Physical Quantities- Measurements and Units

Key Words

to measure	base	length	depth	kilogram	metre
measurement (-s)	derived	width	volume	tonne	mass
magnitude	unit	area	intensive	extensive	matter
scientific notation					

We can state that Physics is based on measurements. When we investigate physical bodies, it is not enough to say that one body is "big" whereas another is "small". Concepts as "big" and "small" are relative. We have to have something, with which we can compare the characteristics of the bodies in an exact way. Since ancient times, man has used different measures to do this.

What are Physical Quantities?

A physical quantity is a measurable property of an object, a substance or a phenomenon (such as time).

A **physical quantity** is made up of two parts, a number and a unit. Physical quantities allow us to describe our surroundings and the phenomena that take place in them.

When you study mathematics, you usually use pure number (like 3 or 6.5 or π), or variables that represent pure numbers (such as x and y). **In science,** however, **numbers are used to represent** physical quantities: **quantities that correspond to something in the physical world**. It is therefore important to know what kind of quantity a number represents. So, how is that done? This is done by specifying units of measurements for each quantity. **Numbers that measure a physical quantity must always include the unit.**

For example, if you see the quantity "2.5 m" you know that it is the measurement of a distance, as distance is measured in metres. But if you see "2.5 m^2" instead, you know that is a surface area that has been measured.

You must always remember to include the unit of measurement when dealing with scientific data or express scientific quantities in any other context.

Base (or fundamental) and derived physical quantities

We can distinguish two types of physical quantities:

Base physical quantities	**Derived physical quantities**
- Can be **measured directly**, without calculations or mathematical operations.	- Are the **results of a mathematical operation** with base physical quantities.

So, **base physical quantities** are fundamental physical quantities that cannot be broken down into simpler ones therefore, that are not defined in terms of other physical quantities. Some examples are length, mass and time.

On the other hand, **derived physical quantities** are those that can be broken down into base physical quantities. Another way of saying is that derived magnitudes are a combination of base quantities by multiplication, division or both.

Please use full sentences and proper English to answer the following questions.

- Use a ruler to measure the length of your notebook. _________________.

- Is length a base or a derived quantity? Why?

- Calculate the area of your notebook. Explain whether area is a base or a derived quantity.

- Look for a definition of *speed* and *density*. Explain if they are base or derived quantities.

➢ Fill in the table.

Quantity	Instrument(s) used	Do we need calculations?	Base or derived quantity?
Length			
Area			
Volume			
Temperature			
Time			
Mass			

A system of units - The International System (SI)

The handspan was one of the first measuring units used by man. However, the handspan is a measure which varies from one person to another. Its use in commerce to measure objects (cloth, thread, land...) caused lots of problems. Therefore, in some places, like the Italian cities Pisa and Geneva, a standard handspan measure was established centuries ago, so that all salesmen of the city would use the same measure.

Nevertheless, later on it became clear that the standard handspan measure in different places was not exactly the same. Today we know, for example, that the handspan used in Pisa was 29.8 cm whereas the handspan used in Geneva was only 24.7 cm!
To finally resolve the problem with measures which varied from one person to the other and from one place to the other, the **International System** of measures (Système International d'Unités, SI) was established.

In order to establish the SI system, first of all, they determined the base quantities and the units used to measure them. And building on those base quantities, they defined the derived quantities and the units which corresponded to each quantity.

In the following table, you can see some **base quantities** which make up the International System, the **base unit** of each one, and the **unit abbreviations or symbol** used to represent them.

In order to make communication between scientist around the world easier, most scientists use the international system (SI units).

Base Quantity	SI unit name	SI unit symbol
Length	metre	m
Mass	kilogram	kg
Time	second	s
Current	ampere	A
Temperature	kelvin	K
Amount of substance	mole	mol
Luminous intensity	candela	cd

Of these seven base quantities length, mass and time are the ones used more often in our everyday life. Therefore, we will define them in greater detail.

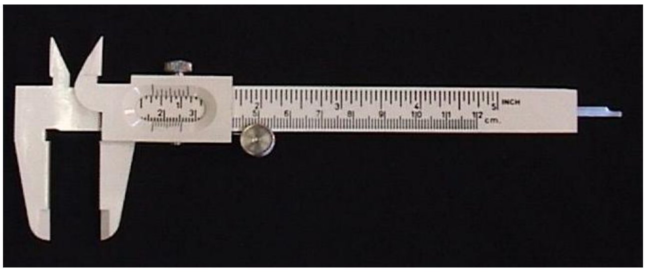
Length

The SI unit of length is the metre (m). At one time, the standard metre was the distance between two marks on a metal bar kept at the Office of Weights and Measures in Paris. A more accurate standard is now used, based on the speed of light. **By definition, one metre is the distance travelled by light in a vacuum in 1/299 792 458 of a second.**

There are larger and smaller units of length based on the metre: (km, cm, mm, nm, etc).

<u>Measuring length</u>

To measure length, we use a **metre** or a **ruler**. For smaller lengths, we can use **Vernier caliper** (picture 1) or even a **micrometer** (picture 2).



Picture 1. Vernier caliper

Picture 2. Micrometer

Mass

Mass is the amount of substance or matter in an object.

Later on in the year you will study in more detail how mass affects objects, as:

- All objects are attracted to the Earth according to their mass. The greater the mass of an object, the stronger is the Earth's gravitational pull on it.
- All objects resist attempts to make them go faster, slower, or in a different direction. The greater the mass, the greater is the resistance to change in motion.

The SI unit of mass is the kilogram (kg).

Measuring mass

To measure mass, we use a **balance**. A beam balance is the simplest and probably the oldest way to measure mass. However, you will use an electric balance or an electric scale when working in the lab, a more modern type of balance.

("Google, 2016)

Length and mass use the decimal system

Sometimes we need to measure something very big, like the distance between the Sun and Earth, or something very small, like the mass of a pollen grain. In these cases, the base units are not the most adequate. Instead, we use the **decimal system** to make **multiples** and **submultiples** of the base units. In the decimal system (deci = ten), the units are multiples of ten. Each multiple equals to ten units of the closest smaller unit, and each submultiple equals to one tenth of the closest bigger unit.

The multiples and submultiples are indicated with **prefixes**. The closest submultiple of a metre is a *deci*metre (1 m = 10 dm). And a gram is the equivalent of one thousandth of a *kilo*gram (multiple) or 1000 *milli*grams (submultiple).

In the following table, you can see the prefixes and their abbreviations.

Prefix	**Abbreviation**	**Example: length**	**Example: mass**
Milli- (= one thousandth)	m-	millimetre (mm)	milligram (mg)
Centi- (= one hundredth)	c-	centimetre (cm)	centigram (cg)
Deci- (= one tenth)	d-	decimetre (dm)	decigram (dg)
-	-	metre (m) **(base unit)**	gram (g)
Deca- (= ten)	Da-	decametre (dam)	decagram (dag)
Hecto- (= hundred)	h-	hectometre (hm)	hectogram (hg)
Kilo- (= thousand)	k-	kilometre (km)	kilogram (kg) **(base unit)**

1 tonne (t) = 1000 kg

Time: The decimal system is not used for all quantities

When we are working with units of time, we notice that they are built up on a different system. Time units were based on observations of astronomic phenomena such as the position of the Sun on the sky, the phases of the Moon and the seasons. This way, the **day**, the **month** and the **year** were defined. Based on these units, the most commonly used time units were calculated: the **hour**, the **minute** and the **second**. In the International system, the **second** has been established as base unit for time.

The units which are bigger than the second do not follow the decimal system!

► Calculate the following quantities. **Do not use a calculator**!

1 .... = 365.2 days = 31 553 280 s

1 day = ... hours = 86 400 s

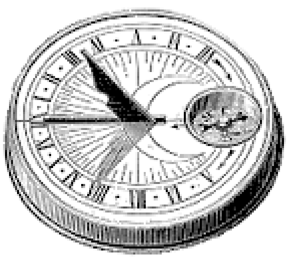
1 hour = ... minutes = ... s

1 min = ... s

However, when we are talking about time units which are **smaller** than the second, we use the decimal system. For example in a sprinter race, we talk about tenths and hundredths of seconds. In some case we even use thousandths of seconds.

Measuring time

Time is measured with **clocks** or **stopwatches**. The first clocks were sundials.

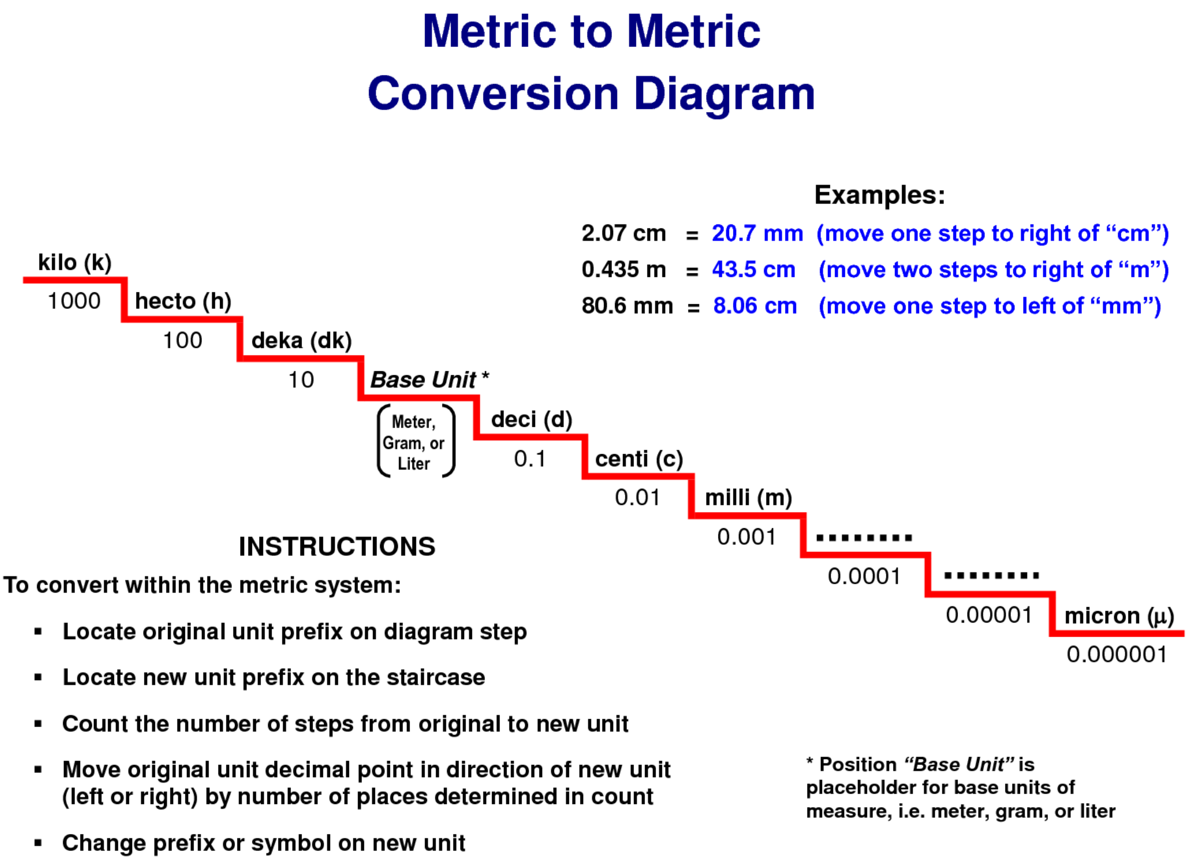


1500-1300 BC

The sundial was first used in Egypt to measure the time of day by the Sun's shadow. Hours are shorter in winter and longer in summer.

Decimal System - How can we easily change the unit?

Changing the place of the decimal separator in a measured value one or various steps right or left, we can easily change the unit to the most adequate multiple or submultiple.



(HubPages, 2015)

<u>You must know the SI unit of the different physical quantities we study throughout the year and be able to use the decimal system.</u> In science SI units are often used, and always when a physical constant is present. You will see what a physical constant is in later units.

- Change the units of the following values.

20 kg = ... mg	653 cg = ... hg	3 dl = ... hl
500 ml = ... dl	0.5 dal = ... cl	110 cg = ... mg
46 dam= .... km	8 t = ... g	0.01 m =........................ cm

Scientific Notation

Scientific notation is another useful tool for expressing physical quantities. Numbers in scientific notation have one nonzero digit to the left of the decimal point, the remaining digits to the right of the decimal point, and are multiply by a power of 10.

By using scientific notation (powers of ten numbers) we intend to avoid two problems:

- Writing lots of zeros is not very convenient.
- You don't always know which zeros are accurate.

To avoid these two problems, numbers are written using powers of ten:

Eg. If we say that a town has approximately 140 000 inhabitants, we would write it using scientific notation:

$140\ 000 = 1.4 \times 10^5$ ($10^5 = 100\ 000$)

By using scientific notation we are avoiding writing all those zeros which may not be accurate. At the same time, this notation is telling you that figures 1 and 4 are important. Those important numbers are what we call **significant figures**. So, the number has been given to ***two significant figures.***

<u>If we know</u> that this number has 3 significant figures, then we will write it the following way:
1.40×10^5

Therefore, **significant figures (sig figs) are the figures in a number that allows us to appreciate the precision in a measurement. In science, when writing a number using scientific notation all the significant figures must be included.**

Rules for determining Significant Figures

- Figures that do not contain zeros are always significant → 134.76
- All figures to the right of a decimal place are significant, including zeros → 12.30
- Zeros at the beginning of a number are not significant → 0.00025 or 0.89
- Zeros at the end of a number without a decimal are not significant → 14500

Let's write using scientific notation the above numbers:

134.76: ___________________ 14500: _______________________

12.30: ____________________

0.00025: ___________________

0.89: _____________________

We will talk more about significant figures throughout the year, especially in the laboratory, as it is very important when dealing with the precision of a measurement and the instrument with which it was recorded**.**

- Represent the following quantities using scientific notation:

a) 1 600 m : ………………………………………

b) 1 400 000 m: ………………………………….

c) 0.0018 g: ……………………………………

d) 0.1601 g: ………………………………….

e) 0.010 g: ……………………………….

Conversion Factor

A conversion factor is a mathematical tool for converting between units of measurement. It consists on **a fraction in which the denominator is equal to the numerator, therefore equal to 1.**

"A *conversion factor* is used to change the units of a measured quantity without changing its value. Because of the identity property of multiplication, the value of a number will not change as long as it is multiplied by one.[3] Also, if the numerator and denominator of a fraction are equal to each other, then the fraction is equal to one. So as long as the numerator and denominator of the fraction are equivalent, they will not affect the value of the measured quantity".

Let's work it out! ☺

How can I change km/h to m/s and vice versa? Well, this is very easy using conversion factors.

Let's say I want to **convert 20 m/s into km/h**

$$\frac{20\ \text{m}}{1\ \text{s}} = ?\ \frac{\text{km}}{\text{h}}$$

We all know that 1000 m = 1 km, and that 3600 s = 1 h.

We also know that 20 • 1 = 20. 20 • 1 • 1 • 1 • 1 • 1 is also = 20

$$\frac{1}{1} = 1 \qquad \frac{1000\ \text{m}}{1\ \text{km}} = 1 \qquad \frac{3600\ \text{s}}{1\ \text{h}} = 1$$

so if we put $$\frac{20\ \text{m}}{1\ \text{s}} \cdot \frac{3600\ \text{s}}{1\ \text{h}} \cdot \frac{1\ \text{km}}{1000\ \text{m}}$$

it is just like if we had $$\frac{20\ \text{m}}{1\ \text{s}} \cdot 1 \cdot 1$$ - which is the same as 20 m/s.

This allows us to eliminate the units we do not need, and get others we need. But, we also need to do the corresponding calculations taking into account all the numbers!!

Attention! We can only eliminate identical units which are on <u>different sides</u> of the (extended) division line:

$$\frac{20\ \cancel{\text{m}}}{1\ \cancel{\text{s}}} \cdot \frac{3600\ \cancel{\text{s}}}{1\ \text{h}} \cdot \frac{1\ \text{km}}{1000\ \cancel{\text{m}}}$$

$$= \frac{20 \cdot 3600 \cdot 1\ \text{km}}{1 \cdot 1 \cdot 1000\ \text{h}}$$

$$= \frac{7200\ \text{km}}{100\ \text{h}} = 72\ \text{km/h}$$

► Now you change the 72 km/h back to m/s and see if you get the correct result! Good luck!

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