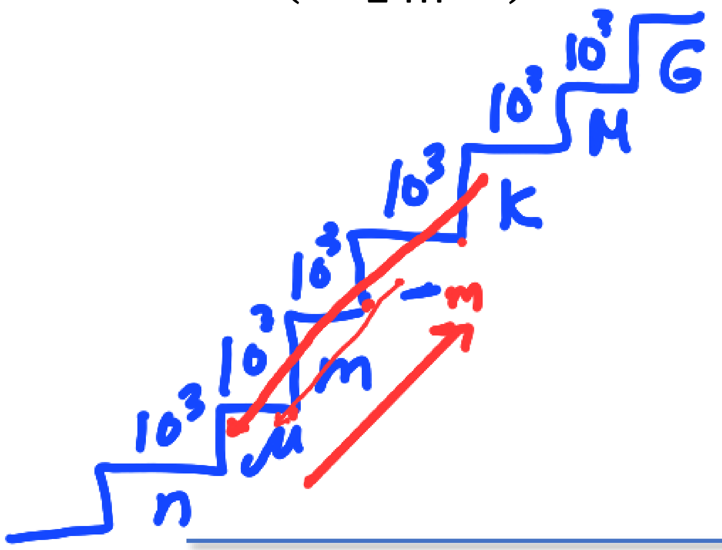
(a) Conversion factors:

1 km = 1×10^3 m and 1 m = 1×10^6 μm,

$\Longrightarrow$ 1 km = 10^3 m

Now we convert 10^3 m to μm:

$$10^3 \text{ m} \times \left(\frac{1\times106\mu\text{m}}{1 \text{ m}}\right) = 10^9 \ \mu\text{m}$$



(b) Conversion factors:

1 cm = 1×10^{-2} m and 1 μm = 1×10^{-6} m,

$\Longrightarrow$ 1 μm = 1×10^{-6} m

Now we convert 1×10^{-6} m to cm:

$$1 \times 10^{-6} \text{ m} \times \left(\frac{1 \text{ cm}}{1\times10^{-2} \text{ m}}\right) = 1 \times 10^{-4} \text{ cm}$$

(c) Conversion factors:

1 yd = 0.91 m and 1 m = 1×10^6 μ m,

$\Longrightarrow$ 1 yd = 0.91 m

Now we convert 0.91 m to μ m:

$$0.91 \text{ m} \times \left(\frac{1\times106\mu\text{m}}{1 \text{ m}}\right) = 9.1 \times 10^5 \ \mu \text{ m}$$

Example: In printing some books, a length unit of "points" and "picas" are used: 12 points = 1 pica, and 6 picas = 1 inch. What is 0.8 cm in (a) picas and (b) points?

cm → inch → picas → point

1 inch = 2.54 cm
1 inch = 6 picas
1 pica = 12 point

Solution:

We need first to convert cm to inch:

Conversion factor:
1 in = 2.54 cm

$$0.8\ \text{cm} \times \left(\frac{1\ \text{in}}{2.54\ \text{cm}}\right) = 0.315\ \text{in}$$

Now we convert in to picas and points:

① التحويل من cm ← inch

$$\frac{0.8\ \text{cm}}{2.54} = 0.315\ \text{inch}$$

② التحويل من inch الى picas

$0.315\ \text{inch} \times 6 = 1.9\ \text{picas}$

a) Conversion factor:
6 picas = 1 inch

$$0.315\ \text{in} \times \left(\frac{6\ \text{picas}}{1\ \text{in}}\right) = 1.9\ \text{picas}$$

b) Conversion factor:
12 points = 1 pica

$$1.9\ \text{picas} \times \left(\frac{12\ \text{points}}{1\ \text{pica}}\right) = 22.8\ \text{points}$$

③ التحويل من Picas ← Points

$1.9\ \text{picas} \times 12 = 22.8\ \text{Points}$

Time

- Any phenomenon that repeats itself is a possible time standard, for example, Earth's rotation, which determines the length of the day, has been used in this way for centuries
- However, the accuracy of measuring time this way is not good enough for science and engineering technology.
- To meet the need for a better time standard, atomic clocks have been developed
- One second is defined as the time taken by 9 192 631 770 oscillations of the light emitted by the cesium atom.
- Atomic clocks are so consistent and accurate.

Example: A plant can grow 3.7 m in 14 days. What was its growth rate in micrometers per second?

μm / s

Solution:

day → hr → min → s
(×24) (×60) (×60)

growth rate سرعه النمو الكلي

$$= \frac{3.7\ \text{m}}{14\ \text{day}} = \frac{3.7 \times 10^{6}}{14 \times 60 \times 60 \times 24} \frac{\mu\text{m}}{\text{s}}$$

$$= 3\ \mu\text{m/s}$$

Conversion factor:

$1\ \text{m} = 1 \times 10^{6}\ \mu\text{m}$ and $1\ \text{day} = 86400\ \text{s}$

The growth rate in m/days = $\frac{3.7\ \text{m}}{14\ \text{day}} = 0.26\ \text{m/day}$

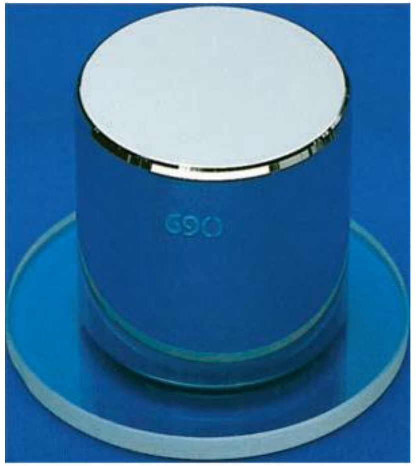
Now, convert 0.26 m/day to μm/s:

$$0.26\left(\frac{\text{m}}{\text{day}}\right) \times \left(\frac{1 \times 10^{6}\ \mu\text{m}}{1\ \text{m}}\right) \times \left(\frac{1\ \text{day}}{85400\ \text{s}}\right) = \left(\frac{0.26\ \text{m} \times 1 \times 10^{6}\ \mu\text{m} \times 1\ \text{day}}{1\ \text{day} \times 1\ \text{m} \times 86400\ \text{s}}\right) = 3\ \mu\text{m/s}$$

Mass

- Mass used to be measured by making a comparison to the "standard kilogram"

- The Standard Kilogram: The SI standard of mass is a cylinder of platinum and iridium that is kept at the International Bureau of Weights and Measures near Paris



- The masses of atoms can be compared with one another more precisely than they can be compared with the standard kilogram. For this reason, **the mass of carbon atom is used as a second mass standard**. By agreement,

mass of carbon atom = 12 atomic mass unit (u).

$$1\ u = 1.66054 \times 10^{-27}\ kg$$

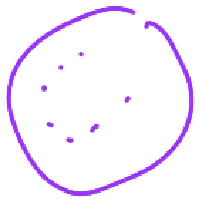
- In 2019, the kilogram definition has changed (it is defined now based on some universal physics constants).

Example: Earth has a mass of 5.98×10^{24} kg. The average mass of the atoms that make up Earth is 40 u. How many atoms are there in Earth?

5.98×10^{24} kg كتلة الارض

40 u كتلة الذرة

$$\text{عدد الذرات} = \frac{\text{كتلة الارض}}{\text{كتلة الذرة}}$$



Solution:

Conversion factor:

1 u = 1.66054×10^{-27} kg

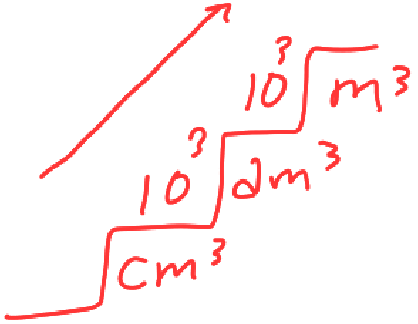
$$\Longrightarrow \text{mass of one atom} = 40\ \text{u} \times \left(\frac{1.66054 \times 10^{-27}\ \text{kg}}{1\ \text{u}}\right) = 6.64 \times 10^{-26}\ \text{kg}$$

$$\text{Number of atoms in Earth} = \left(\frac{\text{mass of Earth}}{\text{mass of one atom}}\right) = \left(\frac{5.98 \times 1024\ \text{kg}}{6.64 \times 10\text{–}26\ \text{kg}}\right) = 9 \times 10^{49}\ \text{atoms}$$

$$\text{atom mass} = 40\ \text{u} = 40 \times 1.66054 \times 10^{-27}\ \text{kg} = 6.64 \times 10^{-26}\ \text{k}$$

$$\text{Number of atoms} = \frac{\text{mass of earth}}{\text{mass of atom}} = \frac{5.98 \times 10^{24}}{6.64 \times 10^{-26}} = 9 \times 10^{49}\ \text{atom}$$

Example: Assuming that water has a density of exactly 1 g/cm³, find the density of water in kg/m³.



Solution:

$$\frac{1\ g}{1\ cm^3} = \frac{1 \times 10^{-3}\ kg}{1 \times 10^{-6}\ m^3} = 1000\ kg/m^3$$

Conversion factor:

$1\ g = 1\times10^{-3}\ kg$ and $1\ cm^3 = 10^{-6}\ m^3$

$$1\left(\frac{g}{cm^3}\right)\times\left(\frac{1\times10^{-3}\ kg}{1\ g}\right)\times\left(\frac{1\ cm^3}{10^{-6}\ m^3}\right) = \left(\frac{10^{-3}}{10^{-6}}\right) kg = 10^3\ kg/m^3 = 1000\ kg/m^3$$

A light-year is a measure of length (not a measure of time) equal to the distance that light travels in 1 year. Compute the conversion factor between light-years and meters.

Solution:

The conversion factor from years to second is

$$1y = 1y \times \frac{365.25d}{1y} \times \frac{24h}{1d} \times \frac{60min}{1h} \times \frac{60s}{1min} = 3.16 \times 10^7 s$$

The speed of light is $3.00 \times 10^8 m/s$.

Thus in 1 year, light travels a distance of

$$(3.00 \times 10^8\ m/s)\ (3.16 \times 10^7 s) = 9.48 \times 10^{15}\ m$$

So that

$$1\ ly\ = 9.48 \times 10^{15}\ m$$