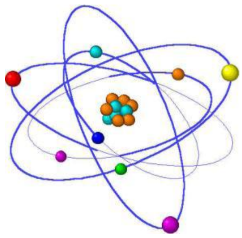
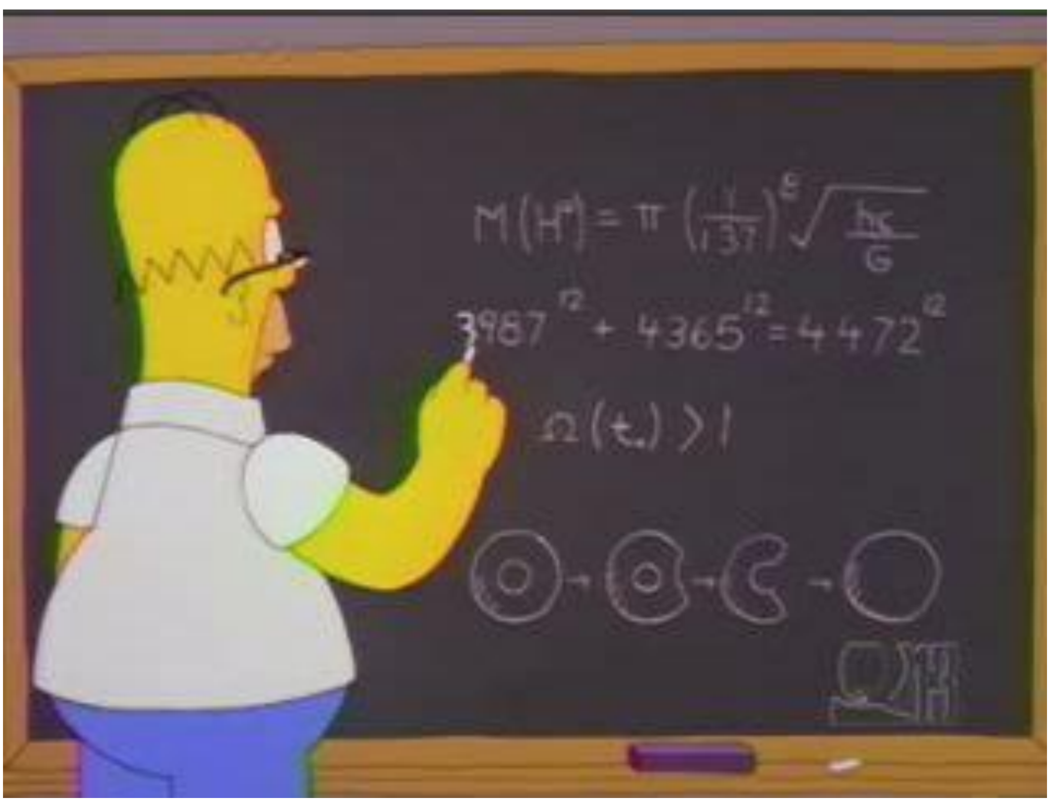
Prestwick Academy



Physics Department

Units, Prefixes and Uncertainties



Success Criteria

Units, prefixes and scientific notation

I can:

- use SI units of all physical quantities appearing in the 'Content Statements'.
- use prefixes (p, n, μ, m, k, M, G, T).
- give answers to calculations to an appropriate number of significant figures.
- use scientific notation.

Uncertainties

I can:

- state that measurement of any physical quantity is liable to uncertainty.
- distinguish between random uncertainties and recognised systematic effects.
- state that the scale reading uncertainty is a measure of how well an instrument scale can be read.
- explain why repeated measurements of a physical quantity are desirable.
- calculate the mean value of a number of measurements of the same physical quantity.
- state that this mean is the best estimate of a true value of the quantity being measured.
- state that where a systematic effect is present the mean value of the measurements will be offset from a "true value" of the physical quantity being measured.
- calculate the approximate random uncertainty in the mean value of a set of measurements using the relationship:

$$\textbf{\textit{approximate random uncertainty in the mean}} = \frac{\textbf{\textit{maximum value - minimum value}}}{\textbf{\textit{number of values}}}$$

- estimate the scale-reading uncertainty incurred when using an analogue display and a digital display.
- express uncertainties in absolute or percentage form.
- identify, in an experiment where more than one physical quantity has been measured, the quantity with the largest percentage uncertainty.
- state that this percentage uncertainty is often a good estimate of the percentage uncertainty in the final numerical result of the experiment.
- express the numerical result of an experiment in the form:

final value ± uncertainty.

Introduction

Physics is the study of how things work. From the smallest atom to the entire universe and everything in between. It allows us to explain how things move, how the universe began and how it might end. But how do we know these things? By experimenting!

Physicists observe the world around them and make predictions and hypotheses based on these observations. Their observations usually involve making measurements and it is critical that these measurements are as reliable as possible.

When people first started measuring things, they did not have rulers. To measure length, they measured things against their own bodies. An inch was about the width of an adult thumb. The foot was about the length of a human foot. A cubit was the length from your elbow to your finger tip.

What problems can you see with this type of measurement?

In 1790, the French decided to make things simpler. They started something called the metric system. This system uses multiples of ten for its units of measurement. The **International System of Units,** which is given the abbreviation **SI** from the French: *Le Système international d'unités*, is the modern form of the metric system and is used almost globally.

However, no measurement can be one hundred percent accurate, this is why we have to consider uncertainties.

Lesson 1: Prefixes, Scientific Notation and Significant Figures

The following prefixes are used to denote multiples and sub-multiples of any unit used to measure a physical quantity.

Name	Symbol	Power of 10
tera	T	$\times10^{12}$
giga	G	$\times10^{9}$
mega	M	$\times10^{6}$
kilo	k	$\times10^{3}$
centi	c	$\times10^{-2}$
milli	m	$\times10^{-3}$
micro	μ	$\times10^{-6}$
nano	n	$\times10^{-9}$
pico	p	$\times10^{-12}$

You must make sure you remember these values and their powers as they will not be given in the exam.

SAQ 1

Use scientific notation to write the measurements in the units shown.

1. 12 GHz = Hz
2. 4.7 MW = W
3. 46 km = m
4. 3.6 mV = V
5. 0.55 mA = A
6. 25 μA = A
7. 630 nm = m
8. 2200 pF = F

SAQ 2

Rewrite the following quantities in the units shown.

1. 14×10^{3} m = km
2. 2.3×10^{7}W = MW
3. 5.6×10^{8} Hz = GHz = MHz
4. 4.6×10^{-3} V = mV = μV
5. 2.5×10^{-5} A = μA = mA
6. 4.50×10^{-7} m = nm
7. 4.70×10^{-9} F = pF = μF

Significant Figures

It is important when you carry out calculations that your answers are given to an appropriate number of significant figures. A voltage written as 6.95 V is given to 3 significant figures.

As a general rule your answer should contain the same number of significant figures as the l*east accurate value in the question.*

Example

A resistor has a current of 2.5 A through it when the voltage across it is 8.95 V. Calculate the resistance of the resistor.

$$R = V/I$$
$$= 8.95/2.5$$
$$= 3.58\ \Omega$$

Since I is only given to two significant figures the answer should be written as R =3.6 Ω.

SAQ 3

Find the answers to the following to the appropriate number of significant figures.

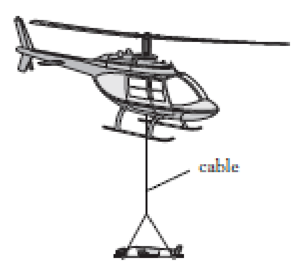
a) Calculate the time taken for a signal to travel along a **glass optical** fibre of length 40 km. The speed of light in the optical fibre is 2.0×10^8 ms^{-1}.

b) A 300 W games console operates at 9.0 % of its power rating when on standby.

   Calculate the number of kilowatt-hours used by the games console whilst on standby for 14 days.

c) A parachutist lands badly and is airlifted to hospital by helicopter. A winch is used to lift the stretcher and parachutist into the helicopter.

   If the combined mass of the stretcher and parachutist is 90.0 kg, calculate the total weight.



Complete Homework 1.

Lesson 2: Errors

It is important to realise that all experimental measurements have a degree of uncertainty associated with them. That is, we cannot take any measurement which is 100% accurate.

Activity
Collect a metre stick and use it to measure the length, breadth and height of the room in millimetres.

Questions
1. How do your groups results compare with the others in the class?
2. Are any groups results very different from the others?
3. If yes, why do you think this is?
4. How could you make your results more accurate?

Mistakes

Anyone can make a mistake when they are taking measurements. It is important that you take repeat readings in order that any obvious mistakes can be discounted.

Errors

There are three different types of error:

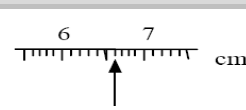
Systematic errors
These occur when all measurements are affected in the same way e.g. a metre stick might have "shrunk", thus giving consistently incorrect readings or an ammeter may be incorrectly zeroed, meaning all results will be out by the same amount.

NB A systematic error might also be present if the experimenter is making the ***same mistake*** each time in taking a reading.

Reading Errors
When using measuring instruments it is important that we take into account how accurate they are. An estimate of reading uncertainty for an analogue scale is generally taken as:

± half the smallest division of the scale.

Example



(6.60 **± 0.05) cm**
Length lies between 6.55 and 6.65) cm

NB For widely spaced scales, this can be a little pessimistic and a reasonable estimate should be made.

Example

(9.0 ± 0.5) m
Length lies between
(8.5 and 9.5) m

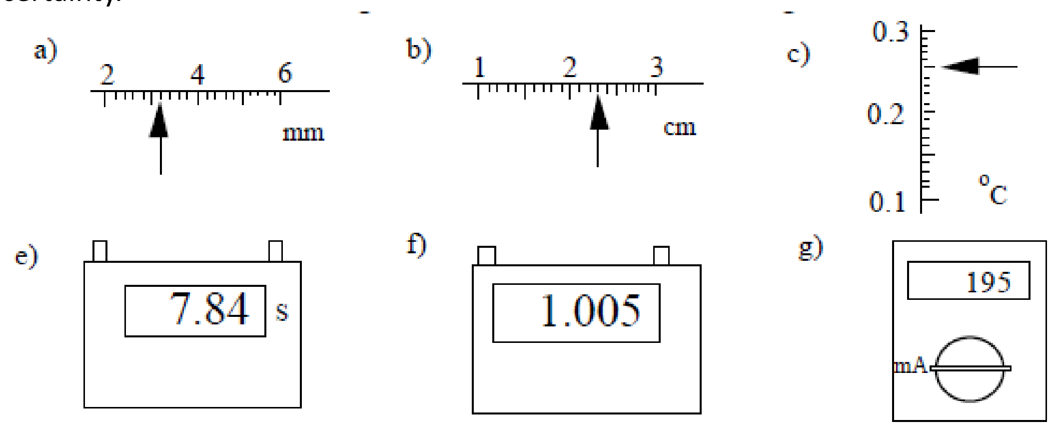
For a digital scale it is taken as

± 1 in the least significant digit displayed

Example **8.94s** (8.94 ± 0.01) s
Time lies between (8.93 and 8.95) s.

SAQ 4

For each of the following scales, write down the reading and estimate the uncertainty.



Random Errors

Random fluctuations can affect measurements from reading to reading, e.g. consecutive timings of the period of a pendulum can differ. The best estimate of the true value is given by repeating the readings and then calculating the mean value.

The random uncertainty is then calculated using the formula below:

$$\textbf{random uncertainty} = \frac{\textbf{maximum value} - \textbf{minimum value}}{\textbf{number of values}}$$

Example
The times for 10 swings of a pendulum are: 1.1, 1.4, 1.2, 1.3 and 1.1 s

Mean value = 1.2 s

$$\text{random uncertainty} = \frac{\text{maximum value} - \text{minimum value}}{\text{number of values}}$$

$$= \frac{1.4 - 1.1}{5}$$

$$= 0.06\text{s}$$

Since the mean is given to two significant figures we write the error and uncertainty as follows:

Time for 10 swings = (1.2 ± 0.1) s

NB When the uncertainty is expressed in units then it is known as the ***absolute uncertainty***.

SAQ 5
a) Calculate the mean time and random uncertainty for the following readings:

0.8 s, 0.6 s, 0.5 s, 0.6 s and 0.4 s.

b) A student uses light gates and a suitably interfaced computer to measure the acceleration of a trolley as it moves down a slope. The following results were obtained.

a / ms^{-2}	5.16, 5.24, 5.21, 5.19, 5.12, 5.20, 5.17, 5.19.

Calculate the mean acceleration and the corresponding random uncertainty.

Lesson 3: Comparing Errors

It is important when we are carrying out practical work that we realise the errors in each measurement contribute to the error in the final result.

Example
A pupil carries out an experiment to find the resistance of an unknown resistor. He uses an analogue meter to measure the voltage across it which he records as (6.2 ± 0.1) V. Then he uses a digital meter to measure the current through the resistor which he records as (28.55 ± 0.01) mA.

Questions
1. Which of the above measurements will have the largest effect on the error in the resistance?
2. Why do you think this?

When comparing uncertainties it is easier to compare the ***percentage errors*** in order to find which will have the largest effect on the final result. To find the percentage error we use the relationship

Percentage error = (error value/actual value) x 100

Consider the example above. The percentage error in the voltage would be found as follows:

Percentage error = (error value/actual value) x 100
= (0.1/6.2) x 100
= 1.6%

and the percentage error in the current would be

Percentage error = (error value/actual value) x 100
= (0.01/28.55) x 100
= 0.04%

This means that the voltage measurement contributes the ***largest error*** to the value of resistance. To calculate the resistance we then use

$$R = V/I = 6.2/28.55\times10^{-3} = 217.2\ \Omega \pm 1.6\%$$

To write the answer in absolute form we would take 1.6% of 217.2 Ω :

$$R = (217.2 \pm 3.5)\ \Omega$$

Activity

Aim: To find the average speed of a trolley moving down a slope, estimating the uncertainty in the final value.

Apparatus: 1 ramp, 1 trolley, an electronic timer and 2 light gates.

Instructions

1. Set up a slope and place the light gates 90 cm apart.
2. Note the scale reading uncertainty.
3. Calculate the percentage uncertainty in the distance.
4. Ensuring the trolley starts from the same point each time, measure the time taken for the trolley to pass between the two points.
5. Repeat 5 times, calculate the mean time and estimate the random uncertainty.
6. Note the scale reading uncertainty in the time.
7. Calculate the percentage uncertainty in the time.
8. Calculate the average speed and associated uncertainty.
9. Express your result in the form:

(speed ± absolute uncertainty) m s^{-1}

SAQ 6

A pupil is carrying out an investigation to calculate the speed of water waves in a tank. The results obtained are shown below:

Frequency (Hz)	26	24	26	25	24	26
Wavelength (m)	0.53	0.55	0.56	0.55	0.54	0.57

Calculate:

a) the mean frequency and it's associated error.
b) the mean wavelength and it's associated error.
c) the percentage uncertainty in the frequency.
d) the percentage uncertainty in the wavelength.
e) the speed and it's associated uncertainty and write it in the form:

(speed ± absolute uncertainty) ms^{-1}

Complete Homework 2.