AH Physics
- Uncertainties

7:30 pm, Wednesday, 7 October 2020

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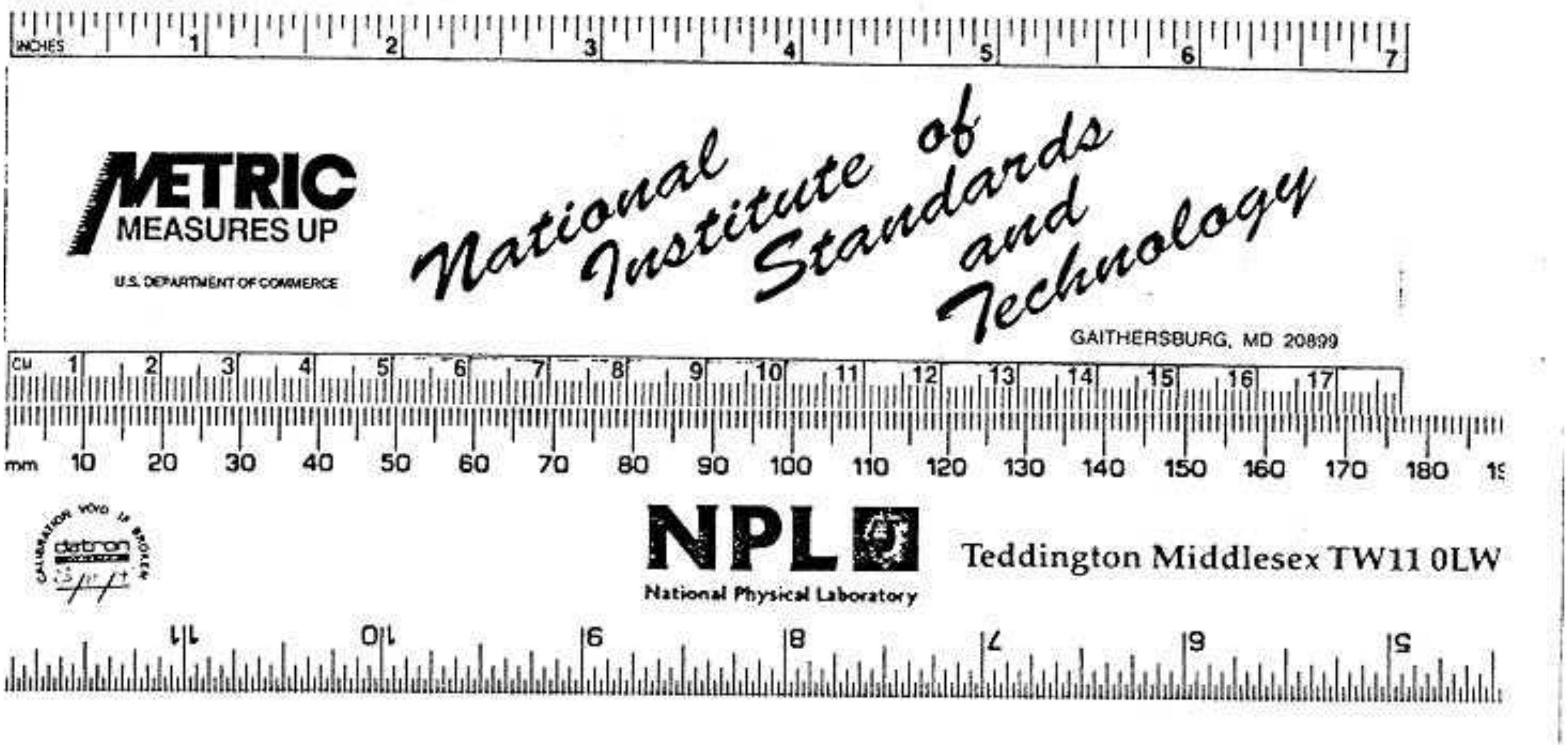
Uncertainties at AH



Practical ideas to introduce measuring

Uncertainties Experiment 1

What do we measure and how did this arise?

Title: Measuring in "Hargreaves" (add your own unit)

Units of Length
4 Farmers = 1 Hargreaves

1 Farmer

1 Hargreaves

Units of time
100 Burrett = 1 Hunter

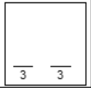
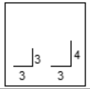
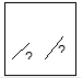
1 Hunter = time for Mrs Hunter to knit 100 stitches
1 Hunter = 102 s

Instructions
- Measure your height in Hargreaves'
- Measure your head size in Hargreaves' and Farmers.
- Measure the time of the lesson in Hunters and Burretts
- Determine your average speed to run around the school field (or alternative). Express your answers in Hargreaves per Hunter

Issues to consider
- Why are Hargreaves and Hunters not standard units?
- Is it possible to measure all lengths in Hargreaves' and all times in Hunters?
- Research the basic SI units and their definitions. How many basic units need to be defined and why so few?

On behalf of the IoP

Uncertainties Experiment 2 **Watch your sig fig when you measure**

Draw two horizontal lines on graph paper each 3 units long	
Now add a vertical line to each, one 3 units tall, the other 4 units:	
Now measure *and* calculate the lengths of the two diagonals.	
Your measurements on each of these drawings are of nearly identical accuracy and give 4.2 units ± a little bit and 5.0 ± a little bit. Your *calculations* on the other hand give 4.24264068712 units and 5 units exactly.	

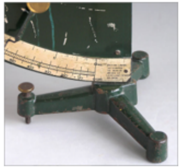
On behalf of the IoP

Uncertainties Experiment 3

Title: systematic effect

Instructions
- Obtain a supply of identical marbles or paper clips and a Butchart balance. Set up the balance but make sure its zero setting is *incorrect* before you start to use it. Do not take note of the amount of this error.
- Now take a handful marbles or paper clips and find the total mass. Take note of the number of marbles and their mass. Record your results in a table.
- Repeat this for different sized handfuls and then make a graph of *mass* against *number of marbles*.
- Work out *from the graph* the mass of one marble or paper clip and the size of the zero error on your machine.
- Check this against the uncertainty from the Butchart Balance.

Other balances are available especially kitchen scales with the zero slider



Calibrate a thermometer

Find it on Talkphysics, and Mrsphysics

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Sequence of experiments for AH Physics

Designed to cover useful equipment and develop basic skills of measurement and uncertainties.
Booklet compiled from HSDU exemplars, SSERC guide, own ideas.

1. Marbles and cups – rationale for uncertainties, finding means, line of best-fit
2. Density of microscope slide – combining uncertainties – Vernier calipers and micrometer
3. Density of ball bearing – combining uncertainties – a power
4. The travelling microscope – Vernier scale
5. The simple pendulum – graphs
6. Mystery density set – consolidation puzzle, graph analysis

Uncertainties

Good Science

Important at AH for your project and in SQA exam questions.

A big chunk of the SQA AH marks

Every measurement is liable to uncertainty.

So go looking to quantify it.

Types:

(SCALE) READING, RANDOM, CALIBRATION
(and watch out for SYSTEMATIC)

And this should form the basis of your project evaluation.

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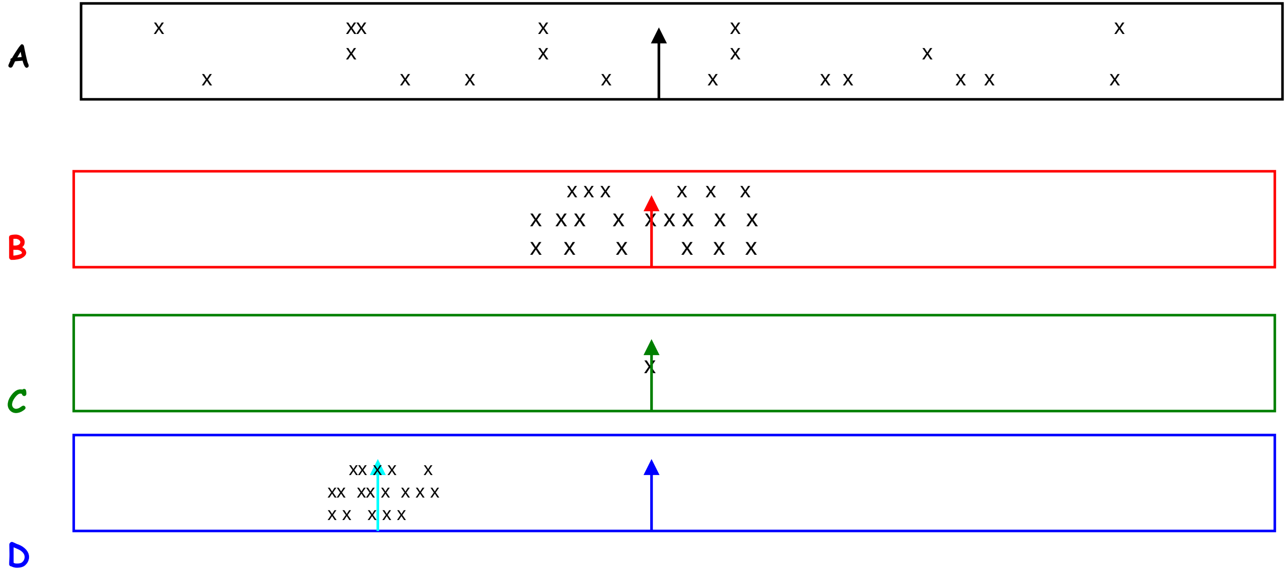
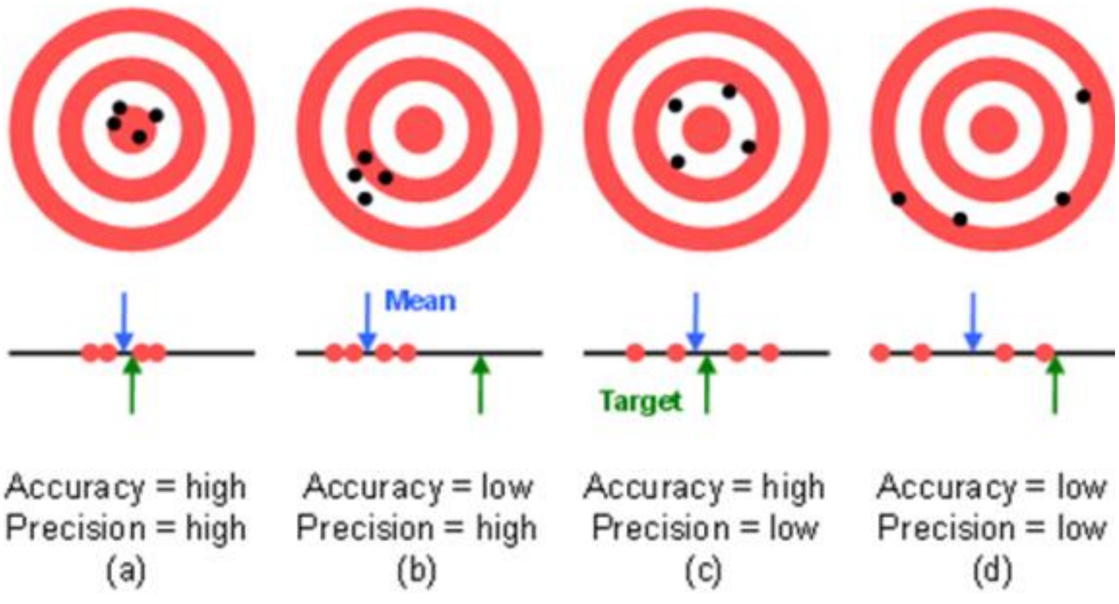
Which experiment has the best design?



Explain your reasoning.

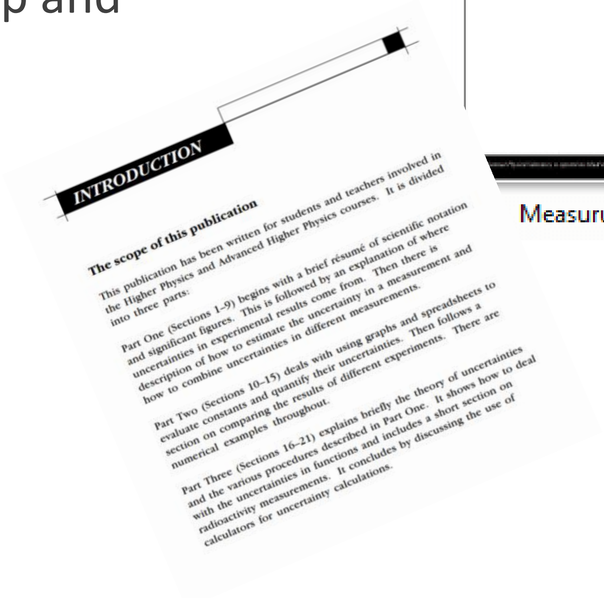
Accuracy v Precision



Accuracy is how close your answer is to the true value. Precision is how repeatable a measurement is.

NB: Difference between IoP and SQA views

Occasionally there is a little disagreement as to the correct Physics. For the sake of the students put this aside and explain what the SQA wants, eg Rounding up and down in uncertainties.



INTRODUCTION

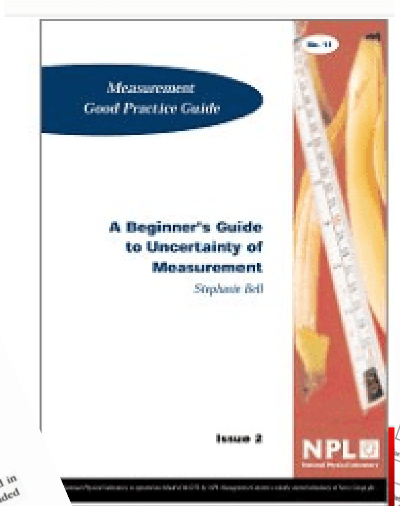
The scope of this publication

This publication has been written for students and teachers involved in the Higher Physics and Advanced Higher Physics courses. It is divided into three parts:

Part One (Sections 1–9) begins with a brief résumé of scientific notation and significant figures. This is followed by an explanation of where uncertainties in experimental results come from. Then there is description of how to estimate the uncertainty in a measurement and how to combine uncertainties in different measurements.

Part Two (Sections 10–15) deals with using graphs and spreadsheets to evaluate constants and quantify their uncertainties. Then follows a section on comparing the results of different experiments. There are numerical examples throughout.

Part Three (Sections 16–21) explains briefly the theory of uncertainties and the various procedures described in Part One. It shows how to deal with the uncertainties in functions and includes a short section on radioactivity measurements. It concludes by discussing the use of calculators for uncertainty calculations.



Measurement Good Practice Guide

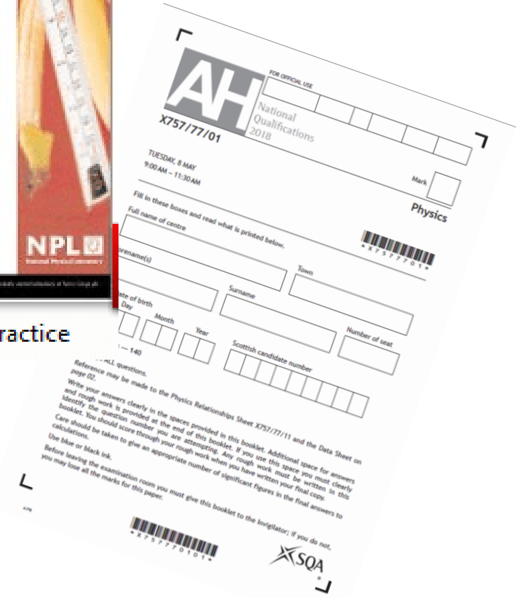
A Beginner's Guide to Uncertainty of Measurement

Stephanie Bell

Issue 2

NPL

Measurung gd practice



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For each reading there should be, where appropriate:

Calibration

Scale reading

Random

These should be combined using Pythagorean relationship.

$$\Delta T = \sqrt{\Delta X^2 + \Delta Y^2 + \Delta Z^2}$$

$$\frac{\Delta T}{T} = \sqrt{\left(\frac{\Delta X}{X}\right)^2 + \left(\frac{\Delta Y}{Y}\right)^2 + \left(\frac{\Delta Z}{Z}\right)^2}$$

Check for shortcuts for $\frac{1}{3}$.

More detail about each uncertainty

(Scale) Reading: Analogue: $\pm$ half least division, Digital: $\pm$least division

Random: $\frac{max-min}{no.of\ readings}$ works for 5 -12 readings of the same measurement.

Nuclear experiments: square root of mean count rate (statistical approach).

Calibration: Don't ignore it if you can't find it! Estimate it or use a table. Better still contact manufacturer etc. *and don't estimate it to be too high to use the law of thirds!*

Systematic: often found as the **graphical** results don't go through the origin.

This is usually worth 1 mark- although no fast rule.

No requirement of standard deviation at this level.

There should be a minimum of 5 pairs of readings repeated 5 times (good range selected).

Calibration Uncertainties

Manufacturer gives information

Metre stick (wood, plastic) = ± 0.5mm

Steel Rule = ± 0.1mm

Vernier callipers = ± 0.1mm

Micrometer = ± 0.002mm

Digital meter - **0.5% of reading plus I digit**

e.g. for a reading of 2.56 mA

0.5% of 2.56 = 0.0128 plus 1 digit **(least significant in reading)** gives 0.0228 = ± 0.02mA rounded.

APPENDIX 2

Appendix 2: Calibration uncertainties in instruments

Manufacturers of scientific measuring instruments know that it is important to state how precisely the scale on the instrument has been calibrated. This table gives typical maximum values for the calibration uncertainties of several common laboratory instruments. The actual calibration uncertainties in particular instruments can be expected to be somewhat less than these.

Wooden metre stick	0.5 mm		
Steel rule	0.1 mm		
Vernier callipers	0.01 mm		
Micrometer	0.002 mm		
Standard masses (chemical balance)	5 mg		
Hg-in-glass thermometer (0°–100°C)	0.5 celsius degree		
Electrical meters			
Analogue	2% of full-scale-deflection		
Digital (3½ digit)*	0.5% of reading + 1 digit		
Audio oscillator	5% of full-scale frequency		
Decade resistance box	1% or 0.1% of value		
Resistors	Brown band or code letter	F	1% of value
and	Red	G	2%
Capacitors	Gold	J	5%
	Silver	K	10%
	no	M	20%

* A 4-digit instrument in which the left-hand digit reads 0 or 1 only. Hence the largest figure that can be displayed is 1999.

https://www.mrsphysics.co.uk/advanced/wp-content/uploads/2016/08/AH-Physics-staff_guide_Uncertainties-Norman-Fancey-Gemmell-Millar.pdf

What is absolute about an uncertainty?

Absolute Uncertainty: is the uncertainty in the measured quantity and has the same units as the quantity itself. *For example if you know a length is 0.428 m ± 0.002 m, the 0.002 m is an absolute uncertainty.*

Fractional Uncertainty: is obtained by dividing the absolute error in the quantity by the quantity itself. The fractional uncertainty is usually more significant than the absolute uncertainty. *For example a 1 mm uncertainty in the diameter of a ball bearing is probably more serious than a 1 mm error in measuring the height of a pupil.* Note that fractional uncertainties are dimensionless.

% Uncertainty When reporting fractional uncertainties it is usual to multiply the fractional error by 100 and report it as a percentage.

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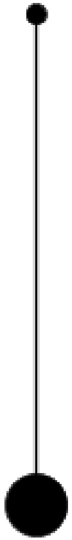
Combining Uncertainties in one measurement

Let's take the pendulum as an example



Teach students where to find symbols

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Presentation of Results

Have a table with clear headings and units

- For one variable you should show the value of the C.U. S.R.U. A.R.U. (ΔCU ΔSU ΔR)
- Combine these appropriately - no need for fractional or percentage uncertainties at this stage.
- Again give one example of the calculations and state the others were carried out in the same way.
- Show how the uncertainties were combined to give the final absolute uncertainty.
- Round this to one S.F.

Some student data to work up uncertainties.

length of thread	Time for three swings (s)							average 3T (s)	a.r.u in 3T	T	$(T)^2$	Period $(T)^2$	g	a.r.u in 3T	Scale reading uncertainty in 3T	calibration uncertainty in 3T	combining uncertainty in 3T	fractional uncertainty in T	Fractional Uncertainty in T^2	absolute uncertainty in T^2	Scale reading uncertainty in l	calibration uncertainty in l	combining absolute uncertainty in l
m	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(av)	(s)	(s)	(s^2)	(s^2)	(ms^{-2})	(s)	(s)	(s)	(s)			(s^2)	(m)	(m)	(m)
0.250	3.04	2.99	2.93	3.08	2.99	2.99	3.00	3.00	0.02	1.00	1.00	1.00	9.85	0.02	0.02	0.0250	0.039	0.013	0.026	0.026	0.001	0.0005	0.0011
0.500	3.26	4.36	4.96	4.34	4.46	4.38	4.59	4.34	0.24	1.45	2.09	2.09	9.45	0.24	0.02	0.0317	0.246	0.057	0.113	0.237	0.001	0.0005	0.0011
0.750	4.99	5.06	5.06	5.06	5.06	5.06	5.06	5.05	0.01	1.68	2.83	2.83	10.45	0.01	0.02	0.0353	0.042	0.008	0.017	0.047	0.001	0.0005	0.0011
1.000	6.24	6.22	6.08	6.06	6.18	6.10	6.14	6.15	0.03	2.05	4.20	4.20	9.41	0.03	0.02	0.0407	0.052	0.008	0.017	0.071	0.001	0.0005	0.0011
1.100	6.59	6.40	6.55	6.47	6.47	6.51	6.54	6.50	0.03	2.17	4.70	4.70	9.24	0.03	0.02	0.0425	0.054	0.008	0.017	0.078	0.001	0.0005	0.0011
1.200	6.39	6.68	6.56	6.44	6.86	6.45	6.46	6.55	0.07	2.18	4.76	4.76	9.94	0.07	0.02	0.0427	0.082	0.013	0.025	0.119	0.001	0.0005	0.0011
1.300	6.32	6.38	6.40	6.64	6.59	6.63	6.39	6.48	0.05	2.16	4.66	4.66	11.00	0.05	0.02	0.0424	0.065	0.010	0.020	0.094	0.001	0.0005	0.0011
1.500	7.45	7.62	7.32	7.31	7.55	7.52	7.27	7.43	0.05	2.48	6.14	6.14	9.64	0.05	0.02	0.0472	0.072	0.010	0.019	0.118	0.001	0.0005	0.0011
1.750	7.93	7.93	8.11	7.63	7.63	7.68	7.69	7.80	0.07	2.60	6.76	6.76	10.22	0.07	0.02	0.0490	0.087	0.011	0.022	0.150	0.001	0.0005	0.0011
2.000	9.01	8.59	8.55	8.41	8.41	8.60	8.82	8.63	0.09	2.88	8.27	8.27	9.55	0.09	0.02	0.0531	0.103	0.012	0.024	0.197	0.001	0.0005	0.0011

Find the excel spreadsheet on mrsphysics or on talkphysics

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The wrong way to calculate g- but an OK table!

length of thread	Time for three swings (s)							average 3T (s)	T	Period $(T)^2$	~~g~~
m	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(av)	(s)	(s^2)	~~(ms^{-2})~~
0.250	3.04	2.99	2.93	3.08	2.99	2.99	3.00	3.00	1.00	1.00	~~9.85~~
0.500	3.26	4.36	4.96	4.34	4.46	4.38	4.59	4.34	1.45	2.09	~~9.45~~
0.750	4.99	5.06	5.06	5.06	5.06	5.06	5.06	5.05	1.68	2.83	~~10.45~~
1.000	6.24	6.22	6.08	6.06	6.18	6.10	6.14	6.15	2.05	4.20	~~9.41~~
1.100	6.59	6.40	6.55	6.47	6.47	6.51	6.54	6.50	2.17	4.70	~~9.24~~
										av	9.88

Taking mean value or random uncertainty of g in these values is invalid.

If possible put all the results, including uncertainties in one table

length of thread	Time for three swings (s)							average 3T (s)	a.r.u in 3T	T	(T)^2	Period (T)^2	g	a.r.u in 3T	Scale reading uncertainty in 3T	calibration uncertainty in 3T	combining uncertainty in 3T	fractional uncertainty in T	Fractional Uncertainty in T^2	absolute uncertainty in T^2	Scale reading uncertainty in l	calibration uncertainty in l	combining absolute uncertainty in l
m	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(av)	(s)	(s)	(s^2)	(s^2)	(ms^{-2})	(s)	(s)	(s)	(s)			(s^2)	(m)	(m)	(m)
0.250	3.04	2.99	2.93	3.08	2.99	2.99	3.00	3.00	0.02	1.00	1.00	1.00	9.85	0.02	0.02	0.0250	0.039	0.013	0.026	0.026	0.001	0.0005	0.0011
0.500	3.26	4.36	4.96	4.34	4.46	4.38	4.59	4.34	0.24	1.45	2.09	2.09	9.45	0.24	0.02	0.0317	0.246	0.057	0.113	0.237	0.001	0.0005	0.0011

For error bars

Length - increase the scale reading uncertainty to allow for centre of bob or measure 5 times etc.

$mean = \frac{\sum x}{n}$	$\Delta R = \frac{R_{max} - R_{min}}{n}$	**Calibration ±0.5% + 1 digit**	**Combining in T**
$mean = \frac{3.26 + 4.36 + 4.96 + 4.34 + 4.46 + 4.38 + 4.59}{7}$	$\Delta R = \frac{4.96 - 3.26}{7}$	$\frac{0.5}{100} \times 4.34 + 0.01$ =0.0317	$\Delta T = \sqrt{0.24^2 + 0.02^2 + 0.0317^2}$ ΔT =0.24 Showing for rule of 3 0.24 is 3x greater $\therefore$ overall ΔT Simplify on the rule of 3
Uncertainty in T^2 As T is raised to the power 2 then the uncertainty in T^2 is $2\left(\frac{\Delta T}{T}\right)$	ΔT =0.246 $\frac{\Delta T}{T} = \frac{0.246}{4.34} = 0.0567$	uncertainty in T^2 is $2\left(\frac{\Delta T}{T}\right)$=2×0.0567=0.113 Or 11.3%	Absolute uncertainty in T^2 $2\left(\frac{\Delta T}{T}\right) \times T^2 = 0.113 \times 2.09 =$ 0.236 or 11.3% of value of T^2

Scale Reading Uncertainty= increasing to 0.02 s for reaction time.
Scale reading uncertainty in length maybe doubled as you can't identify exactly the centre of mass.
Now uncertainty in T^{2}and l can be used for error bars in the graph.

The right way!

length of thread	Time for three swings (s)							average 3T (s)	Period	Period $(T)^2$	a.r.u in 3T	Scale reading uncertainty in 3T	calibration uncertainty in 3T	combining uncertainty in T	Uncertainty in T^2	Scale reading uncertainty in l	calibration uncertainty in l	combining uncertainty in l
(m)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(av)	(s)	(s^2)	(s)	(s)	(s)	(s)	(s^2)	(m)	(m)	(m)
0.250	3.04	2.99	2.93	3.08	2.99	2.99	3.00	3.00	1.00	1.00	0.02	0.02	0.0250	0.037	0.077	0.0005	0.0005	0.0007
0.500	3.26	4.36	4.96	4.34	4.46	4.38	4.59	4.34	1.45	2.09	0.24	0.02	0.0317	0.246	0.491	0.0005	0.0005	0.0007

For error bars

Length - increase the scale reading uncertainty to allow for centre of bob or measure 5 times etc.

$$mean = \frac{\sum x}{n}$$

$$mean = \frac{3.26 + 4.36 + 4.96 + 4.34 + 4.46 + 4.38 + 4.59}{7}$$

$$\Delta R = \frac{R_{max} - R_{min}}{n}$$

$$\Delta R = \frac{4.96 - 3.26}{7}$$

Calibration
±0.5% + 1 digit

$$\frac{0.5}{100} \times 4.34 + 0.01$$

=0.0317

Combining in T

$$\Delta T = \sqrt{0.24^2 + 0.02^2 + 0.0317^2}$$

ΔT =0.24 Showing for rule of 3

0.24 is 3x greater ∴ overall ΔT

Simplify on the rule of 3

Uncertainty in T^2

As T is raised to the power 2 then the uncertainty in T^2 is 2xΔT

ΔT =0.24

$$\Delta T^2 = 2 \times 0.24 = 0.491\ s^2$$

Scale Reading Uncertainty= increasing to 0.02 s for reaction time. Scale reading uncertainty in length maybe double

Now uncertainty in T^2 and l can be used for error bars

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Scale Reading Uncertainty

Measuring the length – no need to take into account the scale reading uncertainty at both ends - zero is being aligned with starting point.

Length of pendulum – repeat or **increase** your scale reading uncertainty to increase confidence in estimating centre of bob.

Accept %age uncertainty in sin or tan = %age uncertainty in angle.

CTRL + “¬” brings up the formulae

average 3T (s)	a.r.u in 3T	T	$(T)^2$	Period $(T)^2$	a.r.u in 3T	Scale reading uncertainty in 3T	calibration uncertainty in 3T	combining uncertainty in T	Uncertainty in T^2	Scale reading uncertainty in l	calibration uncertainty in l	combining uncertainty in l
(av)	(s)	(s)	(s^2)	(s^2)	(s)	(s)	(s)	(s)	(s^2)	(m)	(m)	
=AVERAGE (B3:H3)	=(MAX($B3:$H3)-MIN($B3:$H3))/COUNTA($B3:$H3)	=I3/3	=K3*K3	=K3^2	=(MAX(B3:H3)-MIN(B3:H3))/COUNTA(B3:H3)	0.01	=0.5/100*I3+0.01	=SQRT(O3^2+P3^2+Q3^2)	=2*R3	0.0005	0.0005	=SQRT(T3^2+U3^2)
=AVERAGE (B4:H4)	=(MAX(B4:H4)-MIN(B4:H4))/COUNTA(B4:H4)	=I4/3	=K4*K4	=K4^2	=(MAX(B4:H4)-MIN(B4:H4))/COUNTA(B4:H4)	0.01	=0.5/100*I4+0.01	=SQRT(O4^2+P4^2+Q4^2)	=2*R4	0.0005	0.0005	=SQRT(T4^2+U4^2)

Don’t give the students the spreadsheet, but explain to them how they can devise one and how to put in the formula

Be aware that sometimes EXCEL doesn’t give the same answer as you’d calculate as excel doesn’t round up it just displays rounded numbers!

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Linest- the easiest way to find the overall uncertainty

Formula for linest- an array

=LINEST(M3:M12,A3:A12,1,1)			
			=O17/O16*100
			4.2
			The magic number!

Linest cuts down on hours of parallelogram plots but you'll need to go through with the students what this does. It saves the students hours in working out combinations!

Overall uncertainty best obtained from the graph, (ie Linest)

Wow all this for the students to discuss

4.0057989	-0.00452
0.16890437	0.210471
0.985976385	0.27471
562.4663057	8
42.44680528	0.603724

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2010 SQA AH Paper

(*b*) Data recorded for the turntable is shown belo

Angle of rotation	$(3{\cdot}1 \pm 0{\cdot}1)$ rad
Time taken for angle of rotation	$(4{\cdot}5 \pm 0{\cdot}1)$ s
Radius of disk	$(0{\cdot}148 \pm 0{\cdot}001)$ m

(i) Calculate the tangential speed v.

(ii) Calculate the percentage uncertainty in this value of v.

$$\%\Delta\,\theta = \frac{0{\cdot}1}{3{\cdot}1} \times 100 = 3{\cdot}2\%$$

$$\%\Delta\,t = \frac{0{\cdot}1}{4{\cdot}5} \times 100 = 2{\cdot}2\%$$

$$\%\Delta\,r = \frac{0{\cdot}001}{0{\cdot}148} \times 100 = 0{\cdot}68\%$$

Check correct rounding

$$\%\Delta\,v = \sqrt{(\%\Delta\,\theta^2 + \%\Delta\,t^2 + \%\Delta\,r^2)}$$

$$= \sqrt{(3{\cdot}2^2 + 2{\cdot}2^2 + 0{\cdot}68^2)}$$

$$= 3{\cdot}9\ (\%)$$

Shortcut of ignoring uncertainty less than $\frac{1}{3}$ of the largest .

iii

$$\% \text{ unc in } D = \frac{0 \cdot 005}{4 \cdot 250} \times 100 = 0 \cdot 12\% \qquad (½)$$

$$\% \text{ unc in } L = \frac{2}{67} \times 100 = 3 \cdot 0\% \qquad (½)$$

$$\% \text{ unc in } d = \frac{0 \cdot 01}{0 \cdot 25} \times 100 = 4 \cdot 0\% \qquad (½)$$

$$\text{Total } \% \text{ unc} = (3 \cdot 0^2 + 4 \cdot 0^2)^{½}$$

$$= 5 \cdot 0\% \qquad (½)$$

$$\text{Absolute unc} = 0 \cdot 05 \times 6 \cdot 5 \times 10^{-7}$$

$$= 3 \times 10^{-8} \text{ m} \qquad (1)$$

Explaining Uncertainties in Exam questions

By measuring multiple fringe separations rather than just one, the student states that they have more confidence in the value of diameter of the wire which was obtained.

Suggest one reason why the student's statement is correct.

Reduces the uncertainty in the value of *x* or *d* obtained.

OR

Reduces the impact/significance of any uncertainty on the value obtained for *x* or *d* .

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2011 SQA AH Q7

(*b*) A student investigating the force on a current carrying wire placed perpendicular to a uniform magnetic field obtains the following measurements and uncertainties.

Force (N)	0·0058 0·0061 0·0063 0·0057 0·0058 0·0062 Scale reading uncertainty Calibration uncertainty	 ± 1 digit ± 0·00005 N
Current (A)	Reading Absolute uncertainty	1·98 A ± 0·02 A
Length (m)	Reading Absolute uncertainty	0·054 m ± 0·0005 m

(i) From this data, calculate the magnetic induction, B. **3**

(ii) Calculate the absolute uncertainty in the value of the force. **3**

(iii) Calculate the overall absolute uncertainty in the value of the magnetic induction. **3**

2011 SQA AH answer

$$F = \frac{0.0058 + 0.0061 + 0.0063 + 0.0057 + 0.0058 + 0.0062}{6}$$

$$F = 0.0060N$$

- -

F=BIl

$$6.0 \times 10^{-3} = B \times 1.98 \times 0.054$$

$$B = \frac{6.0 \times 10^{-3}}{1.98 \times 0.054}$$

$$B = 0.056\text{T}$$

Scale Reading uncertainty (SRU)

± 1 digit $\Rightarrow \pm$ 0.0001N (½)

Random uncertainty (RU) (½)

$$= \left(\frac{\max - \min}{n}\right)$$

$$= \left(\frac{0.0063 - 0.0057}{6}\right) = 0.0001\text{N} \quad (½)$$

$$\Delta F = \sqrt{\text{SRU}^2 + \text{RU}^2 + \text{calibration uncert}^2} \quad (½)$$

$$\Delta F = \sqrt{0.0001^2 + 0.0001^2 + 0.00005^2} = \sqrt{2.25 \times 10^{-8}}$$

$$\Delta F = 1.5 \times 10^{-4}\ \text{N} \quad (1)$$

2011 continued

$$\frac{\Delta B}{B} = \sqrt{\left(\frac{\Delta F}{F}\right)^2 + \left(\frac{\Delta I}{I}\right)^2 + \left(\frac{\Delta l}{l}\right)^2}$$ (½)

$$\frac{\Delta B}{B} = \sqrt{\left(\frac{1.5\times10^{-4}}{0.0060}\right)^2 + \left(\frac{0.02}{1.98}\right)^2 + \left(\frac{0.0005}{0.054}\right)^2}$$

(½)+
(½)+
(½)+

$$\frac{\Delta B}{B} = \sqrt{8.12\ \times 10^{-4}}$$

$$\frac{\Delta B}{B} = 0.029$$

$$\therefore B = (0.056) \pm\ 0.0016\text{T}$$ (1)

%Δ F = 2.5% (½)
%Δ I = 1.0% (½)
%Δ l = 0.93% (½)

Allow carry through of incorrect ΔF must compare / combine with % uncertainties in I and l to show dominance if required

2.9% or 2.8% of B

FINAL ANSWER MUST BE ABSOLUTE NOT %

2001 SQA AH Q 1

1. A car accelerates uniformly from rest from a point A and is timed over the distance AB as shown in Figure 1.

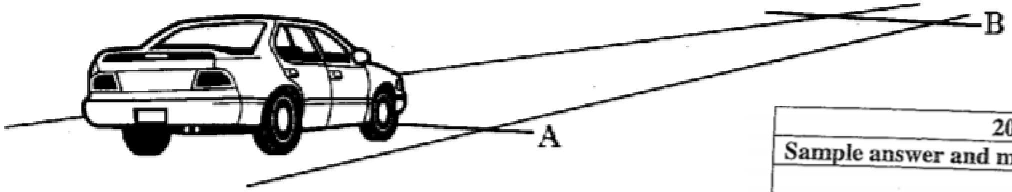

Figure 1

The results are as follows:

distance travelled, AB = (100 ± 1) m

time taken = (8·0 ± 0·4) s.

(*a*) Calculate:

(i) the acceleration of the car;

(ii) the percentage uncertainty in the acceleration

2001 AH Physics Sample answer and mark allocation	Notes	M
1 a) (i) $s = ut + \frac{1}{2}at^2$ (½) $100 = 0 + (0{\cdot}5 \times a \times 8{\cdot}0^2)$ (½) $a = 3{\cdot}1\ \mathrm{m\ s^{-2}}$ (1)	$3{\cdot}125\ \mathrm{m\ s^{-2}}$ acceptable	2
a) (ii) % uncertainty in $t = (\frac{0.4}{8}) \times 100 = 5\%$ (½) % uncertainty in $t^2 = 2 \times 5\% = 10\%$ (½) % uncertainty in $s = (\frac{1}{100}) \times 100 = 1\%$ (½) % uncertainty in $a = 10\%$ (½)	OR % uncertainty in s negligible (½) if missing 1½ max OR $\sqrt{(1^2 + 10^2)} = 10\%$ (½)	2

2006 SQA AH Q1

A child's toy consists of a model aircraft attached to a light cord. The aircraft is swung in a vertical circle **at constant speed** as shown in Figure 1.

X is the highest point and Y the lowest point in the circle.

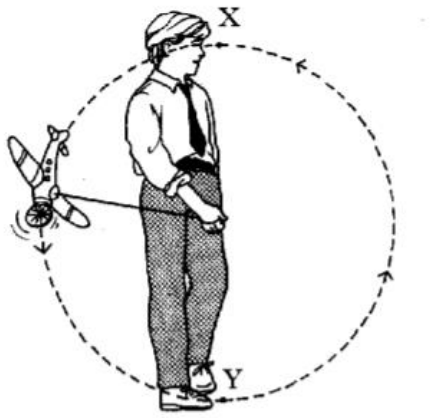

Figure 1

(*a*) The time taken for the aircraft to complete 20 revolutions is measured five times.

The mass of the aircraft and the radius of the circle are also measured. The following data is obtained.

Time for 20 revolutions: 10·05 s; 9·88 s; 10·30 s; 9·80 s; 9·97 s.
Radius of circle = 0·500 ± 0·002 m.
Mass of aircraft = 0·200 ± 0·008 kg.

(i) (A) Calculate the average period of revolution of the aircraft.

(B) Assuming that the scale reading and the calibration uncerts are negligible calculate the absolute uncertainty in the period.

(i) Show that the centripetal force acting on the aircraft is 15.8 N.

(iii) Calculate the absolute uncertainty in this value for the centripetal force. Express your answer in the form

F = (15.8 ±   ) N

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2006 SQA AH Q1 answer

1(a)(i)(A) $\bar{t} = \frac{\text{sum}}{\text{number}}$ **-OR -** $\bar{t} = \frac{10{\cdot}05 + 9{\cdot}88 + 10{\cdot}30 + 9{\cdot}80 + 9{\cdot}97}{5}$ (½)

$\bar{t} = \frac{50{\cdot}00}{5} = 10{\cdot}00$ (½)

$\bar{T} = \frac{10{\cdot}00}{20} = 0{\cdot}500\text{s}$ (½)

(B) uncertainty $= \frac{\text{max} - \text{min}}{N}$

uncertainty $= \frac{10{\cdot}30 - 9{\cdot}80}{5}$ (½)

uncertainty $= \frac{0{\cdot}500}{5} = 0{\cdot}100$ (½)

uncertainty in T $= \frac{0{\cdot}100}{20} = \pm\, 0{\cdot}005$ s (½)

$\bar{T} = \frac{0{\cdot}5025 + 0{\cdot}494 + 0{\cdot}515 + 0{\cdot}490 + 0{\cdot}4985}{5}$ (1)

$\bar{T} = \frac{2{\cdot}500}{5} = 0{\cdot}500\text{s}$ (½)

OR

%age uncertainty in T = 1% (1)

$= \pm\, 0{\cdot}005$s (½)

OR

uncertainty $= \frac{0{\cdot}515 - 0{\cdot}490}{5}$ (1)

uncertainty in T $= \frac{0{\cdot}025}{5}$

uncertainty in T $= \pm\, 0{\cdot}005$s (½)

2006 SQA AH Q1 answer

(a) (iii)

% uncertainty in r $= \frac{0{\cdot}002}{0{\cdot}500} \times 100 = 0{\cdot}4\%$ (½)

% uncertainty in m $= \frac{0{\cdot}008}{0{\cdot}200} \times 100 = 4\%$ (½)

% uncertainty in T $= \frac{0{\cdot}005}{0{\cdot}500} \times 100 = 1\%$ (½)

% uncertainty in $T^2 = 2 \times 1 = 2\%$ (½)

% uncertainty in F $= \sqrt{(4^2 + 2^2)}$ (½)

$= 4{\cdot}47\%$ (½)

$F = (15{\cdot}8 \pm 0{\cdot}7)$ N (1)

ALLOW CARRY THROUGH WRONG ANSWER FROM 1(a)(i)(B)

Allow $\sqrt{(4^2 + 2^2 + 0.4^2}$

$= 4{\cdot}49\%$ OR $4{\cdot}5\%$

2017 SQA AH

An LED from the traffic light is tested to determine the wavelength by shining its light through a set of Young's double slits, as shown in Figure 10B.

The fringe separation is (13·0 ± 0·5) mm and the double slit separation is (0·41 ± 0·01) mm.

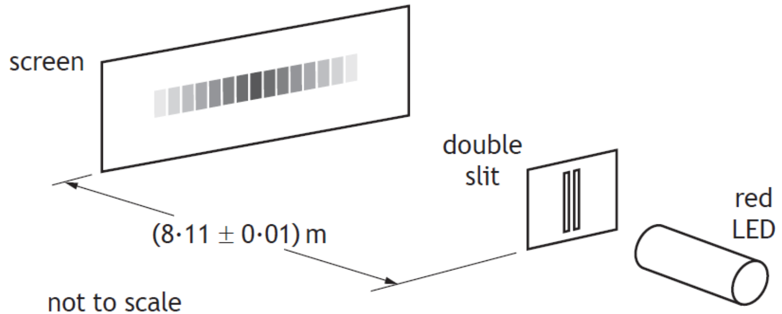

Figure 10B

(i) Calculate the wavelength of the light from the LED.

(ii)Determine the absolute uncertainty in this wavelength.

% Uncertainty in fringe separation

$$=\left(\frac{0\cdot5}{13\cdot0}\right)\times100 \qquad 1$$

$$=3\cdot85\%$$

% Uncertainty in slit separation

$$=\left(\frac{0\cdot01}{0\cdot41}\right)\times100 \qquad 1$$

$$=2\cdot44\%$$

% Uncertainty in slit-screen separation

$$=\left(\frac{0\cdot01}{8\cdot11}\right)\times100$$

$$=0\cdot123\%$$

(can be ignored)

% uncertainty in wavelength

$$=\sqrt{\left(\frac{0\cdot5}{13\cdot0}\right)^2+\left(\frac{0\cdot01}{0\cdot41}\right)^2}\times100\%$$

$$=4\cdot56\%$$

$$\Delta\lambda=\frac{4\cdot56}{100}\times6\cdot6\times10^{-7}$$

$$\Delta\lambda=0\cdot3\times10^{-7}\,\mathrm{m}$$

2016 SQA AH

Uncertainties in r		Uncertainties in B	
reading	$\pm 0{\cdot}002$ m	reading	$\pm 0{\cdot}1\ \mu T$
calibration	$\pm 0{\cdot}0005$ m	calibration	$\pm 1{\cdot}5\%$ of reading

(i)	ignore calibration (less than 1/3) $\%unc = 0{\cdot}002 / 0{\cdot}1 \times 100 = 2\%$ 1	1	Accept 2·1% if calibration not ignored. (Accept 2%, 2·06%, 2.062%)
(ii)	reading $5 = 0{\cdot}1 / 5 \times 100 = 2\%$ 1 total%=$\sqrt{}$(reading%^{2}+calibration%^{2}) 1 total % = $\sqrt{(1{\cdot}5^2 + 2^2)}$ = 2·5% 1	3	Accept 3%, 2·50%, 2·500%
(iii)	total % = $\sqrt{(2^2 + 2{\cdot}5^2)} = \sqrt{10{\cdot}25}\%$ 1 abs u/c= $\dfrac{\sqrt{10{\cdot}25}}{100} \times 2{\cdot}5 = 0{\cdot}08$ A 1	2	Accept 0·1, 0·080, 0·0800 Consistent with b(i) and (ii).
	Uncertainty in measuring exact distance from wire to position of sensor.	1	

The student estimates the uncertainties in the measurements of *B* and *r*.

(i) Calculate the percentage uncertainty in the measurement of *r*.

(ii) (ii) Calculate the percentage uncertainty in the measurement of *B*.

2007 SQA AH

The following data are obtained.

Distance between adjacent nodes = $(0{\cdot}150 \pm 0{\cdot}005)$ m
Frequency of signal generator = (250 ± 10) Hz

(*a*) Show that the wave speed is $75\ \mathrm{m\,s^{-1}}$. **2**

(*b*) Calculate the absolute uncertainty in this value for the wave speed. Express your answer in the form $(75 \pm \quad)\ \mathrm{m\,s^{-1}}$. **3**

(*c*) (i) In an attempt to reduce the absolute uncertainty, the frequency of the signal generator is increased to (500 ± 10) Hz. Explain why this will **not** result in a reduced absolute uncertainty. **1**

(ii) State how the absolute uncertainty in wave speed could be reduced. **1**

(7)

(ii) measure the distance over several nodes and take an average (1)

(b) % uncertainty in $\lambda = \frac{0.005}{0{\cdot}150} \times 100$

$= 3{\cdot}3\%$ (½)

% uncertainty in f $= \frac{10}{250}$ x 100

$= 4\%$ (½)

% uncertainty in v $= \sqrt{4^2 + 3{\cdot}3^2}$ (½)

$= 5\%$ (½)

---

absolute uncertainty $= 75 \times \frac{5}{100}$ (½)

$= 4\ \mathrm{ms^{-1}}$

v $= (75 \pm 4)\ \mathrm{ms^{-1}}$ (½)

(c) (i) % uncertainty in λ will increase (1)

Appendix 1. Using LINEST- if you have problems

Note: If you have a current version of Microsoft 365, then you can simply enter the formula in the top-left-cell of the output range, then press **ENTER** to confirm the formula as a dynamic array formula. Otherwise, the formula must be entered as a legacy array formula by first selecting the output range, entering the formula in the top-left-cell of the output range, and then pressing **CTRL+SHIFT+ENTER** to confirm it. Excel inserts curly brackets at the beginning and end of the formula for you. For more information on array formulas, see Guidelines and examples of array formulas.

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Use of Spreadsheet (Excel)

Highlight numerical columns you want plotted.

Go to charts - **select scatterplot** - from chart styles select smallest points possible.

From menu - **select chart layout.**

Input major and minor gridlines.

Label axes - remember units.

Chart title - insert title

From menu - **go to trendline**

select linear trendline

Go to trendline options select “display equation on chart”.

Ensure the graph is expanded to at least half a page.

Use of Spreadsheet (Excel)

Error Bars - x and y. Set for each individual point.

Format Data Series - allows change in style and size of plotted point.

Linest - uncertainty in gradient . This can be taken as the overall uncertainty $\left(\frac{\Delta m}{m}\right)$ $fractional\ uncertainty\ in\ gradient = fractional\ uncertainty\ in\ the\ experiment.$

Expand graph to at least half a page.

Incorrect Use of Random Uncertainty

Calculation of λ using a diffraction grating.
Values calculated for n = 1, 2 & 3.
Incorrect to find mean value plus max – min / 3.

Must calculate the uncertainty in λ for each value of n.
Comment on best value obtained.
(Accuracy / precision)

Accuracy - comparison of calculated value to accepted value.

Precision - indication of uncertainty in value.

Correct Use of Random Uncertainty

For each length used, calculate the random uncertainty and compare this with the scale reading / calibration uncertainty.

Combine using Pythagorean relationship

(3 times smaller can be ignored)

Plot a graph of T^2 against L.

Use Excel to calculate the gradient of the line of best fit.

Error bars – good indicator - use in discussion.

Uncertainty in Powers

- R = V/I – Use Pythagorean rule

- $\% \Delta R^2 = \% \Delta V^2 + \% \Delta I^2$
  (probability of some cancellation)

- This rule does not apply for powers.

- % uncertainty in t^2 = 2 x % uncertainty in t
  (no cancellation of uncertainties in this case).