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SESSION PLAN

Physics Tutorial 3: Analysing Like a Physicist

Aim

To understand how and why uncertainties are used in science, and how they are calculated

Learning Objectives

By the end of this session, the mentees will be able to...

- State the difference between absolute and percentage uncertainty
- Apply uncertainty propagation to simple formulae
- Assess how to reduce uncertainties in an experiment

Prepare in Advance

- There shouldn't be anything to prepare in advance, just have a read through the answers and make sure you understand and can explain them!

Scaffolding

If a mentee finishes early:

- Get them to try the optional extras (if they haven't already)
- Challenge them to design an experiment to measure the volume of water in a cup with the most accuracy and precision *(and the least if they have time!)*

If a mentee is struggling to calculate using standard form:

- Standard Form GCSE Revision: https://www.bbc.co.uk/bitesize/guides/zxsv97h/revision/1
- Walk them through the first self-study question step-by-step, or pair them with a mentee who can do so

Session Flow

Time	Activity
5 min	**Introduction** • Run through the aim and LOs • Recap the ground rules if needed
20 min	**Self-study Recap** • Go through the self-study materials and any solutions (on next page) • Answer any questions the mentees may have about the materials
10 min	**Importance of Uncertainties** • Run through uncertainties and errors to ensure mentees understand why they're important • Mentees try some calculations
20 min	**Mars Rovers** • Compare the uncertainties in the landing areas of different Mars Rovers • Discussion with mentees on why different rovers needed different landing areas on Mars
5 min	**Plenary** • Allow some time for mentees to ask questions and discuss today's topic

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MENTOR GUIDANCE

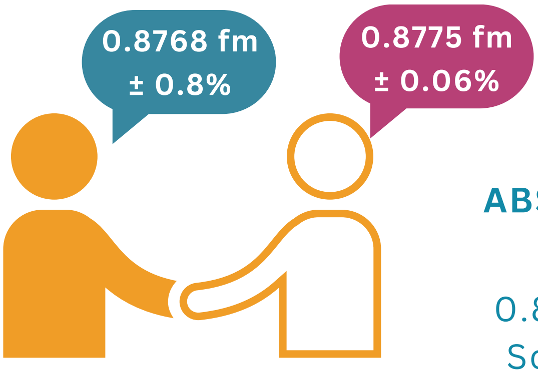
SESSION 3: ANALYSING LIKE A PHYSICIST

PART 1: SELF-STUDY RECAP

This first half of this tutorial is going through the self-study materials to ensure that mentees understand what uncertainty is, why we use it, and how to calculate it.

TASK 1: RADIUS OF A PROTON (PROVE IT!)

By finding the **absolute uncertainties** of the other two values, show that the value found in 2010 **does not agree** with the other two.



2010 VALUE

0.842 fm ± 0.1%

0.1% of 0.842 is 0.0008
So, 2010 value is between 0.8412 and 0.8428 fm

ABSOLUTE UNCERTAINTY OF VALUE 1

0.8% of 0.8768 is 0.007
So, Value 1 is between 0.8698 and 0.8838 fm

ABSOLUTE UNCERTAINTY OF VALUE 2

0.06% of 0.8775 is 0.0005
So, Value 2 is between 0.877 and 0.878 fm

The 2010 value range doesn't overlap with the other two ranges, so they don't agree!

TASK 2: PROPAGATION PRACTICE

1. POWER EQUATION

$$P = \frac{W}{t} =$$

(5 kJ ÷ 5 mins) ± (5%+4%)
(5,000 J ÷ 300 s) ± 9%
16.67 ± 9% W

$P =$?
$W =$ 5 kJ ± 5%
$t =$ 5 mins ± 4%

mentees might forget to convert from kJ and mins into J and s

2. EXTENSION OF A SPRING

$$F = kx =$$

(60 N/m x 75 cm) ± 2%
(60 N/m x 0.75 m) ± 2%
45 ± 2% N

$F =$?
$k =$ 60 N/m
$x =$ 75 cm ± 2%

mentees might forget to convert from cm to m

3. MAXIMUM KINETIC ENERGY OF AN EMITTED PHOTOELECTRON

$E_k =$?
$hf =$ 9.8 eV ± 0.8%
$\phi =$ 5.1 eV ± 2%

$$E_k = hf - \phi =$$

(9.8 eV - 5.1 eV) ± ((0.008 x 9.8) + (0.02 x 5.1))
4.7 ± 0.1804 eV
4.7 ± 0.2 eV

when adding, use **absolute** uncertainty!

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TASK 3: SIG FIG PRECISION

1 Assumed absolute uncertainty is ± the final sig fig, so it's **A = 1093.6 ± 0.1**

2 0.1% of 299792458 = 299792.458. Making sure it's to the right number of sig figs, the absolute uncertainty is **± 299792**

TASK 4: EXPERIMENTS

1

SOURCES OF UNCERTAINTY

- **Human error** in taking the time on the stopwatch
- The ruler and stopwatch have relatively **small** uncertainties, but it's fine if they're included/discussed

INCREASING PRECISION

- **Increase height** ball is dropped from (which also increases time)
- Using a more precise method of **timing,** e.g. a light gate or a sensor

2

AVERAGE DIAMETER

Average diameter is just the mean $= \frac{2.577 + 2.581 + 2.585 + 2.583 + 2.574}{5}$

$= 2.58$ m

ABSOLUTE UNCERTAINTY

Absolute uncertainty $= \frac{range}{2} = \frac{2.585 - 2.574}{2} = 0.0055$

mentees should know this as part of their curriculum

So absolute uncertainty is 2.58 ± 0.0055, or **2.58 ± 0.01** to the right sig figs

PERCENTAGE UNCERTAINTY

Percentage uncertainty is nice and simple from here: $= 2.58 \times 0.01 = 0.0258$

So percentage uncertainty is **2.58 ± 0.0258%**

OPTIONAL EXTRAS

DETECTING GRAVITATIONAL WAVES

The LIGO has to be able to detect a change **1,000 times smaller than a proton** over a distance of **4 km.**

So, **absolute** uncertainty is ± 0.0008768 fm

In metres, this is **± 8.768x10^{-19} m**

mentees encountered prefixes last session so should be able to look up **fm = 1x10^{-15}m**

As a **percentage** uncertainty, we calculate:

(8.768x10^{-19} ÷ 4,000) x 100 = **2.192x10^{-20}%**

in other words, **miniscule!!!**

SIZE OF A PROTON

0.8768 ± 0.007 fm

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OPTIONAL EXTRAS

HARDER UNCERTAINTY CALCULATIONS

1 $s = ut + \frac{1}{2}at^2 = (5.5 \times 45) + \left(\frac{1}{2} \times 10.8 \times 45^2\right) = 247.5 + 10,935$

= 11,182.5m

We use **percentage** uncertainty for multiplication and **absolute** uncertainty for addition:

$s =$ 11,182.5 ± ?? m
$u =$ 5.5 ± 0.1 m/s = 5.5 **± 1.82%**
$t =$ 45 ± 1 s = 45 **± 2.22%**
$a =$ 10.8 ± 0.2 m/s = 10.8 **± 1.85%**

So, uncertainties become:

$ut =$ 1.82 + 2.22 = ± 4.04% of 247.5 = ± 9.999 = **± 10.0**

$\frac{1}{2}at^2 =$ 1.85 + (2 x 2.22) = ± 6.29% of 10,935 = ± 687.8115 = **± 687.8**

mentees might forget the rule for squared numbers, or that constants are ignored

Then: $ut + \frac{1}{2}at^2 =$ 10.0 + 687.8 = **± 697.8m** **So, s = 11,182.5 ± 697.8m**

2

VOLUME OF THE RECTANGULAR PRISM

We know the volume of the rectangular prism is:

$$V_R = L \times W \times D = 112.5$$

VOLUME OF THE SEMI-CIRCLE

The volume of the semi-circle shape is area x depth

The area of the full circle is $\frac{1}{2}\pi W^2$

so the area of the half circle is $\frac{1}{4}\pi W^2$

So the volume of the semi-circle shape is:

$$V_C = \frac{1}{4}\pi W^2 \times D = 29.5$$

Put these together and you get:

$$V = (L \times W \times D) + \left(\frac{1}{4}\pi W^2 \times D\right)$$

We can quickly calculate **V = 141.95m** using the values given. Now let's work out the uncertainties...

$V =$ 141.95 ± ?? m
$L =$ 15 ± 0.01 m = 15 ± **0.07%**
$W =$ 5 ± 0.05 m = 15 ± **1%**
$D =$ 1.5 ± 0.2 m = 1.5 ± **13.3%**

Similar to the previous question, we need to use **percentage** uncertainty first then add together the **absolute** uncertainties.

So, the error in $V_R =$ 0.07 + 1 + 13.3 = **112.5 ± 14.4% = 112.5 ± 16.2**

and the error in $V_C =$ (2 x 1) + 13.3 = **29.5 ± 15.3% = 29.5 ± 4.5**

We can then add these two absolute uncertainties together to get the final answer:

$V =$ (112.5 + 29.5) ± (16.2 + 4.5) = **141.95 ± 20.7 m²**

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PART 1: SELF-STUDY RECAP

OPTIONAL

EXAM PRACTICE

All formulae/constants are given in mentees' data booklets during exams

1. (a) (i) Use of: $R = \frac{\rho A}{L}$ re-arranged to: $\rho = \frac{RA}{L}$ **1 mark**

Wires have a circular cross-section, so we can calculate A using:

$R = 2.2\ \Omega$
$L = 812\text{ mm} = 0.812\text{ m}$
$A = ??$

$$A = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{4.8\times10^{-4}}{2}\right)^2 = 1.81\times10^{-7}\text{ m}^2$$ **1 mark**

And so

$$\rho = \frac{RA}{L} = \frac{2.2\times1.81\times10^{-7}}{0.812} = 4.90\times10^{-7}\ \Omega\text{m}$$

1 mark

must include unit to get mark

if mentees get 20×10^{-7} or 19.6×10^{-7}, only lose 1 mark

(a) (ii) There are 2 methods to choose from for this one:

METHOD 1: FRACTIONAL/PERCENTAGE UNCERTAINTIES

First calculate the **percentage** uncertainties δ of each value:

$$\delta d = \pm0.01mm = \pm2.1\%$$

so
$$\delta A = 2\times2.1 = \pm4.2\%$$
$$\delta R = \pm0.1 = \pm4.5\%$$
$$\delta L = \pm1mm = \pm0.12\%$$

1 mark

remind mentees of the rules when propagating uncertainties!

Then add these together to find the uncertainty of ρ:

$$\delta\rho = \delta R + \delta A + \delta L$$
$$= 4.5 + 4.2 + 0.12 = \pm8.82\%$$

1 mark

Then convert to **absolute** uncertainty:

$$0.0882\times4.90\times10^{-7} = 4.32\times10^{-8}$$
$$= 0.43\times10^{-7}$$

$$resistivity = 4.90\pm0.43\times10^{-7}\ \Omega\text{m}$$

1 mark

METHOD 2: MAXIMUM VALUE

First, work out the maximum value each component can be:

$$A_{max} = \pi\left(\frac{4.8\times10^{-4}+1\times10^{-5}}{2}\right)^2 = 1.887\times10^{-7}$$

and $R_{max} = 2.3$ $L_{min} = 0.811$

1 mark

we're maximising ρ, so we want the minimum length

Then we can work out the maximum value of ρ, and calculate the difference between them to get uncertainty:

$$\rho_{max} = \frac{2.3\times1.887\times10^{-7}}{0.811} = 5.35\times10^{-7}$$

1 mark

so

$$\delta\rho = 5.35\times10^{-7} - 4.90\times10^{-7} = 0.45\times10^{-7}$$

$$resistivity = 4.90\pm0.45\times10^{-7}\ \Omega\text{m}$$

1 mark

allow error carried forward (ecf) from (i)

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OPTIONAL

EXAM PRACTICE

1. (b) Either: **Longer wire** results in less percentage/fraction uncertainty in **resistance**

1 mark **1 mark**

OR

Winding wire (or equivalent) to measure several diameters at once results in less percentage uncertainty in **diameter**

1 mark **1 mark**

2. (a) From the question, we know the resolution of the ruler is ±0.1 cm at the top and the bottom. So the **total** uncertainty is ±0.2 cm. The length is to one significant figure, which matches the significant figure of the uncertainty.

1 mark for resolution/±0.1 cm

1 mark for ±0.2 cm

2. (b) (i) Use of volume of a cylinder: $V = \pi r^2 h$

$r = \frac{d}{2} = 0.75 \text{ mm} = 7.5 \times 10^{-4} \text{ m}$

$h = l = 11.5 \text{ cm} = 0.115 \text{ m}$

$$V = \pi \times \left(7.5 \times 10^{-4}\right)^2 \times 0.115$$ **1 mark**

$$= 2.03 \times 10^{-7} \text{m}^3$$ **1 mark**

or equivalent answer in cm^3 or mm^3

must have correct units

2. (b) (ii) First calculate the percentage uncertainties:

$$\delta r = \delta d = \pm 0.1 = \pm 6.\dot{6}\%$$

$$\delta l = \pm 0.2 = \pm 1.74\%$$

mentees can use fractions throughout instead

Then use the rules of percentage uncertainties to calculate the uncertainty of V:

$$\delta V = 2\delta r + \delta l = \left(2 \times 6.\dot{6}\right) + 1.74$$ **1 mark**

$$= \pm 15\%$$ **1 mark**

can have ecf if used ±0.1 for length instead of ±0.2

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MENTOR GUIDANCE

SESSION 3: ANALYSING LIKE A PHYSICIST

PART 2: SKILLS PRACTICE

The second half of this tutorial gives students an opportunity to practice their skills and ask any questions.

IMPORTANCE OF UNCERTAINTIES

10 MINS

Discuss the difference between **uncertainty and error** with the mentees:

1. Challenge them to create a definition for each term
2. Discuss the difference between the two terms and how they might be used in science

Tell the mentees the story of the Hubble telescope, and how a small error resulted in such a big change in the quality of the photos:

THE STORY

In 1990, the Hubble telescope was sent into space, but the images weren't as sharp as they should be. A NASA investigation discovered that the telescope's 8-foot primary mirror had been ground **just a little bit too flat** around the edges due to a **miscalibrated measuring instrument,** which made the mirror flatter than it should be by just **one-fiftieth of the width of a human hair.**

They got the **percentage error** wrong!

NASA managed to find a solution so that the telescope could be altered via several space walks in 1993, resulting in a **much** sharper image (see PPT for image comparison). Even though it was a tiny difference in percentage error, the effects were massive. You can use this example to **highlight the importance of being accurate** to the mentees.

You can watch the space walk with mentees here: https://www.bbc.co.uk/videos/cd1p0z05103o *(2 mins)*

MARS ROVERS

20 MINS

Watch the second half of a TED talk about the Mars Rovers with mentees: https://youtu.be/hRAFPdDppzs?si=dYM5y_KwSgLc2vfi&t=163 *(2 mins, starts at 2:43)*

1. Guide the mentees through the calculation of the Viking rover's uncertainty
2. Challenge them to find the uncertainty of the Curiosity rover *(can do in pairs or alone in breakout rooms)*
3. Using these two answers, discuss why the Viking rover couldn't land in the Gale Crater where the Curiosity was able to

TOP TIPS

- If you have some time, you can watch the whole TED talk instead
- Mentees might get stuck. Encourage them to work together and help each other; make it more about the discussion of the topics than getting the right answer every time

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PHYSICS TUTORIAL 3: ANALYSING LIKE A PHYSICIST

BRIGHT IDEAS!

This page contains ideas for alternative sessions, changes/additions, extra activities, etc.
Feel free to use as you wish!

Uncertainties Everywhere

You could challenge mentees to think of various careers and situations where uncertainties are critical. Some examples:

- Engineering and construction: must be precise when designing and building structures
- Biology and chemistry: uncertainties make a huge difference at the microscopic level
- Physics (of course!): astronomy, semiconductors

Physics Skills

If you think the mentees are struggling to link the topic to wider skill applications, you can run an activity where they list the skills they use to solve the problems, and then discuss where they use those skills in physics.

Mars Rover Substitute

Instead of the Mars Rovers, you could find another example of when accuracy/precision has been important in science media. You could even chat to your co-mentor to see if there is an example from their field (if they are not a physics specialist).

There's a lot of examples out there using the microscopic level instead of astronomical!

Experiment

Depending on what you/mentees have at home, you could demo an experiment or get the mentees to complete a simple series of experiments to measure the volume of water in a cup and compare the accuracy and precision of each method.

- What's more accurate/precise? Using a ruler, using your eyes, weighing the cup, etc.
- **Please contact the project team** if you want mentees to complete this so we can let them know ahead of time to prepare any equipment