

A Level Physics – Bridging Booklet



A collection of physics equations and diagrams drawn on a blackboard background. The content includes:

- Electromagnetism:** $F = \frac{q_1 q_2}{4\pi\epsilon_0 r^2}$, $\vec{E} = \sum_{i=1}^n \vec{E}_i$, $R = \sigma T^4$, $\sigma = 5.67 \cdot 10^{-8} \frac{W}{m^2 \cdot K^4}$, $\lambda_m = \frac{b}{T}$, $b = 2.9 \cdot 10^{-3} m \cdot K$.
- Mechanics:** $v = \frac{1}{T}$, $\omega = 2\pi\nu$, $T = \frac{2\pi}{\omega}$, $\rho = mg$, $L = \mu\mu_0 n^2 V$, $\lambda = \nu T$, $k = \frac{2\pi}{\lambda}$.
- Special Relativity:** $E = mc^2$, $\beta = \frac{v}{c}$, $\gamma = \frac{1}{\sqrt{1-\beta^2}}$, $E = \gamma mc^2$, $p = \gamma mv$, $\Delta m = Zm_p + Nm_n - m$.
- Quantum Physics:** $h = 6.63 \cdot 10^{-34} J \cdot s$, $\psi_n = \sqrt{\frac{2}{l}} \sin \frac{n\pi x}{l}$, $E_n = \frac{h^2}{8ml^2} n^2$, $\lambda = \frac{h}{p}$, $\phi = \frac{W}{q_0}$.
- Other Equations:** $\Phi = \int \vec{B} \cdot d\vec{s}$, $\vec{D} = \epsilon_0 \vec{E} + \vec{P}$, $\vec{a} = \frac{d\vec{v}}{dt}$, $\Delta s = s_2 - s_1$, $\langle v \rangle = \frac{\Delta s}{\Delta t}$, $\vec{a} = \vec{a}_n + \vec{a}_t$, $\langle v \rangle = \frac{\Delta s}{\Delta t}$, $\Delta s = s_2 - s_1$, $\vec{a} = \vec{a}_n + \vec{a}_t$, $\langle v \rangle = \frac{\Delta s}{\Delta t}$, $\Delta s = s_2 - s_1$.
- Diagrams:** A sine wave representing a wave, a Bohr-style atomic model with a central nucleus and three elliptical orbits, and a circular diagram showing wave interference or diffraction.

Name:

Due Date:

How the use this Bridging Booklet

Hello!

It is great that you are considering A-level physics. It is a superb course covering fundamental knowledge and skills that are essential for university study in a number of areas. Physics is the most fundamental of the sciences as we are interested in the very laws which make the universe tick. It is immensely rewarding to study, and will reveal the fundamental beauty of the universe in a way that no other subject can.

Physics is also useful! Because you will be learning broad and deep thinking and problem-solving skills, physics synergises very well with other sciences, and with subjects like design technology, computer science, geography, or economics. If you are intending to study physics (obviously) or engineering at university, A-level Physics is essential for you.

A note on mathematics: maths is the toolkit we use to do physics, in the same way a mechanic uses a spanner, screwdrivers, etc. Every lesson will be highly mathematical. Any course that uses physics at university will require you to be studying maths A-level as well. As such, you are **very strongly advised** to take A-level maths alongside physics. I cannot in good conscience tell you it's a good idea to take physics without maths – it isn't.

Please work through this booklet, and self-mark it using the answers provided. There is a reflection at the back for you to complete.

At the end of the booklet there are also some links to some videos and books to entertain and inspire you. It would be a really good idea for you to start to explore the course and even start pre-learning some material so that you can make a really positive start to A-level Physics.

Enjoy!

Mr Dennis

Physics Bridging

Objectives:

- *To give you the skills needed for the successful study of Physics.*
- *To help you to identify areas in which you might need help.*

There are several areas in which students struggle:

- Use of symbols;
- Use of SI units;
- Use of a calculator;
- Use of formulae;
- Plotting of the data in a graph;
- Interpretation of graphical data.
- Calculating errors and uncertainties.

These notes and activities are to help you to become confident with these basic skills, which will help your studies to be more productive and enjoyable. I have included commentary on how we do things at A-level, and pitfalls to avoid. There are a total of 108 marks available, but the bonus activities mean that you could theoretically get $120/108 = 111\%$. There's your target!

Using Symbols

An **equation** is a mathematical model that sums up how a system behaves. For example, we know that, if we have a current flowing through a wire and double the voltage, the current will double as well. We know that the quantities of current and voltage are related by the simple rule:

$$V = IR$$

In physics problems we are given certain quantities and use them to find an unknown quantity with an equation. Always in every problem you will have only one unknown. At AS level you will never be expected to tackle a problem with two or more unknowns. That said you may need to look up some quantities from the data sheet.

There are some basic equations that you will have to learn for the exams. These are written down for you at the back of the **Physics Guide**.

1. Write down three equations that you can remember from GCSE	(3)

Symbols

In GCSE you were often given equations in words:

$$\text{Distance (m)} = \text{speed (m/s)} \times \text{time (s)}$$

You will notice from the data sheet at the end of these notes that the equations are given in **symbols**. The symbols all mean something; they are abbreviations. The symbols used in exams and most textbooks are those agreed by the Association of Science Education.

Some symbols are easy; V stands for voltage. Some are not so easy. I for current comes from the French *intensité du courant*, since it was a French physicist who first worked on it.

2. What are the meanings for these symbols?	(7)
a	
A	
F	
m	
I	
p	
Q	

You will come across symbols written in Greek letters as well as Latin. The normal (Latin) alphabet has 26 characters. No symbols are used with modifiers like ä (a – umlaut) or ê (e – circumflex). The Greek alphabet adds another 24.

3. How many distinct symbols might it be possible to get from the Latin and Greek alphabets? Think carefully and look at the Greek alphabet overleaf (2)

The Greek Alphabet is this:

<i>Greek</i>	<i>Name</i>	<i>Letter</i>	<i>Greek</i>	<i>Name</i>	<i>Letter</i>
α (A)	alpha	a	ν (N)	nu	n
β (B)	beta	b	ξ (9)	xi	x
γ (Γ)	gamma	g	ο (O)	omicron	Short o (ō)
δ (Δ)	delta	d (D)	π (Π)	pi	p
ε (E)	epsilon	Short e (ë)	ρ (P)	rho	r
ζ (Z)	zeta	z	σ (Σ)	sigma	s (S)
η (H)	eta	Long e (ē)	τ (T)	tau	t
θ (Θ)	theta	th	υ (Y)	upsilon	u
ι (I)	iota	i	φ (Φ)	phi	ph [or f (F)]
κ (K)	kappa	k	χ (Ξ)	chi	ch
λ (Λ)	lambda	l (L)	ψ (Ψ)	psi	ps
μ (M)	mu	m	ω (Ω)	omega	Long o [(ooh)]

The ones in grey are the ones you won't generally come across in A-level. You will come across the others in the context of:

- Particles – many particles are given Greek letters, e.g. π meson.
- Physics equations, e.g. $c = f\lambda$

4. The wave equation is $c = f\lambda$. What do the symbols refer to? (3)

c

f

λ

The most common uses of Greek letters are:

- α – as in alpha particle, also used to denote % uncertainty;
- β – as in beta particle;
- γ – as in gamma ray or photons more generally;
- Δ – change in (Δt is time interval, Δl would be a change in length, etc);
- θ – angle (or temperature);
- π – obviously
- ρ – density.

5. Find two other formulae in the data sheet that use Greek letters	(2)

In Question 3 you worked out that there are 86 different letters available to measure quantities. There are many hundreds of quantities that can be measured in Physics. Therefore it doesn't take a genius to see that some symbols have several meanings, for example I for current, and I for energy intensity.

6. Write down two other letters where the same letter stands for different quantities. Write what they mean and the equations in which they are used.	(6)

When you use an equation, you will need to know exactly what each term means. But don't worry; the terms will be explained when the formula is introduced to you.

Units

Physics formulae use **SI** (Système International) **units** based on seven **base units**:

- **Distance** – metre (m);
- **Mass** – kilogram (kg);
- **Time** – second (s);
- **Temperature** – Kelvin (K);
- **Current** – ampere (A);
- **Amount of substance** – mole (mol);
- **Intensity of light** – candela (cd) [which you will not come across at A-level.]

Many physics formulae will give you the right answer **ONLY** if you put the quantities in SI units. This means that you have to convert. You will often find units that are prefixed, for example kilometre. The table below shows you the commonest prefixes and what they mean:

<i>Prefix</i>	<i>Symbol</i>	<i>Meaning</i>	<i>Example</i>
pico	p	$\times 10^{-12}$	1 pF
nano	n	$\times 10^{-9}$	1 nF
micro	μ	$\times 10^{-6}$	1 μ g
milli	m	$\times 10^{-3}$	1 mm
centi	c	$\times 10^{-2}$	1 cm
kilo	k	$\times 10^3$	1 km
Mega	M	$\times 10^6$	1 M Ω
Giga	G	$\times 10^9$	1 GWh

When converting, it is perfectly acceptable to write the number and the conversion factor. For example, all of the following are acceptable:

$$250 \text{ nm} = 250 \times 10^{-9} \text{ m} = 2.50 \times 10^{-7} \text{ m}$$

Notice how we kept the same number of significant figures when we converted. This is important.

7. Convert the following quantities to SI units in standard form where necessary: (5)	
15 cm	
500 g	
3 km	
35 mV	
220 nF	

When you write out your answer, you must always put the correct **unit** at the end. The number 2500 on its own is meaningless; 2500 J gives it a meaning.

Failure to put units in loses 1 mark in the exam, which is 2 %. Repeated across a paper, it can mean the difference of two grades.



This little character is about to walk into a **bear trap**. In the notes you will see him where there are common bear traps such as failing to convert into SI units.

Converting areas and volumes causes a lot of problems.

$$1 \text{ m}^2 \neq 100 \text{ cm}^2.$$

$$1 \text{ m}^2 = 100 \text{ cm} \times 100 \text{ cm} = 10\,000 \text{ cm}^2 = 10^4 \text{ cm}^2$$

8. Convert the following:	(4)
$1 \text{ m}^2 =$	mm^2
$0.45 \text{ mm}^2 =$	m^2
$1 \text{ cm}^3 =$	m^3
A cube which is $24\text{mm} \times 24\text{mm} \times 24\text{mm} =$	m^3

Standard Form

Standard form consists of a number between 1 and 10 multiplied by a **power** of 10. For big numbers and very small numbers standard form is very useful. We will use it all the time in physics.

9. Comment on what happens if you try to put the following numbers into your calculator as they are. Can you do any calculations on them?

(a) 3200

(b) 5 600 000

(c) 2 800 000 000 000

(d) 0.0000000000000341

(2)

You should have found that very small numbers entered into a calculator are read as 0, unless they are entered as standard form. The following number is shown in standard form:

$$\begin{aligned} & \mathbf{3.28 \times 10^5} \\ & = 3.28 \times 100\,000 = 328\,000 \end{aligned}$$

Look at this number:

4 505 000 000 000 000 000



Start counting from here to get the power of 10.

We find that there are 18 digits after the first digit, so we can write the number in standard form as:

$$4.505 \times 10^{18}$$

For fractions we count how far back the first digit is from the decimal point:

0.00000342

In this case it is six places from the decimal point, so it is:

$$3.42 \times 10^{-6}$$

A negative power of ten (negative index) means that the number is a fraction, i.e. between 0 and 1.

10. Convert these numbers to standard form:	(7)
86	
381	
45300	
1 500 000 000	
0.03	
0.00045	
0.0000000782	

There is no hard and fast rule as to when to use standard form in an answer. Basically if your calculator presents an answer in standard form, then use it. I generally use standard form for:

- numbers greater than 100 000
- numbers less than 0.001
- Where a limited number of significant figures are needed (see later on in the calculator section)

When doing a **conversion** from one unit to another, for example from millimetres to metres, it is perfectly acceptable to write:

$$15 \text{ mm} = 15 \times 10^{-3} \text{ m}$$

- This is because 1mm *is* 10^{-3} m, that's what the m for "milli" means.
- Doing this reduces the number of steps in a calculation you might make mistakes in.
- Your calculator will recognise 15×10^{-3} m perfectly happily.

However, when you give your final answer to a calculation, you should put it into proper standard form, ie $1.5 \times 10^2 \text{ m}$.

The only reason not to do this would be if you were asked to answer in, say, gigameters (Gm), at which point writing $220 \times 10^9 \text{ m}$ in the step before your final answer makes sense because that's clearly 220 Gm, which is what you would write as the actual answer.

On calculators

A **scientific calculator** is an essential tool in Physics, just like a spanner is to a mechanic. All physics exams assume you have a calculator, and you should always bring a calculator to every lesson. There is no excuse for not having one. Your phone is not an acceptable substitute (most phone calculator apps are terrible, and in any case you can't take it into the exam).

The calculator should be able to handle:

- **standard form;**
- **trig** functions (sin, cos, tan, etc)
- **angles** in **degrees** and **radians;**
- **natural logarithms** and **logarithms to base 10.**

Most scientific calculators have this and much more.

There are no hard and fast rules as to what calculator you should buy, but here are some tips:

- **Get one that you are happy with.** My calculator was my 15th birthday present and I've used it lovingly these ~20 years since. It's old, it's ugly, but it gets the job done. As above, so below!
- **Learn to use it!** A tool you can't use is useless. If you don't know how to do something, ask your teacher, Google it, or (god forbid) read the manual. As you progress you will discover your calculator has lots of superbly useful functions like solving quadratic or simultaneous equations!
- **I recommend a Casio FX-85GTX** which can be had for less than £15 in shops or online. It's a good balance of price, power, and ease of use for the novice physics student.
- Those intending to study physics or engineering at university may wish to think about a more advanced model as they progress. A Casio FX-CG50 would be a good investment as you move towards university.

I am assuming that you know the basic functions of your calculator, but I need to draw your attention to a couple of points:

Misuse of the EXP (or $\times 10^X$) key:

Suppose we have a number like 2.31×10^7 . You key it in like this:



Do NOT key it in like this:



This will give you 2.31×10^8 . Misuse of the calculator will always cost marks.

Too Many Significant Figures

Consider this calculation:

$$V_{rms} = \frac{13.6}{\sqrt{2}}$$

Your calculator will give the answer as $V_{rms} = 9.6166526 \text{ V}$

There is almost never a reason in A-level Physics to write any answer to any more than 3 significant figures. Three significant figures is claiming accuracy to about one part in 1000. Blindly writing your calculator answer is claiming that you can be accurate to one part in 100 million, which is absurd at this level. If you write more than 3 sf, expect to be asked to justify yourself or lose marks.

The **examination mark schemes** give answers that are no more than 3 significant figures. So our answer becomes:

$$\begin{aligned} V_{rms} &= 9.6167 \text{ V (5 s.f.)} \\ V_{rms} &= 9.62 \text{ V (3 s.f.)} \end{aligned}$$

Do any rounding up or down **at the end of a calculation**. If you do any rounding up or down in the middle, you will end up with rounding errors. Mark schemes do allow a little leeway and “error carried forward” but you can very easily fall outside these boundaries and lose marks.

Choosing how many significant figures to use:

The number of sig fig. you write is the smallest number in the source data for a calculation.

Example 1: Consider the following

$$2.316 \times 6.5 = 15.054$$

The calculator gives 15.054, ie 5 significant figures. How many should we give our answer to?

Look at the data. We have 2.316, which is 4sf. We also have 6.5 which is 2 sf. So our answer should be the lesser of the two – ie 2sf.

So we write 15 as our answer.

Example 2: Calculating kinetic energy using $E_k = \frac{1}{2}mv^2$

Let's imagine $m = 3.54\text{kg}$ and $v = 27.89\text{m/s}$

$$E_k = \frac{1}{2} \times 3.54\text{kg} \times (27.89\text{m/s})^2$$

The calculator returns $E_k = 1376.789217 \text{ J}$

The mass was given to 3sf and velocity to 4sf – so we must use 3sf in the answer, $E_k = 1.38 \times 10^3\text{J}$

Important notes:

- Notice we had to put this into standard form. Why didn't we just round 1376.789217 to 1380?
- This is a common mistake which you even see some teachers make. 1380 is **4sf**, not 3 - and anyone who tells you otherwise is simply wrong. That zero on the end of 1380 is telling us we know the number is 1380 and not 1379 or 1381 – so it *must* be significant. The only way to get 3sf out of 1376.789217 is to put it into standard form, 1.376789217×10^3 , then round it to 3sf = 1.38×10^3 .
- **The exponent part $\times 10^3$ does not count** for sig fig.
- **The fraction $\frac{1}{2}$ didn't count** either – it's **not a measurement**, so it doesn't have significant figures associated with it so it doesn't affect our result. Writing it as a fraction rather than the decimal 0.5 helps us see this.
- **Mathematical constants** like π and e **do not affect significant figures**.
- **Measured constants** in data books, like $G = 6.67 \times 10^{-11} \text{ Nkg}^{-2}\text{m}^2$, $h = 6.63 \times 10^{-34} \text{ Js}$, or $c = 3.00 \times 10^8 \text{ m/s}$ **do count** towards sf, as they are given with a specific number of sf (usually 3) in the data book.

11. Use your calculator to do the following calculations. Write your answers to no more than three significant figures. (10)	
	<i>ANSWER</i>
(a) $\frac{3.4 \times 10^{-3} \times 6.0 \times 10^{23}}{235}$	
(b) $\frac{27.3^2 - 24.8^2}{\sqrt{38}}$	
(c) 1.4509^3	
(d) $\sin 56.4$	
(e) $\cos^{-1} (0.4231)$	
(f) $\tan^{-1} (2.143)$	
(g) $\sin^{-1} (1.00052)$	
(h) Reciprocal of 2.34×10^5	
(i) $\log_{10} 200$	
(j) $45 \sin 10$	

Some other tips on use of calculators:

- Take one step at a time and write intermediate results. Use the ANS function to reuse intermediate results to avoid rounding errors accumulating.
- It is easy to make a mistake such as pressing the \times key rather than the \div key. It is a good idea to do the calculation again as a check.
- As you get more experienced, you will get a “feel” for what is a reasonable answer. 1000 N is a reasonable force that a car would use to accelerate; $2 \times 10^{-10} \text{ N}$ is most certainly not.

Re-arrangement of Formulae

In maths you may have called this “making something else the subject of an expression”

Simple example:

We have that $p = mv$. Write an expression for m .

Answer: $m = p/v$

Complex example:

The strain-energy equation is $W = \frac{EA(\Delta l)^2}{l_0}$. Find an expression for Δl .

Answer: $\Delta l = \left(\frac{Wl_0}{EA}\right)^{\frac{1}{2}}$

The **rearrangement** of formulae is a skill that is absolutely essential for the study of Physics. It is no more possible to succeed without it any more than it would be to win a Formula 1 race without a car.

Some students find rearrangement very difficult and it hampers their progress and enjoyment of the subject. They try to get around it by learning all the variants of a formula, which is a waste of brain power. Some other students attempt to use “formula triangles”. This approach worked at GCSE but is no longer satisfactory at A-level where equations will quickly become much more complex.

It is far better to get into the habit of rearranging formulae from the start. The best thing to do is to practise.

Key Points:

- What you do on one side you have to do on the other side. It applies whether you are working with numbers, symbols, or both.
- Don't try to do too many stages at once.
- Don't be afraid to use trial-and-error if you need to! We're here to learn, we don't judge.

Re-arranging Simple Formulae

Simple formulae are those that consist of three quantities, taking the form $A = BC$. A typical example is $V = IR$

12. Write down two other formulae of this kind. (2)

Suppose we are using the equation $V = IR$ and wanted to know I .

We want to get rid of the R on the RHS so that I is left on its own.

So we divide both sides by R which gives us:

$$\frac{V}{R} = \frac{IR}{R}$$

The R s on the RHS cancel out because $R/R = 1$. So we are left with:

$$\frac{V}{R} = I, \text{ ie } I = \frac{V}{R}$$

It does not matter which way the equation ends up but it is usual to write the variable we're calculating on the left hand side for ease of reading.

13. Rearrange these equations: (4)		
<i>Equation</i>	<i>Subject</i>	<i>Answer</i>
$V = IR$	R	
$p = mv$	v	
$\rho = \frac{m}{V}$	m	
$Q = CV$	C	

Formulae with Four Terms

Do the same method as above. Consider this formula:

$$R = \frac{\rho L}{A}$$

Make ρ the subject.

So we want ρ but we have a $\times L$ and a $\div A$ getting in our way. Let's start with the L

Get rid of the L by dividing the whole equation by L :

$$\frac{R}{L} = \frac{\rho L}{AL}$$

The L terms cancel to give:

$$\frac{R}{L} = \frac{\rho}{A}$$

To get rid of the A downstairs we need to multiply both sides by A :

$$\frac{AR}{L} = \frac{\rho A}{A}$$

The A terms cancel to give us our final result:

$$\rho = \frac{AR}{L}$$

14. Rearrange these equations: (4)		
<i>Equation</i>	<i>Subject</i>	<i>Answer</i>
$pV = nRT$	V	
$Ep = mg\Delta h$	Δh (Δh is a single term)	
$V = -\frac{Gm}{r}$	G	
$\lambda = \frac{ws}{D}$	D	

Equations with + or -

If there are terms which are added or subtracted, we need to progress like this:

$$E_k = hf - \phi$$

We want to find h.

To get rid of the ϕ term we need to add it to both sides of the equation:

$$E_k + \phi = hf - \phi + \phi$$

$$E_k + \phi = hf$$

Now we can get rid of the f on the RHS by dividing the whole equation by f :

$$\frac{E_k + \phi}{f} = \frac{hf}{f}$$

Which gives us our final result of:

$$h = \frac{E_k + \phi}{f}$$

15 Rearrange these equations: (2)		
<i>Equation</i>	<i>Subject</i>	<i>Answer</i>
$v = u + at$	t	
$E = V + Ir$	r	

Dealing with Squares and Square Roots

If we have a square root, we get rid of it by squaring. If there is a square, we get rid of it by taking the square root.

Consider this formula:

$$T = 2\pi \sqrt{\frac{l}{g}}$$

Suppose we want to find g .

Get rid of the square root by squaring the whole equation:

$$T^2 = 4\pi^2 \frac{l}{g}$$

(notice that squaring 2π gives $4\pi^2$)

Now bring g upstairs by multiplying the equation on both sides and cancelling:

$$gT^2 = 4\pi^2 l$$

Now get rid of the T^2 by dividing the whole equation by T^2 and cancelling.

$$g = \frac{4\pi^2 l}{T^2}$$

Note that the constant $4\pi^2$ goes at the front – this is done to keep things looking neat. If l was a constant you could write $g = 4\pi^2 l \left(\frac{1}{T^2}\right)$. We might do this if we wanted to be really clear that g depends on $\frac{1}{T^2}$ multiplied by some constants. Think about making your equations as and simple and clear (we call this *elegant*) as possible.

16. Rearrange these equations: (6)		
<i>Equation</i>	<i>Subject</i>	<i>Answer</i>
$Ek = \frac{1}{2}mv^2$	v	
$T = 2\pi\sqrt{\frac{m}{k}}$	k	
$f = \frac{1}{2\pi\sqrt{LC}}$	C	

Harder (for a **bonus of 5**):

$$V = V_0 e^{-t/RC}$$

Make t the subject. (hint: look up what the inverse operation of e^x is)

Graphical Skills

On their own, numbers do not mean a lot. A table of numbers can be confusing. A graph allows us to see a picture of how the numbers relate to each other.

1. Always use a sharp pencil and a ruler.
2. Draw the axes
3. **Label** the axes with the quantity and the units
4. When you plot *Quantity 1* **against** *Quantity 2*, you put *Quantity 1* on the X axis. For example, if asked to plot force vs extension, force goes on the X axis. In general, this X axis should be the independent variable in your experiment.
5. Look for the highest value in each range. You put numbers on your axes to the nearest convenient step above your highest value.
6. Use a sensible scale. Trial and error is fine if you need to.
7. **Plot** your points with **crosses** (×). Dots get lost.
 - Represent the pattern in your points with a line of best fit. It must be a smooth curve which fits the points. Use common sense and look at it. If it's far away from the points, it's wrong. **Never draw dot-to-dot.**

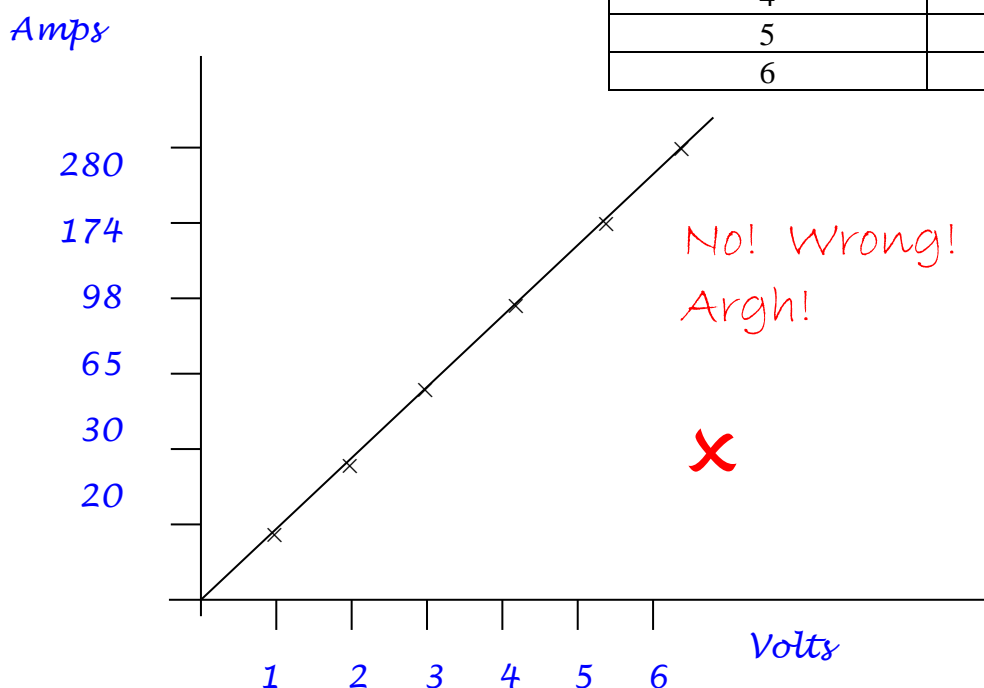
It can be difficult to decide whether a set of results is a straight line or a curve. If it's clearly a straight line, draw your **line of best fit** with a ruler. If the graph is a curve, then try to make a smooth curve. You will get better at this with time and practice.

If a point is way out from the rest, then it's probably an **anomalous result**. If you can, recheck the data or do that part of the experiment again. If not, ignore it.

The table shows some data to plot:

Voltage (V)	Current (mA)
0	0
1	20
2	30
3	65
4	98
5	174
6	280

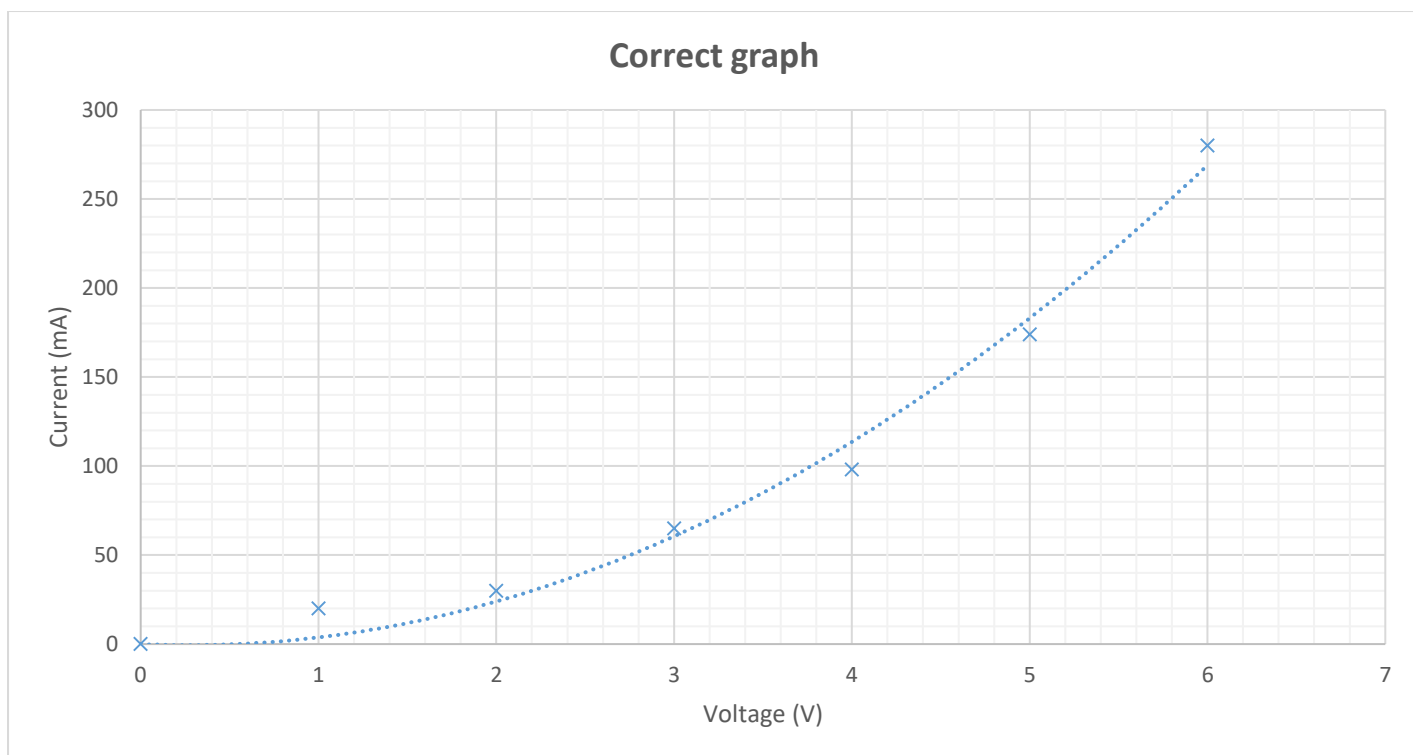
DO NOT DO THIS:



This graph is nonsense. Can you see why? Although graphs drawn like this are quite useless, they are depressingly common, and worth zero marks.

The correct graph is shown below:

Correct graph



Notice:

- Axes labelled with quantities and units;
- Scales are sensible and linear – ie equal steps up.
- Smooth line of best fit drawn to fit the points. Either a straight line or a smooth curve. Do not try to follow every lump and bump of the graph – show the *pattern*.
- The line **must fit the points**. Use common sense and look at it. If it's far away from the points, it's wrong.
- **No dot-to-dot. Not this time, not ever, JUST NO.**

17. Use the data below to plot a graph of Frequency (X) against Reactance (Y) using the graph paper provided. Remember the rules! (8)

<i>Frequency (Hz)</i>	<i>Reactance (Ω)</i>
500	100
1000	200
1500	310
2000	396
2500	420
3000	600
4000	820
5000	1040

What is the value of the reactance at a frequency of 4200 Hz?	(2)
---	-----

What frequency gives a value of reactance of 700 ohms?	(2)
--	-----

Reading values off the graph is called **interpolating**.

18. Work out the gradient of your graph. Show on your graph how you got the gradient. (4)

Bonus: Write down the units you think the value of gradient should have. +2

19. (Harder) This graph shows the variation of the reactance of an inductor (a coil of wire) with the frequency of an electrical signal. The formula is $X_L = 2\pi fL$ where:

- X_L is the reactance in ohms, Ω
- f is the frequency in Hertz, Hz
- L is the inductance in Henrys, H

Use the answer to 15 to work out the value of the inductor, L . (4)

$L = \underline{\hspace{2cm}} \text{ H}$

The graph above was a straight line. The reactance was **directly proportional** to the frequency. A straight-line graph has the general equation $y = mx + c$ where m is the gradient and c is the **intercept**, the point at which the line cuts the vertical axis.

20. Extend the line on your graph to reach the y axis. What is the value of the y-intercept? (2)

When we extend the graph, we are **extrapolating**.

Not all graphs are a straight line, as in the following example. The data show the power dissipated by a resistor as voltage increases.

<i>Voltage (V)</i>	<i>Power (W)</i>
0	0
2.5	2.0
5.0	4.1
7.5	18.4
10.0	31.8
12.5	52.1
15.0	72.6
17.5	100
20.0	128

21. Plot the data on the graph paper provided and draw a smooth line of best fit. Remember that the line will not go through all the points. **DO NOT DO DOT-TO-DOT.** (8)

22. This graph looks like one you learned in maths. Which kind of graph does this look like? Use this to write a proportionality relationship between Power and voltage (use the \propto sign!) (2)

Bonus: Can you use 2 of the equations you learned at GCSE to show that power does indeed relate to voltage in the way you showed in 22? Hint: you'll need an *electrical power equation*, and a *law about resistance*. (5 marks)

Errors and Uncertainties

Measurement uncertainty: The uncertainty of a measurement is the doubt that exists about its value. For any measurement – even the most careful – there is always a margin of doubt.

This will take the concept of precision you met at GCSE and extend it in to a more rigorous quantitative analysis.

When we talk about uncertainty, we are referring to the range of values one expects the true value to lie within around the mean.

This section will take you through this concept in detail. It is quite technical so read carefully and make your own notes, repeating the calculations yourself as you go along. The key points are numbered in bold

1. like this.

Let's get started!

Uncertainties

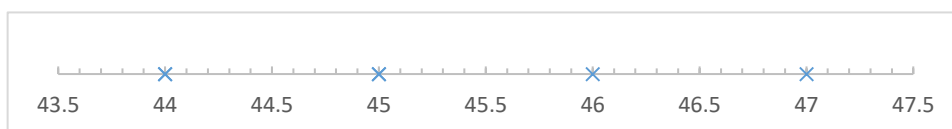
Let us imagine that we are measuring the mass of an object. We obtain the following values using a balance in the lab:

45g; 44g; 44g; 47g; 46g; 45g

What is the real mass of this object? It must have one, but *what is it?*

Looking at the values, we have obtained numbers between 44g and 47g, so the real mass lies within this range.

Plotted on a number line, this becomes a bit more obvious.



We can clearly see that the mass must be between 44 and 47 as all our values were in this range. The truth is in there somewhere!

Firstly, we will summarise these values using the mean, just like we did at GCSE.

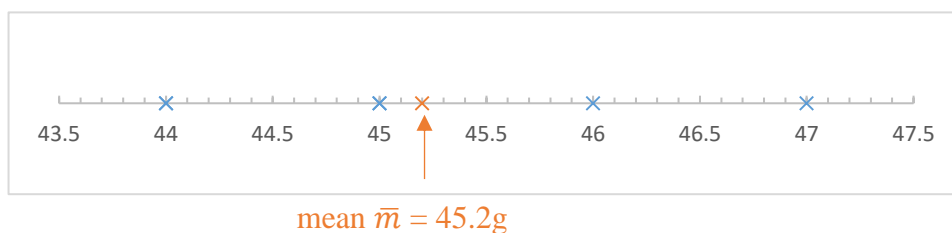
- 1. The mean** is calculated by adding the readings together and dividing by the number of readings.

The mean mass is denoted as \bar{m} , which is read as “m bar”. A mean length would be \bar{l} , a mean time \bar{t} , and so on.

Readings: 45g; 44g; 44g; 47g; 46g; 45g

$$\text{Mean mass } \bar{m} = \frac{(45+44+44+47+46+45)}{6} = 45.2\text{g}$$

Back on the number line:



Notice that the mean (orange cross) is not in the exact middle of the values because we had 2 measurements of 44g, which are stacked on top of each other on the number line. They're pulling the mean off-center to the left.

Now we can clearly see that the value is most likely to be the mean, 45.2g, but we can't be sure because of the scatter in the values we measured – one of the times we got 47g!

We express this uncertainty with the **uncertainty in the mean**. It comes in two flavours, absolute uncertainty, and percentage uncertainty. Both have their uses, but percentage is the one we really need to get to. First, the range.

2. **The range** is equal to the difference between the highest and lowest reading in a data set, eg:

Readings: 45g; 44g; 44g; 47g; 46g; 45g
Range: = 44g – 47g (= 3g)

3. **The absolute uncertainty** (sometimes called absolute or probable error) in the mean value of a measurement is half the range expressed as a \pm value. It is given the symbol ϵ .

$$\text{“Absolute uncertainty” } \epsilon = \frac{1}{2} \times \textit{range}$$

Example: If mean mass $\bar{m} = 45.2\text{g}$ and the range is 3g then the absolute uncertainty on the mean $\epsilon_{\bar{m}} = \pm 1.5\text{g}$.

Notice that the subscript \bar{m} is used to show that it's the uncertainty on \bar{m} .

At GCSE you called this “precision”. It is a measurement of precision (if it were large, precision would be poor), but now we are giving it its technical name “absolute uncertainty”.

4. **Percentage uncertainty** (percentage error) is simply the absolute uncertainty as a % of the value we actually measured (the mean usually). It is given the symbol α .

$$\text{Percentage uncertainty} = \frac{\text{absolute uncertainty}}{\text{measurement}} \times 100$$

This is quite wordy, so in symbols we write

$$\alpha_{\bar{m}} = \frac{\epsilon_{\bar{m}}}{\bar{m}} \times 100$$

Notice that we've used the subscript \bar{m} to show that $\alpha_{\bar{m}}$ is the percentage uncertainty on \bar{m} . $\epsilon_{\bar{m}}$ is the absolute uncertainty on \bar{m} as above. If our example was talking about times, we'd be seeing \bar{t} instead.

Example: Calculate the % uncertainty on the mean mass measurement $\bar{m} = 45 \pm 1.5g$

Using the equation above: Percentage uncertainty $\alpha_{\bar{m}} = \frac{1.5g}{45g} \times 100$



$$\alpha_{\bar{m}} = 3.33\%$$

$$\alpha_{\bar{m}} = 3\%$$

Percentage errors should be given to 1 sf unless there is a compelling reason otherwise, ie here **3%**

Finishing up:

When we state a value we have measured, we state it with its percentage uncertainty, like so

$$\bar{m} = 45.2g \pm 3\%$$

Notice that when we wrote absolute uncertainty the unit came at the end, like $45 \pm 2g$, but here we have a percentage, which does not have a unit, so the unit goes after the mass (45.2).

This is the end result of our process. We started with the raw values 45g; 44g; 44g; 47g; 46g; 45g and asked "What is the real mass of this object?". We now know that it is **within $\pm 3\%$ of 45.2g**. Pretty close.

Obviously the smaller the uncertainty, the better. The more precise we need to be, or the more that is riding on a value being right, the smaller uncertainty we need. 3% is OK for A-level, but if we were machining rocket parts, it would be totally unacceptable. We might need an uncertainty of $\pm 0.01\%$ to build a successful rocket.

23. Calculate the mean, range, absolute uncertainty, and % uncertainty for the following sets of data

34g, 35g, 35g, 34g, 31g, 37g, 35g, 36g

$$m = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}} \% \text{ (4)}$$

17.5N, 17.1N, 17.4N, 17.7N, 17.6N, 18.2N

$$F = \underline{\hspace{2cm}} \pm \underline{\hspace{2cm}} \% \text{ (4)}$$

Total = 108 marks

Review	Score =	%
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Self-marking completed	Yes/No
What I did well:	
What I found hard:	
What I will do to improve my areas of weakness:	

Exploring the A-level physics course:

We teach the OCR A A-level physics course. You can find the specification here:

<https://www.ocr.org.uk/qualifications/as-and-a-level/physics-a-h156-h556-from-2015/>

Taking a look at it will show you the topics you will study and roughly the order we will study them in.

There are some superb resources online to help you study, for example DrPhysicsA

<https://www.youtube.com/user/DrPhysicsA>

and Professor Dave Explains:

https://www.youtube.com/channel/UC0cd_e49hZpWLH3UIwoWRA/playlists?view=50&sort=dd&shelf_id=19

AliceDoesPhysics has great insights into what the life of a Physics student (at Oxford!) is like, and her video “How I got an A* in A-level Physics” is a must-watch:

<https://www.youtube.com/channel/UChw2nOY1TKsSqB-gktzHMUA>

Further resources to inspire you:

It is important to feed your brain and your curiosity whilst you study. We expect you to be much more immersed in the subject than you were at GCSE, after all, you’re *choosing* to study physics now – get keen! As such, you should be reading around the subject and viewing content to broaden your horizons and take your learning deeper than we can do in class. A full reading list will be published in September, but here are some places to get started:

Books:

How to build your own spaceship <i>A fun and accessible introduction to modern spaceflight.</i>	Piers Bizony
We have no idea <i>Fun summary of the things we don't understand – dark matter, dark energy, and so on. Not too technical - an easy read.</i>	Jorge Cham and Daniel Whiteson
What if.....? <i>Serious scientific answers to absurd hypothetical questions. A fantastically entertaining – and detailed - read. Highly recommended to show how physical laws can be applied anywhere with a little thought.</i>	Randall Monroe
How to.... <i>The sequel to What If...? Superb.</i>	Randal Munroe
Space: 10 things you should know <i>Does what it says on the tin. If you're interested in astrophysics, read this book.</i>	Becky Smethurst

Youtube Channels:

Title	Presenter	URL
DrBecky <i>A working Astrophysicist at the university of Oxford. Probably the best general astrophysics channel at the moment.</i>	Dr Becky Smethurst	https://www.youtube.com/channel/UCYNbYGI89UUowy8oXkipC-Q
Smarter Every Day <i>An ex-NASA rocket scientist presents science education and travels the world. Fun and very</i>	Destin Sandler	https://www.youtube.com/user/destinws2

<i>accessible. Highly Recommended.</i>		
Minute Physics <i>Does what it says on the tin. Great short summaries of physics concepts</i>	Henry Reich	https://www.youtube.com/user/minutephysics
Physics Girl <i>Cool videos on a range of physics problems</i>	Dianna Cowern	http://www.youtube.com/user/physicswoman
Veritasium Engaging and well-presented physics education videos, interviews and animations. Excellent.	Derek Muller	http://www.youtube.com/user/1veritasium
Sixty Symbols <i>Videos from the University of Nottingham Physics department on a massive range of topics. Excellent and well recommended.</i>	Various	https://www.youtube.com/user/sixtysymbols
Kurzgesagt <i>Excellent, detailed animations about the big stuff – stars, black holes, and the end of the universe. Wonderful.</i>	Animated	https://www.youtube.com/user/Kurzgesagt
Practical Engineering <i>A professional civil engineer builds practical demonstrations and uses them to teach engineering concepts. Essential for anyone interested in engineering at university.</i>	Grady Hillhouse	https://www.youtube.com/user/gradyhillhouse
Real Engineering <i>A large range of videos from the accessible to the technical across all fields in engineering.</i>	Brian McManus	https://www.youtube.com/channel/UCR1IuLEqb6UEA_zQ81kwXfg