Equations

$$Mean = \frac{Sum\ of\ the\ results}{No.\ of\ observations}$$

$$Random\ Uncertainty = \frac{Max - Min}{No.\ of\ observations} \qquad \Delta R = \frac{R_{max} - R_{min}}{n}$$

$$Percentage\ Uncertainty = \frac{Random\ Uncertainty}{Mean} \times 100\%$$

Key Words	Meaning
Uncertainty	How close the calculated result may be to the actual value. All experiments have uncertainties
Error	A word often used in place of uncertainty in some Journals
Accuracy	Results which are accurate have a mean value very close to the real value. Accurate results may be spread over a wide range.
Precision	Results which are precise will be spread over a very small range. This does not mean they will be close to the real value. A result can be precise but not accurate!
SI Units	The International System of Units (SI) states the 7 base units that must be used in all calculations. These are: Second (time), Meter (distance), Kilogram (mass), Ampere (current), Kelvin (temperature), Mole (amount of a substance), and Candela (light intensity). All other units are derived from these 7. https://www.npl.co.uk/si-units
Mean	Mean is the type of average used in physics. A mean value of serval results should always be found when analysing experiments.
Random	Random uncertainties are present in every experiment. This is the reason we MUST repeat all measurements.
Scale Reading	The scale reading is the uncertainty that accords because of the scale on the device used. These are never completely precise.
Digital	The uncertainty in a digital scale (such as an electronic balance) can be taken as ± 1 in the smallest significant figure displayed.(my scales can read ± 0.2 kg)
Analogue	Analogue device, has a pointer or marks and you can "read between the lines!" The uncertainty in an analogue scale (such as ana metre stick) can be taken as $\pm\frac{1}{2}$ in the smallest scale division.
Systematic	A systematic effect is a type of error that skews all results by the same amount in the same direction. E.g. slow running clocks, scales not set to zero
Zero Error	This is the most common systematic error. It occurs because the zero point of the device is not set perfectly. E.g. the end of a meter stick has worn away. This can be eliminated by starting all measurements from a different value on the metre stick.
Reducing Uncertainty	We can attempt to reduce the random uncertainty by taking multiple observations and calculating a mean from these observations. The more measurements the better.
Percentage	Percentage uncertainty is when you convert an absolute uncertainty to a % by dividing it by the reading or mean: "Value Units $\pm$ percentage uncertainty %"
Overall uncertainty	The largest percentage uncertainty is the best estimate of the overall uncertainty in a experiment. A result including this should be in the form: "Value Units $\pm$ percentage uncertainty %"
Absolute uncertainty	This is the 'total' uncertainty in an experiment. A result including this should be in the form: "(Value $\pm$ absolute uncertainty) units"

ACCURACY V PRECISION

Both accuracy and precision reflect how close a measurement is to an actual value, but they are not the same. Accuracy reflects how close a measurement is to a known or accepted value, while precision reflects how reproducible measurements are, even if they are far from the accepted value. Measurements that are both precise and accurate are repeatable and very close to true values.

SIGNIFICANT FIGURES – NOT THE SAME AS DECIMAL PLACES AND CAN BE SLIGHTLY DIFFERENT TO MATHS

SUMMARY
Be realistic about the number of significant figures you quote a value to.
DO NOT write down all the numbers you see on your calculator.
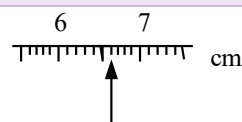**DO use the FIX or SCI button if you feel confident about using them.**

- Don't round up too early in a calculation , only the last line!
- Your answer should have a consistent number of significant figures as the least significant data given in the question. E.g if a question gives you data at 3 significant figures then you should give your answer to 3 significant figure, however through out the questions
- **DO NOT** round until the final answer.
- Marks will de deducted in the exam if you use too many significant figures.
- Good planning and experimentation normally avoids this mismatch of values and significant figures.
- Try not to choose apparatus where you can obtain too few or an unnecessarily high number of significant figures.
- Try to obtain all measurements to the same number of significant figures.

Prefix	Symbol	Multiple	Multiple in full
Tera	T	$\times 10^{12}$	$\times$1 000 000 000 000
Giga	G	$\times 10^{9}$	$\times$1 000 000 000
Mega	M	$\times 10^{6}$	$\times$1 000 000
Kilo	K	$\times 10^{3}$	$\times$1 000
Centi	C	$\times 10^{-2}$	$\div$100
Milli	M	$\times 10^{-3}$	$\div$1 000
Micro	μ	$\times 10^{-6}$	$\div$1 000 000
Nano	N	$\times 10^{-9}$	$\div$1 000 000 000
Pico	P	$\times 10^{-12}$	$\div$1 000 000 000 000

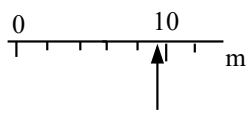| Quantity		Symbol	Unit & Unit Symbol
Mass		m	kilogram, kg
Length		l	metre, m
Time		t	second, s
Temperature		T	degrees Celsius, Kelvin, K
Current		I	ampere, A

REDUCING UNCERTAINTIES

- **Always try to get the most accurate piece of apparatus to do the job.**
- **Analogue scales can be read to the nearest 0.5 of a scale division.**
- **Repeat measurements to reduce the random uncertainty in an experiment. You must repeat measurements in your Assignments**
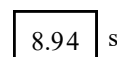
SCALE READING UNCERTAINTY

This value indicates how well an instrument scale can be read.

An estimate of reading uncertainty for an **analogue scale** is generally taken as:

± half the least division of the scale.

For a **digital scale** it is taken as

± 1 in the least significant digit displayed.

(6.60 $\pm$ 0.05) cm

Length lies between
(6.55 and 6.65) cm

(9.0 $\pm$ 0.5) m

Length lies between
(8.5 and 9.5) m

8.94 s

(8.94 $\pm$ 0.01) s

Time lies between
(8.93 and 8.95) s.

The greatest percentage uncertainty in any one measurement is taken as the overall unicertainty in the experiment. When comparing uncertainties, it is important to take the percentage in each.
This percentage uncertainty is often a good estimate of the percentage uncertainty in the final numerical result of the experiment.

eg if one measurement has an uncertainty of 3% and another has an uncertainty of 5%, then the overall percentage uncertainty in this experiment should be taken as 5%

QUANTIFYING UNCERTAINTIES

Find the mean

$$\text{mean value} = \frac{\Sigma \text{results}}{\text{no. of observations}} \qquad (\Sigma = \text{sum of})$$
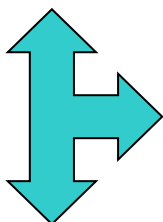
This is the best estimate of the "true" value but not necessary the "true" value

Find the approximate random uncertainty in the mean (absolute uncertainty)

$$\text{approximate random uncertainty} = \frac{\text{maximum value} - \text{minimum value}}{\text{number of observations}}$$
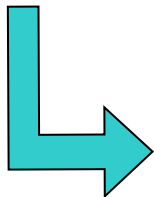
$$\Delta R = \frac{R_{max} - R_{min}}{n}$$

At this point the answer should be shown as
MEAN±approx. random uncertainty (UNITS)
Or mean ± absolute uncertainty (UNITS)
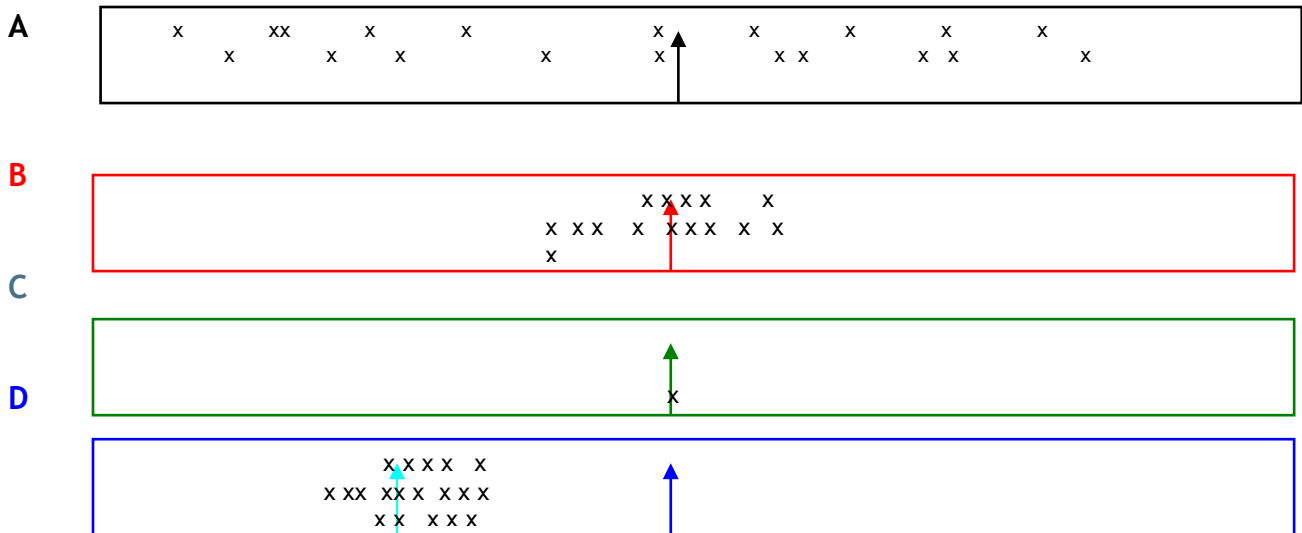
Find the percentage uncertainty.

$$\text{percentage uncertainty} = \frac{\text{approx. random uncertainty}}{\text{mean value}} \times 100\%$$

stop here and quote the result with a percentage uncertainty

MEAN (UNITS)± percerntage uncertainty (%)

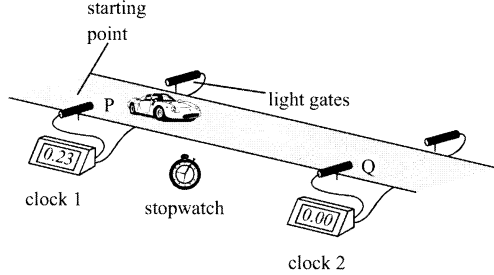### Which experiment has the best design?

B, not offset, average is the true value, little spread of readings (ie giving a small approximate random uncertainty)

C, beginners luck, now evidence that this is the real value as you've no repeats

D, small random uncertainty but a systematic effect. Might show in a graph, where best fit line doesn't pass through the origin.

Example

A student sets up the apparatus in the diagram to measure the average acceleration of a model car as it travels between P and Q

For one run, the following measurements were recorded along with their estimated uncertainty.	starting point
clock 1 reading = 0.23 s ± 0.01 s clock 2 reading = 0.12 s ± 0.01 s stopwatch reading = 0.95 s ± 0.20 s length of car = 0.050 m ± 0.002 m distance PQ = 0.30 m ± 0.01 m	light gates P clock 1 stopwatch Q clock 2
The measurement which gives the largest percentage uncertainty is the a) reading on clock 1 b) reading on clock 2 c) reading on the stopwatch d) length of the car e) distance PQ.	$t_1 = \dfrac{0.01}{0.23} = 4\%$ $t_2 = \dfrac{0.01}{0.12} = 8\%$ $t = \dfrac{0.20}{0.95} = 21\%$ $l = \dfrac{0.002}{0.050} = 4\%$ $d = \dfrac{0.01}{0.30} = 3\%$

SQA Higher Paper 1994

During an experiment to measure the specific heat capacity of a liquid the relationship $VIt = mc\Delta T$ is used

The following quantities are measured
V= 12.0 ± 0.1 V
I = 4.2 ± 0.1 A
t =300 ± 1s
m=500± 2 g
DT = 15 ± 1 °C

$V = \dfrac{0.1}{12} = 0.8\%$

$I = \dfrac{0.1}{4.2} = 2\%$

$t = \dfrac{1}{300} = 0.3\%$

$m = \dfrac{2}{500} = 0.4\%$

$DT = \dfrac{1}{15} = 7\%$

Which quantity will contribute the largest uncertainty to the final answer for the specific heat capacity, c?

A Voltage
B Current
C Time
D mass
E temperature difference

OPEN ENDED QUESTIONS

Any number of answers may be given which are equally correct (or incorrect
0 marks.- not demonstrated any understanding of the physics.
1 mark.- demonstrates a limited understanding of the physics.
2 marks.- demonstrates a reasonable understanding of the physics.
3 marks. -demonstrates a good understanding of the physics. Might include a statement of the principles involved, a relationship and the application.
This does not mean the answer has to be what might be termed an "excellent" answer or a complete one.

Strategy for Solving Open-Ended Questions.

In answering open ended questions you should:
1) read the question - taking care not to skim read.
2) reread the question.
3) try to understand/define the problem situation and what is asked.
4) visualise the situation.
5) draw a diagram and include any relevant information such as speeds, velocities, forces, vector directions etc.
6) determine and write down
a) relevant physics principles e.g. conservation of momentum
b) note area/topic of physics involved in problem e.g. internal resistance of supplies
c) relationship relevant to variables in the problem.
7) use knowledge of familiar quantities such as body mass, body height, length of running track to create estimated values as required.
8) with the information noted previously solve the problem or do what can be done.
9) reread the response to see if it makes sense and answers the question.