CAIE Physics A-level

Topic 1: Physical Quantities and Units

Notes

1 - Physical Quantities and Units

1.1 - Physical Quantities

A **physical quantity** consists of a numerical value and a unit. For example the length of an object, l, has a magnitude of 4 and a unit, metres (m).

Estimation is a skill physicists must use in order to approximate the values of physical quantities, in order to make comparisons, or to check if a value they've calculated is reasonable.

1.2 - SI Units

SI units are the fundamental units which are used alongside the base SI quantities. They are made up of:

Quantity	Unit
Mass	Kilogram (kg)
Length	Metre (m)
Time	Second (s)
Current	Ampere (A)
Temperature	Kelvin (K)
Amount of substance (A-level only)	Mole (mol)

The SI units of quantities can be **derived** using their equation, e.g. F = ma.
For example, to find the SI units of force (F) multiply the SI units of mass and acceleration:
$kg \times ms^{-2} = kgms^{-2}$ Which is the SI unit of force, also known as N.

A **homogeneous equation** is one where the units on either side are the same. **All equations in physics (which are valid) are homogeneous**, which is why you can derive a quantity's SI units as above. You can assess whether an equation is homogeneous by checking whether the units on either side are equal.

Prefixes can be added to SI units and they will act as a multiplier, which is a different power of 10 depending on the prefix. Below are the **prefixes** which could be added before any of the above SI units:

Name	Symbol	Multiplier
Tera	T	10^{12}
Giga	G	10^{9}
Mega	M	10^{6}

Some examples:

6pF (picofarads) is **6 x 10^{-12} F**

9GΩ (gigaohms) is **9 x 10^{9} Ω**

10μm (micrometres) is **10 x 10^{-6} m**

Kilo	k	10^3
Deci	d	10^{-1}
Centi	c	10^{-2}
Milli	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}

Converting mega electron volts to joules:

1eV=1.6 x 10^{-19}J

e.g. convert 76 MeV to joules:

First, convert from MeV to eV by multiplying by 10^6 — 76 x 10^6 eV

Then convert to joules by multiplying by 1.6 x 10^{-19} — 1.216 x 10^{-11}J

Converting **kWh** (kilowatt hours) to Joules:

1 kW = 1000 J/s   1 hour= 3600s

1kWh = 1000 x 3600

= 3.6 x 10^6J

= 3.6 MJ

1.3 - Errors and Uncertainties

Random errors affect precision, meaning they cause differences in measurements which causes a spread about the mean. You **cannot** get rid of all random errors.

An example of random error is electronic noise in the circuit of an electrical instrument.

To reduce random errors:

- Take **at least 3 repeats** and calculate a **mean**, this method also allows anomalies to be identified
- Use **computers/data loggers/cameras** to reduce human error and enable smaller intervals
- Use **appropriate equipment**, e.g a micrometer has higher resolution (0.1 mm) than a ruler (1 mm)

Systematic errors affect accuracy and occur due to the apparatus or faults in the experimental method. Systematic errors cause all results to be too high or too low by the same amount each time.

An example is a balance that isn't zeroed correctly (zero error) or reading a scale at a different angle (this is a parallax error).

To reduce systematic error:

- **Calibrate** apparatus by measuring a known value (e.g. weigh 1 kg on a mass balance), if the reading is inaccurate then the systematic error is easily identified

- In radiation experiments correct for background radiation by measuring it beforehand and subtracting it from the final results
- Read the meniscus (the central curve on the surface of a liquid) at eye level (to reduce parallax error) and use controls in experiments

You must understand the difference between precision and accuracy:

Precision	Precise measurements are consistent, they fluctuate slightly about a mean value - this doesn't indicate the value is accurate.
Accuracy	A measurement close to the true value is accurate.

The **uncertainty** of a measurement is the bounds in which the accurate value can be expected to lie e.g. 20°C ± 2°C , the true value could be within 18-22°C.

Absolute Uncertainty: uncertainty given as a fixed quantity e.g. 7 ± 0.6 V

Fractional Uncertainty: uncertainty as a fraction of the measurement e.g. $7 \pm \frac{3}{35}$ V

Percentage Uncertainty: uncertainty as a percentage of the measurement e.g. $7 \pm 8.6\%$ V

To reduce percentage and fractional uncertainty, you can measure larger quantities.

Readings are when one value is found (e.g. reading a thermometer). Measurements are when the difference between 2 readings is found, since both the starting point and end point are judged (e.g. a ruler).

The **uncertainty in a reading** is ± half the smallest division,

e.g. for a thermometer the smallest division is 1°C so the uncertainty is ±0.5°C

The **uncertainty in a measurement** is at least ±1 smallest division,

e.g. a ruler, must include **both** the uncertainty for the start and end value, as each end has ±0.5mm, they are added so the uncertainty in the measurement is ±1mm

When pieces of measured data are used in calculations, their uncertainty will also affect the result of the calculations, therefore you must be able to combine uncertainties as shown below:

- **Adding / subtracting data - ADD ABSOLUTE UNCERTAINTIES**

E.g. A thermometer with an uncertainty of ± 0.5 K shows the temperature of water falling from 298 ± 0.5 K to 273 ± 0.5K, what is the difference in temperature?

298-273 = 25K   0.5 + 0.5 = 1K (add absolute uncertainties)   difference = 25 ± 1 K

- **Multiplying / dividing data - ADD PERCENTAGE UNCERTAINTIES**

E.g. a force of 91 ± 3 N is applied to a mass of 7 ± 0.2 kg, what is the acceleration of the mass?

a=F/m =91/7 = 13ms^{-2}

percentage uncertainty= $\frac{uncertainty}{value} \times 100$

Work out % uncertainties $\frac{3}{91} \times 100 + \frac{0.2}{7} \times 100$ = 3.3% + 2.9% add % uncertainties
= 6.2%

So a= 13 ± 6.2% ms^{-2} 6.2% of 13 is 0.8

a=13 ± 0.8 ms^{-2}

- **Raising to a power - MULTIPLY PERCENTAGE UNCERTAINTY BY POWER**

The radius of a circle is 5 ± 0.3 cm, what is the percentage uncertainty in the area of the circle?
Area = π x 25 = 78.5 cm^2
Area = π r^2
% uncertainty in radius = $\frac{0.3}{5} \times 100$ = 6% % uncertainty in area = 6 x 2 (2 is the power from r^2)
= 12%

78.5 ± 12% cm^2

1.4 - Scalars and Vectors

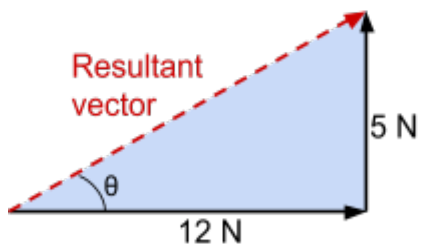
Scalars and vectors are physical quantities. **Scalars** describe only a magnitude while **vectors** describe magnitude and direction. Below are some examples:

Scalars	Vectors
Distance, speed, mass, temperature	Displacement, velocity, force/weight, acceleration

Here are two methods you can use to add vectors:

- **Calculation**
  This should be used when the two vectors are perpendicular.

  For example, two forces are acting perpendicular to each other and have magnitudes of 5 N and 12 N. Find the resultant force, and its direction from the horizontal.

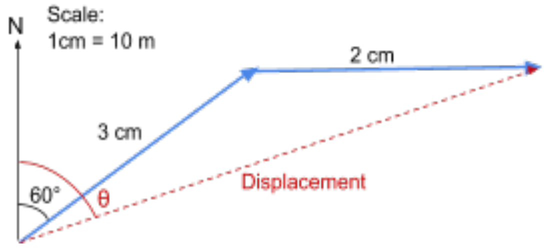
  

  To find the resultant magnitude (R) you can using **Pythagoras' theorem**:
  $12^2 + 5^2 = 169 = R^2 \qquad R = 13\ N$
  In order to find the direction, you can use **trigonometry**:
  $tan\ \theta = \frac{5}{12} \qquad \theta = 22.6°$
  Direction = 22.6° from the horizontal
  It is very important to state how the angle you find signifies the direction.

- **Scale drawing**
  This should be used when vectors are at angles other than 90°.

For example, a ship travels 30 m at a bearing of 060°, then 20 m east. Find the magnitude and direction of its displacement from its starting position.

You will need to draw a **scale diagram**, using a ruler and a protractor as shown on the right. Make sure to show the scale you are using.



Finally, measure the missing side and convert it to the magnitude using your scale and measure the missing angle θ, to find the bearing of the displacement.

Magnitude = 4.9 cm = 49 m to scale   Direction = 072°

If two vectors are moving in the exact same direction, adding/subtracting them can be done by simply adding/subtracting their magnitudes. Otherwise, they will have to be resolved into their horizontal and vertical components, as explained below.

The opposite of adding two vectors is called **resolving vectors**, and is done using trigonometry. It is extremely helpful to do this in certain situations because vectors which are perpendicular don't affect each other, so can be evaluated separately.

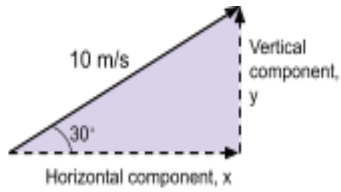
There are formulas to show how to resolve the vector V, into its components x and y.

x = V cos θ   **y= V sin θ**

However, if you struggle with remembering formulas a good hint to remember is:

If you are moving from the original vector through the angle θ to get to your component, use cos.

If you are moving away from the angle θ to get to your component, use sin.



For example, a ball has been fired at a velocity of 10 m/s, at an angle of 30° from the horizontal, find the vertical and horizontal components of velocity.

x= 10 cos 30°   y= 10 sin 30°
  = 8.7 m/s   = 5 m/s

Resolving vectors is a very useful tool and can be used when adding vectors that are at angles other than 90°, if you do not wish to make a scale drawing. In the 'scale drawing' example, a new right angled triangle with a Northern displacement vector of 3cos60 and an Eastern displacement vector of 3sin60 + 2 can be formulated. Subsequently using Pythagoras' theorem yields the same result for vector magnitude as measured by scale drawing: magnitude = $\sqrt{(3cos60)^2 + (3sin60+2)^2}$ = 4.9 cm = 49 m to scale.