Principles of practical physics

Key knowledge

- **independent, dependent and controlled variables**
- **the physics concepts specific to the investigation and their significance, including definitions of key terms, and physics representations**
- **the characteristics of scientific research methodologies and techniques of primary qualitative and quantitative data collection relevant to the selected investigation, including experiments (gravity, magnetism, electricity, Newton's laws of motion, waves) and/or the construction and evaluation of a device; precision, accuracy, reliability and validity of data; and the identification of, and distinction between, uncertainty and error**
- **identification and application of relevant health and safety guidelines**
- **methods of organising, analysing and evaluating primary data to identify patterns and relationships including sources of uncertainty and error, and limitations of data and methodologies**
- **models and theories, and their use in organising and understanding observed phenomena and physics concepts including their limitations**
- **the nature of evidence that supports or refutes a hypothesis, model or theory**
- **the key findings of the selected investigation and their relationship to concepts associated with waves, fields and/or motion**
- **the conventions of scientific report writing and scientific poster presentation, including physics terminology and representations, symbols, equations and formulas, units of measurement, significant figures, standard abbreviations and acknowledgment of references.**

Introduction

Physicists deal with **physical quantities,** which are those things that are *measureable* such as mass, length, time, electrical current, etc.

Units

In Physics we use SI (Système Internationale) units. There are seven basic quantities from which all others are derived.

Quantity	Unit	Unit Symbol
Mass	kilogram	kg
Length	metre	m
Time	second	s
Electric current	ampere	A
Temperature	kelvin	K
Luminous intensity	Candela	cd
Amount of substance	mole	mol

metre (m): the length of the path travelled by light in a vacuum during a time interval of 1/ 299 792 458 of a second.

kilogram (kg): mass equal to the mass of the international prototype of the kilogram kept at the Bureau International des Poids et Mesures at Sèvres, near Paris.

second (s): the duration of 9 192 631 770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium-133 atom.

ampere (A): that constant current which, if maintained in two straight parallel conductors of infinite length, negligible circular cross-section, and placed 1 m apart in vacuum, would produce between these conductors a force equal to 2 × 10^–7 newtons per metre of length.

kelvin (K): the fraction 1/ 273.16 of the thermodynamic temperature of the triple point of water.

mole (mol): the amount of substance of a system that contains as many elementary entities as there are atoms in 0.012 kg of carbon–12. When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles.

candela (cd): the luminous intensity, in a given direction, of a source that emits monochromatic radiation of frequency 540 × 1012 hertz and that has a radiant intensity in that direction of 1/ 683 watt per steradian.

All quantities that are not fundamental are known as *derived* and these can always be expressed in terms of the fundamental quantities through a relevant equation. Examples:

Quantity	Unit	Unit Symbol	Derivation
Force	newton	N	$kg\ m\ s^{-2}$
Energy	joule	J	$kg\ m^{2}\ s^{-2}$
Power	watt	W	$kg\ m^{2}\ s^{-3}$
Pressure	pascal	P	$kg\ m^{-1}\ s^{-2}$
Electric charge	coulomb	C	A s
EMF (electric potential)	volt	V	$kg\ m^{2}\ s^{-3}\ A^{-1}$
Frequency	hertz	Hz	s^{-1}

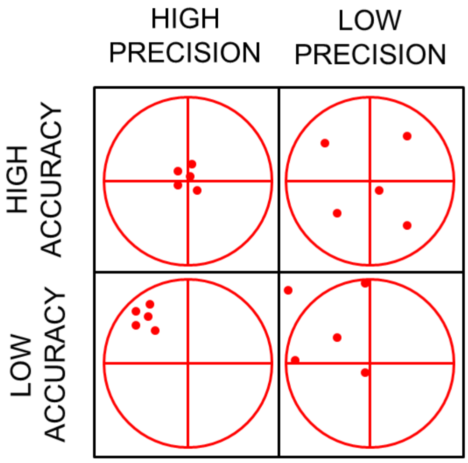
10^{24}	10^{21}	10^{15}	10^{12}	10^{9}	10^{6}	10^{3}	10^{0}
Yotta	Zetta	Peta	Tera	Giga	Mega	kilo	
Y	Z	P	T	G	M	k	

10^{-3}	10^{-6}	10^{-9}	10^{-12}	10^{-15}	10^{-18}	10^{-21}	10^{-24}
milli	micro	Nano	pico	femto	atto	zepto	yocto
m	µ	N	p	f	a	z	y

Uncertainties

When we take measurements it can be useful to know how certain we are about those measurements, so that we know how certain we are about our results.

No measurement is exact. When a quantity is measured, the outcome depends on the measuring system, the measurement procedure, the skill of the operator, the environment, and other effects. Even if the quantity were to be measured several times, in the same way and in the same circumstances, a different measured value would in general be obtained each time, assuming the measuring system has sufficient resolution to distinguish between the values.



Measuring devices:

Different measuring devices have different levels of uncertainty. The standard rule is ± ½ the smallest division. For example, if you are measuring the length of a piece of paper and you have 2 rulers; one that measures in centimetres and one that measures in millimetres, you would expect more precision with a ruler calibrated in mm.

Scientific form and significant figures

Scientific form is when the quantities are written in powers-of-ten notation.
E.g. 3 021 000 is written as 3.021×10^6 and 0.0045 is written as 4.5×10^{-4}.

The values of all observed measurements are ‘best estimates’ of the ‘true value’. In stating best estimates, only those figures which are **significant,** and in fact known, are included.

The level of precision of your measurement is dependent on the instrument that you are using to take the measurement. E.g. If you measured an object with a ruler you might find that its length was 2.4 cm. This means that your reading was closest to 2.4 cm, but could have been between 2.35 and 2.449 cm. Your approximation was that it was 2.4 cm.
If you measured the same object with a micrometre, your answer may have been 2.42 cm, again the ‘2’ is just a best estimate.

The value 2.4 has two significant figures, whereas 2.42 has 3 sig figs. Since they were measurements you cannot add further ‘zeroes’ on the right-hand end, as these will specify a greater level of precision of the measurement.

If you were asked to quote your answer in metres, then your answer could be 0.024 m. This still has just 2 sig figs, because this answer could be written in scientific form as 2.4×10^{-2} m, thus identifying that it has only two figures that were measured (ie. significant).

Summary

- All non-zero digits are significant.
- Zeros between non-zero digits are significant.
- Leading zeros are never significant.
- In a number with a decimal point, trailing zeros, those to the right of the last non-zero digit, are significant.
- Whole numbers will have the same significant figures as number of digits,
  for example 400 has three significant figures while 400.0 has four.

Some numbers are exact, i.e. counting numbers and so have an infinite number of sig figs. Eg. If there are 25 students in your class, then this can be written as 25.00000…….. The zeroes do not add any clarity to the measurement. Fractions behave in this manner also.

In general terms, the number of significant figures is a measure of the precision of the measurement, so the zeroes on the right hand end of the number are significant, but the zeroes on the left hand end only give the place value, which can be overcome by using scientific form notation.

When working with sig figs, you can only reliably quote your answer to the level of precision of the measurement with the least number of significant figures, used in your calculation.

We must take significant figures into consideration whenever we are using '**measured**' values in our calculations.

<u>Types of error</u>

Random

Caused by unknown and unpredictable changes in the experiment. Random error can occur in measuring instruments or environmental conditions. The amount of random error limits the precision of the experiment.

Systematic

Systematic errors usually come from measuring instruments, for example if there is something wrong with the instrument/data handling, or if the instrument is used incorrectly (this can also include parallax error). The amount of systematic error limits the accuracy of the experiment. Systematic errors can be more difficult to detect than random errors. Repeating a reading never removes the systematic error.

Definitions

Independent, dependent and controlled variables
The independent variable is the variable that the experimenter changes, to find out what changes occur to the dependent variable.
Controlled variables are unchanged throughout the experiment.

Precision, accuracy, reliability and validity of data;
Precision is the closeness of the data to itself. Accuracy is the closeness to the true value. Reliability is a measure of close repeated experiments give the same result. Validity refers to how well a test measures what it is purported to measure.

Uncertainty and error
Uncertainty is the margin of error of a measurement. Error is the difference between a measured value and the true value.

Hypothesis, model or theory
A hypothesis is an idea that can be tested experimentally. A model is an evidence based representation of something that cannot be displayed directly. It is often said that a good model predicts things that are previously unknown. A theory is often a set of principles used to explain a set of facts or phenomena; it is based on repeated verification.

Dimensions

The dimensions of any quantity can be written in terms of the dimensions of the fundamental quantities.

Eg. force = mass × acceleration

$$= \text{mass} \times \frac{\text{velocity}}{\text{time}}$$

$$= \text{mass} \times \frac{1}{\text{time}} \times \frac{\text{displacement}}{\text{time}}$$

Letting M = mass (kg), L = length (m), and T = time (s) this equation becomes

$$= [M] \times [T]^{-1} \times [L][T]^{-1}$$

$$= [M][L][T]^{-2}$$

For any equation to be correct, the dimensions on the LHS of the equation must equal the dimensions on the RHS. Therefore, the units of force (newtons, N) must have the same dimensions.

Measuring and Propagating Uncertainties

Types of uncertainties:

- An **Absolute Uncertainty** is denoted by the symbol "Δ" and has the same units as the quantity.

- A **Relative** or **Percent Uncertainty** is denoted by the symbol "ε" and has no units.

To convert back and forth between the two types of uncertainties use the following rules:
If m = (3.3 ± 0.2) kg = (3.3 kg ± 6.1%)

The Absolute Uncertainty is: $\Delta m = \frac{\varepsilon_m}{100} \times m = \frac{6.1}{100} \times 3.3 = 0.2$ kg

The Relative Uncertainty is: $\varepsilon_m = \frac{\Delta m}{m} \times 100\% = \frac{0.2}{3.3} \times 100\% = 6.1\%$

In general, the uncertainty in a single measurement from a single instrument is **half the least count of the instrument.**

Adding and subtracting uncertainties

ADD the Absolute Uncertainties

Rule: $(A \pm \Delta A) + (B \pm \Delta B) = (A + B) \pm (\Delta A + \Delta B)$

$(A \pm \Delta A) - (B \pm \Delta B) = (A - B) \pm (\Delta A + \Delta B)$

Multiplying and dividing uncertainties

ADD the Relative Uncertainties

Rule: $(A \pm \varepsilon_A) \times (B \pm \varepsilon_B) = (A \times B) \pm (\varepsilon_A + \varepsilon_B)$

$(A \pm \varepsilon_A) / (B \pm \varepsilon_B) = (A / B) \pm (\varepsilon_A + \varepsilon_B)$

Powers

For a number raised to a power, fractional or not, the rule is simply to MULTIPLY the Relative Uncertainty by the power.

Rule: $(A \pm \varepsilon_A)^n = (A^n \pm n\varepsilon_A)$

Consider the number: (2.0 m ± 1.0%)

Cube: $(2.0\text{ m} \pm 1.0\%)^3 = (8.0\text{ m}^3 \pm 3.0\%)$
Square Root: $(2.0\text{ m} \pm 1.0\%)^{1/2} = (1.4\text{ m}^{1/2} \pm 0.5\%)$

Multiplying by a constant

For multiplying a number by a constant there are two different rules depending on which type of uncertainty you are working with at the time.

Rule - Absolute Uncertainty: $c(A \pm \Delta A) = cA \pm c(\Delta A)$

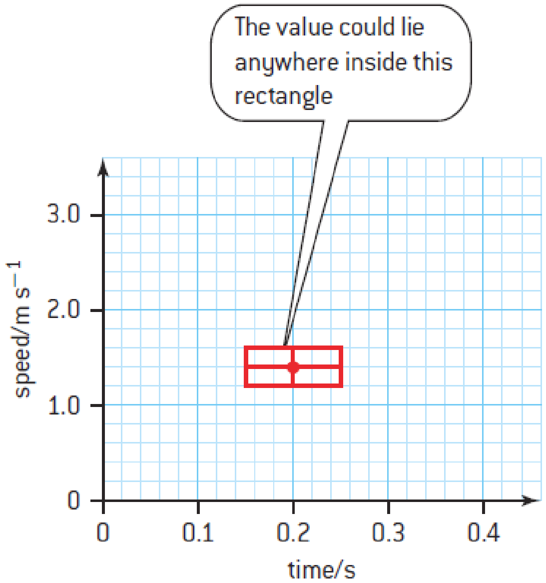
Consider: 1.5(2.0 ± 0.2) m = (3.0 ± 0.3) m. Note; Absolute Uncertainty **is** multiplied by the constant.

Rule - Relative Uncertainty: $c(A \pm \varepsilon A) = cA \pm \varepsilon A$

Consider: 1.5(2.0 m ± 1.0%) = (3.0 m ± 1.0%) Note; Relative Uncertainty **is not** multiplied by the constant.

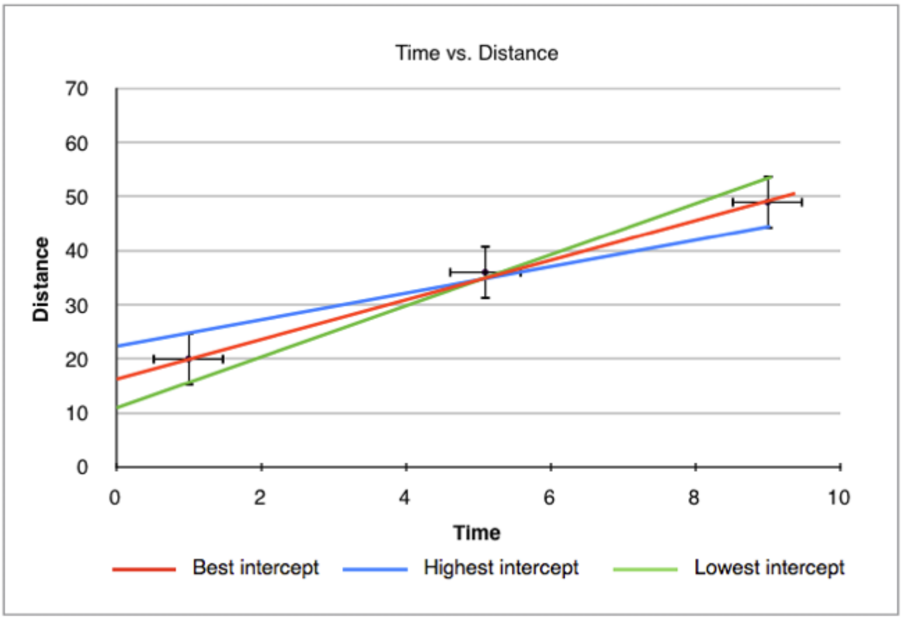
Error bars

In plotting a point on a graph, uncertainties are recognized by adding error bars. These are vertical and horizontal lines that indicate the possible range of the quantity being measured. Suppose at a time of (0.2 ± 0.05) s the speed of an object was (1.2 ± 0.2) m /s this would be plotted as shown in figure below.
This means that the value could possibly be within the rectangle that touches the ends of the error bars as shown in figure 8. This is the **zone of uncertainty** for the data point. A line of best fit should be one that spreads the points so that they are evenly distributed on both sides of the line and also passes through the error bars.



Uncertainties with gradients

You can add the trend lines with the steepest and shallowest gradients that are just possible – while still passing through all the error bars. Students quite commonly, but incorrectly, use the extremes of the error bars that are furthest apart on the graphs. Although these could be appropriate, it is essential that all the trend lines you draw pass through all of the error bars.



Time vs. Distance
70
60
50
40
30
20
10
0
Distance
0
2
4
6
8
10
Time
Best intercept
Highest intercept
Lowest intercept