Antonine Physics

Topic 1 Induction And Physics Skills

How to Use this Book

How to use these pages:

- This book intended to complement the work you do with a teacher, not to replace the teacher.
- Read the book along with your notes.
- If you get stuck, ask your teacher for help.
- The best way to succeed in Physics is to practise the questions.

There are many other resources available to help you to progress:

- Web-based resources, many of which are free.
- Your friends on your course.
- Your teacher.
- Books in the library.

This is an electronic book which you can download. You can carry it in a portable drive and access it from your school's computers (if allowed) as well as your own at home.

I would advise you NOT to attempt to read this topic all at once. There are parts where equations are used which you won't be familiar with. This could be off-putting. You should refer to the book throughout the course, especially as you consider uncertainties and more advanced graphical skills.

To start with, I suggest you read the notes in this order:

Tutorial 1.01	Induction
Tutorial 1.02	Symbols and units
Tutorial 1.03	Standard Form and Significant Figures
Tutorial 1.04	Equations
Tutorial 1.08	Presentation
Tutorial 1.10	Using ICT in Physics

As you progress through the course, read through:

Tutorial 1.05	Experimental Uncertainty
Tutorial 1.06	Basic Graphical Skills
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Figure 1 Welcome New Student!

A very warm welcome to the world of Physics. I hope you enjoy it every bit as much as I have and continue to do so.

These tutorials will guide you through the extensive range of skills that you will develop as you progress through the A-level course. The notes that I have written here are based on the notes that I have given to my students as an A-level teacher of thirty years' experience.

You don't have to be a complete genius to study Physics successfully. You just need to be able to graft away when you come across topics you might not find that easy. *Practice make perfect* is an old saw. It needs to be *Effective practice repeated often enough makes perfect*.

The skills you will develop will then form the basis of many of the skills you need to do well at university and in your professional career. Even though you may do an induction at the start of your course, it is unlikely you will cover everything in these tutorials in the first few weeks. Therefore, these notes assume that **you will revisit them regularly** as you progress through the course. In my experience, even Year 2 A-level students may need to revise these notes from time to time!

The tutorials are not meant to replace your tutor, or the need to do all your assignments on time to the best of your ability. However, I hope you will find them helpful.

If you need to review stuff from GCSE, have a look at my GCSE notes.

1.02 What is Physics?

Physics is a plural word used as a singular (rather like "a gallows"). If you look in any dictionary, you will see it defined as:

The branch of science concerned with the nature and properties of matter and energy.
(Oxford English Dictionary)

You will see Physics described as a **numerate discipline**. The word *discipline* has rather negative connotations in the way that it is used in the context of being told off. The word actually comes from the Latin *discere* meaning 'to learn'. It means an area of learning. *Numerate* means that numbers are involved. It is also described as **quantitative**. *Quantitative* is to do with numerical measurements and values.

Like all sciences, Physics involves:
- Observation of things that happen (phenomena).
- Measurement.
- Analysis (Do the measurements fit a pattern?).
- Interpretation (What does it mean?).
- Explanation (Does it make sense?).

1.03 Why study Physics?

You are reading this page because you are **interested in the Physics**. You are about to make a journey that I promise you will be fascinating. You may well be using it to give you grounding in technology, engineering, etc. Or you may be starting to explore Physics for its own sake. I hope you will enjoy the story as much as I do.

Remember that enjoyment and interest are essential for successful study. I can read a textbook on sociology or business, but I would not make a good student of either of these subjects. I was my English teacher's worst pupil. I was not very good at literature. Recently I tried to get back into Thomas Hardy, but I found his works as impenetrable now as I did forty-five years ago. (Sorry, I did try.)

There are many aspects to the discipline that range from the very small (e.g. sub-atomic particles) to the very large (e.g. the Universe). It explains many everyday phenomena (things that can be observed) which we not only take for granted, for example, the colours we see in the garden or the sounds of the birds gorging at the birdfeeder, but also that we use without thinking about. These notes are brought to you by a laptop computer on my dining room table that uses basic principles of electricity to process words, and images. People, far cleverer than I am, have worked out how to get what is an adding machine, to do all the marvellous things that computers can do.

Physics underpins that technology and engineering that benefit all citizens, the hallmark of any civilised society.

Physics is a **beautiful subject**. Few people can doubt the beauty of the Universe, even though it's not well understood. Few doubt the beauty of natural shapes, many of which are used to great effect in buildings. They use principles of Physics and Mathematics. The many aspects of the subject link together like a big jigsaw puzzle. There can be many ways which can be used to save the same problem. For example, the speed of a falling object in a gravity can be worked out with the equations of motion, or by considering the conversion of potential energy into kinetic energy. Gravity and electric fields, which are completely different things, actually behave in a very similar way. All physics can be explained using four fundamental forces, which you will study in these notes.

The late **Professor Stephen Hawking**, although cruelly trapped in his hideous prison caused by Motor Neurone Disease, described his feelings as he studied the Universe as "one of wonder". I hope you will feel the same.

1.04 People in Physics

Physics is **international**. The discipline crosses all international boundaries and cannot be claimed by any one country or its nationalist politicians. Indeed, it's universal. The Laws of Physics apply not just to The Earth, but also to the furthest flung galaxies.

Physics is about the **past**, the **present**, and the **future**. Much of the physics we will study happened at a time when other significant historical events were happening. It also involved the social aspects of our society, not just in this country, although the class system exaggerated matters. Many physicists were posh people with large estates.

Henry Cavendish (1731 – 1810) who worked on gravity was a member of the Cavendish family who, as the Dukes of Devonshire, own Chatsworth House in Derbyshire, and have extensive land holdings in Yorkshire.

Alessandro Volta (1745 - 1827) had aristocratic lineage. Much of today's laboratory equipment which we take for granted is based on stuff that was borrowed from the butler's storerooms!

Isaac Newton was not so posh but still lived in a substantial farmhouse. His mother wanted him to be a farmer; he hated it.

Michael Faraday was from a family that was not well off. At 14, with just the most basic education he was apprenticed to a bookbinder. He educated himself by reading the books in the workshop, particularly Jane Marcet's books that popularised science. He also approached Physics in a non-mathematical way, for the simple reason he wasn't very good at Maths.

James Prescott Joule (who gave us the Joule) was from a Manchester brewing family.

Although most physicists in history are men, women latterly made considerable contributions to the advances in Physics. The Physics community is working hard to increase the proportion of women studying and working in Physics. **Marie Curie** worked on radioactivity in the latter part of the Nineteenth Century.

Rosalind Franklin did much work with X-ray crystallography.

Lise Meitner was an Austrian physicist who worked on fission. Women are making valuable contributions to Physics nowadays and will continue to do so in the future.

Peter Higgs (he of the Higgs Boson) was not very good at Physics at school. He found it uninspiring.

As for the future, many young people use these notes. I am sure that some of them will go on to discover something that is ground-breaking. Is it going to be you?

Above all, Physics is **about people**. Throughout history, men and women have made observations of things they have seen and have used their intellects to make sense of what they have seen and to explain it so that others can understand. They were and are living people who have all the feelings and aspirations of everyone else. They sleep, eat, drink, go to the lavatory, get ill, leap for joy, get angry, get drunk, etc, just like everyone else. Their computers crash just like yours does. They play music. Most are very pleasant people. Sir Isaac Newton was decidedly obnoxious, narcissistic, malicious, and manipulative. Henry Cavendish was desperately shy and socially inept. Both may have had Asperger's syndrome.

Many physicists make good musicians, e.g. **Brian May** from the legendary group *Queen*, who is now a leading astrophysicist. The poster-boy for Physics, **Brian Cox**, is another one who played in a rock band. **William Herschel**, a Seventeenth Century Astronomer Royal, was a composer, while **Albert Einstein** was a dab hand at the violin. **Johann Wolfgang Goethe**, the German poet whose reputation is akin to our William Shakespeare, was a meteorologist and geophysicist.

Not every physicist was born to the subject. **Robert Millikan** was a Classics scholar (Latin and Greek). His Greek professor nominated him to teach a foundation physics year at Oberlin College, despite Millikan's objections that he knew no physics. "If you can do Greek with me, you can do Physics," was the reply. Millikan did so, keeping a few pages ahead of his students. He found he liked it and always enjoyed teaching his students. He gained the Nobel Prize for discovering the charge on the electron. The theoretical physicist **Edward Witten** who works in gravitation and relativity was originally a history graduate.

Physics is a story of **human endeavour**. It is a story that any student can access. One day a reader of this book may even achieve a Nobel Prize.

1.05 The Professional Physicist

What makes a good physicist? The answer is same characteristics of any good scientist. A few characteristics are listed below:

- A person who can make links between the different areas of physics.
- Someone who is curious.
- Someone who is concerned with what is true.
- One who can collaborate with others and recognises the part played by all members of their group.
- One who communicates clearly and with integrity.
- A good learner.

- One who weighs up the benefits and risks of their work to society.

In the exams, whatever syllabus you are studying, you may be asked to consider the scientific process, for example how data are validated. (They are obtained fairly from a sound experimental procedure and can be repeated by any scientist.) You may also be asked to consider the impact of the work of scientists on society. An example of this may be the impact of artificial intelligence and robotics on the world of work. As you read these pages over the next couple of years, try to think about the impact that Physics will have on your future. It will change your future in ways I cannot imagine. For example, when I was a teen, computers were massive and mysterious machines housed in huge and secretive buildings. Now you can put one in your pocket. A massive hard drive had a capacity of 100 megabytes (a small picture file). Your flash memory that goes around your neck is 64 gigabytes.

1.06 How to Study Physics

Physics has a reputation of being the most difficult of the A-level subjects. At GCSE it enjoys a bad reputation as it's often badly taught in classes where there is an atmosphere of wilful non-achievement. If you approach it with fear and trepidation, that reputation will be self-fulfilling.

It is true that you have to learn many facts, and there is a lot of numerical content. Imagine trying to explain relationships in physics without numbers - it would be very wordy at best. In many cases it would be almost impossible. However, the numerical content is basically processing a few numbers to get another number. There are many equations in physics code which may seem off-putting. They are the rules of Physics summed up in shorthand. Do not try to learn equations parrot-fashion. Most are written down on a datasheet.

Successful study, like with all other subjects, depends on **effective practice**. I know this stuff, not because I am particularly brainy, but because I have **practised** it. To succeed, you should do the following:

- If your course gives you 5 hours teaching time per week, you should spend **at least** 5 hours a week outside class time. This is the expectation for all subjects in all A-levels in all schools and colleges.
- Read around the topic using a good textbook. Your tutor will recommend one. A textbook may be low-tech, but it doesn't crash. Its batteries don't run out. It is easy

to carry about and can be used anywhere. It looks good on the shelf. It may invoke happy memories when you are a grandfather or grandmother.

- Use web-based resources. (You are using one already!) The internet stores a whole library of learning. There are lots of video clips that explain physics concepts. There are animations and tutorials. Use whichever make most sense to you. However, make sure that what you are looking at is actually on the syllabus. If in doubt, get your tutor to advise you.
- Understand the Physics. It is NOT an exercise in Applied Mathematics.
- You do not have to be a mathematician to do Physics A-level. However, if you are going to do it at university level, you will need to do A-level Mathematics.
- Maths is a tool, as essential to physics as a setsquare is to a joiner. But Maths is not the be-all and end-all of Physics. It's amazing how many mathematicians can't do physics. I know. Almost all my maths colleagues said they could not do physics.
- Practise questions. Look up the answer. If you get the answer wrong, don't get upset. You may find it helpful to start at the answer, and work backward to the question.
- Learn from your mistakes. We all make mistakes.
- Work with another student. Discuss homework with each other, but don't copy off each other. Submit your own versions of the homework in your own words. (My own approach to students who copied work was to share out the marks. If the script, copied by two students, was worth 16/20, each student would get 8/20.)
- Support others by teaching them things you know. There is nothing like **having to teach something to make you learn it**. I had to do it - and get it right. (As a teacher, you have to convince your students you know what you are talking about, even if you are only three pages ahead of them in the book.) It does become easier with practice.
- Meet the deadlines. Don't waste time making excuses.
- Read the feedback from your tutor. This might be of variable quality. Your tutor is human as well and gets tired.
- Use your tutors. They will offer support tutorials, especially as exams approach.
- Review your previous studies regularly. Remember that you will have questions in the A-level exam on what you did in the first year.

Remember that Physics is there to be enjoyed. There will be times when it will be hard graft. Meaningful achievement is the result of effort and hard graft. In an age of instant entertainment, self-discipline is often derided as old-fashioned. But many young students get down to it and achieve. You can too.

1.07 Studying AQA Physics

The tutorials on these pages were written for the AQA Modular syllabus. The structure of the site reflects this. I have more recently added material for other syllabuses in the appropriate places. I hope that this will help students who are studying not only the physics syllabuses in England (AQA, Edexcel, Eduqas, and OCR), but also Scottish, Welsh, and Irish (both north and south of the border). If you aren't sure what syllabus you are doing, ask your tutor.

When you study A level Physics with the **AQA syllabus**, you will cover in the first year (not necessarily in this order):

- Particle Physics.
- Quantum Phenomena.
- Electricity.
- Mechanics.
- Solid Materials.
- Waves.

In the second year (which your teacher or tutor might still call A2), you will study:

- Further Mechanics.
- Fields.
- Capacitors.
- Electromagnetism.
- Nuclear Physics.
- Thermal Physics.
- Kinetic Theory.

There are five **optional** topics for AQA (usually chosen by your teacher, unless you are part of a very large centre where there are at least five teachers, each offering one). These are:

- Astrophysics.
- Medical Physics.
- Engineering Physics (Applied Physics).
- Turning Points in Physics.
- Electronics.

You will also do a number of **required practicals** which are assessed for your A level (but not AS level).

There are four options in the Welsh Board and Eduqas syllabuses. These are:

- Alternating Currents.

- Medical Physics.
- The Physics of Sports.
- Energy and the Environment.

The order you find the topics in this book represent the order in which I taught them with my students. It also reflects the order of the old modular syllabus. Your tutor may well do things in a different order, depending on the schemes of work within your department. If you cover everything, it doesn't matter.

In the AS topics there will be bits that will be tested in the A-level only. These will be made clear at the time. The AS material has a blue header, while the A-level material has a dark blue header.

AS level material	A-level material

Remember that A-level students will need to know the AS level stuff.

1.08 My Journey into Physics

I think Physics is the best subject. I would say that, wouldn't I? I was a physics teacher. In these pages I share with you my notes on the subject in the hope that they will make a difference, and that my enjoyment of Physics will rub off onto you. If I can do it, you can do it as well, if not better - as my thoughts below will demonstrate.

As a teenager I was a very indifferent student. I was pretty clueless when my first copy of *Abbott* was handed to me. (It was big and heavy.) I still see them in schools; they're like old friends. If my physics teachers, both of whom taught me in the nineteen seventies, are still alive, they will testify to that. If they had known that fifteen years later, I too was a physics teacher, they would have fallen on the floor laughing (or lain in a darkened room in despair). Despite the many pious statements about successful study at Physics that I have made, I did few of them. I remember struggling with parallel circuits. I picked up my interest in electricity through my interest in model trains. I learned about voltages and currents by setting up my trains. There was a lot of trial and error, but I learned bit by bit. My first escapades into electronics were through making model train controllers. Again, these were through trial and error and rather crudely built.

I wanted to be a doctor, but it was clear that I would never have made the grades. I would have made a lousy doctor anyway; my bedside manner would have been appalling. I ended up as getting a degree in Biology. How, I don't know - when I look at my marks, I genuinely wonder how I succeeded at all.

I would describe what passed for my career as a series of pratfalls, blunders, and car crashes (figurative). After one such metaphorical car-crash, I retrained as a physics teacher. Although being a university student again at the age of thirty was quite a culture-shock, I have quite fond memories of my course at Sheffield.

My career as a teacher started with naive idealism and optimism, which was soon snuffed out. I would describe much of it in terms that are jaded, negative, and depressing. I emphatically say that <u>none</u> of this was due to the subject of Physics.

To counter that I would say that the vast majority of my pupils that I have taught have been lovely people. They are biddable, polite, and considerate. I have been privileged beyond all measure to have taught excellent young people who are far brighter than I. I have helped them to get into the top universities, and they will achieve more than I ever did. I am confident that one or two will become household names. Some have come from wealthy and supportive homes, but others have been brought up by single parents in deprived areas. One arrived from Iran at our college as a seventeen-year-old refugee with no English (How would you get on if you ended up in Tehran with not one word of Farsi?) At twenty-one, he went to one of Scotland's premier universities. Another student had got indifferent results in his first modules. I did a number of tutorials with him. He and I had conversations in Physics, and waffle would not do. He certainly sharpened up my act, and he ended up with an A*. That is what my job was about.

I have worked with excellent people from all subjects. I have no time whatever for those who say that young people have no manners or have no work ethic. I have even less time for those who think that things were so much better in the old days. I have found that there are plenty of old people who are rude and ignorant. I would also say that I still enjoy learning new things about Physics.

I have never regretted my journey into Physics. It is a truly worthwhile endeavour, full of wonder. I have taught students who have done far better than I ever have and have achieved more than I ever will. Many of you reading these notes will no doubt follow in their footsteps. That I have helped many hundreds in person or many thousands though this book on their first steps in their physics journey makes it all worthwhile.

I wish you all well. I love my subject. I genuinely hope you will enjoy with wonder the story I have to tell.

Tutorial 1.02 Symbols and Units	
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1.021 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 we have to use them to find an unknown quantity with an equation. In all problems in AS level, you will only ever have ONE unknown. 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.

In GCSE you were often given equations in words:

Distance (m) = speed (m s^{-1}) × time (s)

You will notice from the data sheet at the end of these notes that the equations are given in **symbols**, which in my notes I refer to as **Physics Code**. 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. In print you will always find the codes written in *Times New Roman Italics*. In my notes, I do try to, but sometimes I miss it. As you can't do italics in normal handwriting, then don't worry. Here are some examples:

Symbol	*Meaning*
a	Acceleration
A	Area
F	Force
m	Mass
I	Current
p	Pressure
Q	Charge

You will come across codes written in **Greek** letters. The normal (Latin) alphabet has 26 characters. No codes are used which are like ä (a – umlaut) or ê (e – circumflex). The Greek alphabet adds another 24. The Greek Alphabet is shown in the table below. Note that there is a special symbol font, called appropriately "Symbol". However, to get some symbols you may have to use an unrelated letter. For example, "eta - η" is a long letter "ē". You get it by typing "h" and changing into Symbol font to give "η". Remember to change the font back to what you were using. Otherwise, ψου ωιλλ γετ τηισ.

Greek	*Name*	*Letter*	*Greek*	*Name*	*Letter*
α	alpha	a	ν	nu	n
β	beta	b	ξ	xi	x
γ	gamma	g	o	omicron	Short o (ŏ)
δ (Δ)	delta	d (D)	π	pi	p
ε	epsilon	Short e (ĕ)	ρ	rho	r
ζ	zeta	z	σ (Σ)	sigma	s (S)
η	eta	Long e (ē)	τ	tau	t
θ	theta	th	υ	upsilon	u
ι	iota	i	ϕ (Φ)	phi	ph [or f (F)]
κ	kappa	k	χ	chi	ch
λ (Λ)	lambda	l (L)	ψ (Ψ)	psi	ps
μ	mu	m	ω (Ω)	omega	Long o [ō (Ō)]

Some quantities share the same physics codes, e.g. Q for charge, and Q for energy. You will need to be aware of this when you do the exam, and knowing what each code stands for is part of your examination preparation.

1.022 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.]

This little chap warns you that you are about to walk into a **bear trap** (something students often get wrong through carelessness). I have fallen into bear-traps often...

Note that you write 7.5 metres as 7.5 m, NOT 7.5 ms. If you see 7.5 ms, that would mean 7.5 milliseconds, which gives a completely different meaning.

And please do not abuse the apostrophe by writing m's. I have seen this often. It will cost you marks as a **unit error**.

Notice that the physics codes are typed in *italics*, while the symbols for the units are typed in plain text. In most books, physics codes are typed in Times New Roman font. (The font in which this document is written is called **Aptos**.).

Notice that the unit for mass has the kilo- prefix. This says that the base unit for mass is 1000 grams. Originally the gram was the base unit, but was displaced by the kilogram in 1960, after twelve years work and discussion by many leading academics. If you want to find out the fundamental definitions, the National Physics Laboratory has a link, http://www.npl.co.uk/reference/measurement-units/ .

Notice also that the SI unit for temperature is **kelvin**, not Celsius. Note that you do not write "*degrees kelvin*".

Traditional **Imperial units** (for example, pound, foot, yards) were once used in mechanics many years ago. They have not been used for at least fifty years. There are no imperial measurements for areas such as electricity. Imperial units are never used in any modern science, technology, or engineering. They certainly have no place whatever in a modern technological society. Imperial units may have a place in an historical novel or poem or certain right-wing newspapers that are one hundred years behind the times. (The house style of one such publication demands that journalists carefully convert every metric unit into an imperial unit, thinking that its readership is incapable of using metric units. It's rather patronising.) The sooner they are permanently consigned to the museum of historical culture, the better.

1.023 Combining Units

Clearly these base units on their own are rather limited, but we can combine them. We know that speed is measure in **metres per second**, which we write as:

$$\mathrm{m\ s^{-1}}$$

Make sure that you:

- Separate the symbols with a space.
- Do not use capitals unless the unit symbol is a capital.

In many texts, you will see it written as with the terms separated by a **solidus** (/), i.e. m/s, which is quite acceptable, although "not as correct" as $\mathrm{m\ s^{-1}}$. Note also the need for a space between the 'm' and the 's'. If we write $\mathrm{ms^{-1}}$ it actually means "milliseconds to the minus one".

There is a more compelling reason to use the "power" notation over the separation with a solidus. Consider the units for specific heat capacity:

Joules per kilogram per kelvin

J/kg/K looks clumsy and could be confusing. The correct way to write it is:

$$\mathrm{J\ kg^{-1}\ K^{-1}}$$

Often a unit is derived from a **definition**, where the definition is *quantity* ***per unit*** *something*. For example, voltage is defined as:

Energy per unit charge.

The units for this are:

Joules per coulomb

$J\ C^{-1}$

Note that if a unit is divided by itself, the units cancel out.

1.024 Conversions

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:

Prefix	*Symbol*	*Meaning*	*Example*
pico	p	$\times 10^{-12}$	1 pF
nano	n	$\times 10^{-9}$	1 nF
micro	µ	$\times 10^{-6}$	1 mg
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 MW
Giga	G	$\times 10^{9}$	1 GWh

Failure to do conversions is a very common bear trap.

Also remember that micro is "μ" a Greek letter "m". If you are copying text, it may well copy as "m"

Converting areas and volumes causes a lot of problems.

- $1\ m^2 \neq 100\ cm^2$.
- $1\ m^2 = 100\ cm \times 100\ cm = 10\,000\ cm^2 = 10^4\ cm^2$

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.

In the AQA exam, at least one question will ask you for the correct unit. This will be made clear in the question:

Answer = ... Unit ....

Many units are made up from base units. They are sometimes called **derived** units. We all know that force is measured in Newtons. We also know the familiar equation for force:

$$\text{Force (N)} = \text{mass (kg)} \times \text{acceleration (m s}^{-2}\text{)}$$

We multiply the units for mass (kg) and acceleration to give **kg m s^{-2}**. Therefore **1 N = 1 kg m s^{-2}**.

Note:
While it is perfectly OK to write the units for speed as m/s (metres per second), we should get into the habit of writing m s^{-1}.

1.025 Conversions from other Units

SI units and derived units may not be appropriate to use in some contexts. For example, **joules** may be far too big for particle physicists. Or they can be far too small if you are buying electricity.

When you buy electricity, you use kilowatt hours. The kilowatt hour is the amount of energy used by an appliance of 1 kilowatt used for one hour.

You will soon find out that particle physicists use **electron-volts** (eV) in preference to joules when they talk about energy:

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

So, when you see for example, 3.6 MeV, you will know that it will need to be converted into joules before it can be used in a formula.

And it's important to convert from joules to eV, by dividing by 1.6×10^{-19}.

1.026 Unit Analysis

Unit analysis is now part of the syllabus, and it is a useful technique for understanding the relationship between units. This is done by expressing quantities in base units. We have seen these above, but here they are again:

- **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.]

In GCSE, you will have come across the idea that:

Work done (J) = Force (N) × distance moved in the direction of the force (m)

So, we can say that:

1 Joule (J) = 1 Newton (N) × 1 metre (m)

$$1 \text{ J} = 1 \text{ N m}$$

You will have also come across Newton's Second Law which is summed up by:

$$\text{Force (N)} = \text{mass (kg)} \times \text{acceleration (m s}^{-2}\text{)}$$

So, we can say that:

$$1\ \text{Newton (N)} = 1\ \text{kilogram (kg)} \times 1\ \text{metre per second squared (m s}^{-2}\text{)}$$

$$1\ \text{N} = 1\ \text{kg m s}^{-2}$$

So, we can combine the two to say:

$$1\ \text{J} = 1\ \text{kg m s}^{-2} \times 1\ \text{m}$$

which gives:

$$1\ \text{J} = 1\ \text{kg m}^2\ \text{s}^{-2}$$

In some old textbooks you may well come across energy as being described as M L^2 T^{-2} (mass × length^2 × time^{-2}). I will always use the SI units.

If you try Question 4 below, it will show you that quantities expressed as base units are rather clumsy. What is a cubic second (s^3)? Use the accepted units.

1.027 Checking Homogeneity of Equations

A use of base units is to check for whether an equation is correct. If we break everything down to base units, the units on the left-hand side are the units on the right-hand side. **Homogenous** means made up of identical parts. The table shows a number of important **derived** units:

Quantity	***Definition***	***Base unit***	***Derived Unit***
Density	Mass (kg) ÷ volume	kg m^{-3}	
Momentum	Mass (kg) × velocity (m s^{-1})	kg m s^{-1}	
Force	Mass (kg) × acceleration (m s^{-2})	kg m s^{-2}	Newton (N)
Pressure	Force (N) ÷ area (m^2)	kg m^{-1} s^{-2}	Pascal (Pa)
Work	Force (N) × distance moved (m)	kg m^2 s^{-2}	joule (J)
Power	Energy (J) ÷ time (s)	kg m^2 s^{-3}	watt (W)
Charge	Current (A) × time (s)	A s	coulomb (C)
Voltage	Energy (J) ÷ charge (C)	kg m^2 A^{-1} s^{-3}	Volt (V)
Resistance	Voltage (V) ÷ current (A)	kg m^2 A^{-2} s^{-3}	Ohm (W)

Consider the equation:

$$E_k = \frac{1}{2}mv^2$$

Energy is kg m^2 s^{-2} and is on the left-hand side. ½ is a number and has no units. Mass, *m*, is in kg, and speed, *v*, is in m s^{-1}. Squaring speed gives us:

$$m^2\ s^{-2}$$

So, using the equation:

$$E_k = \frac{1}{2}mv^2$$

$$\text{kg m}^2\ \text{s}^{-2} = \text{no units} \times \text{kg} \times \text{m}^2\ \text{s}^{-2}$$

It doesn't take a genius to see that:

$$\text{kg m}^2\ \text{s}^{-2} = \text{kg m}^2\ \text{s}^{-2}$$

Questions 1.02

1.02.1

This question is about Physics codes. What do they refer to?

a) $F = ma$
b) $E = 1/2\ mv^2$
c) $c = f\lambda$.

1.02.2

Convert the following quantities to SI units:

a) 15 cm
b) 500 g
c) 3 km
d) 35 mV
e) 220 nF

1.02.3

Convert the following quantities to SI units or non-SI units as appropriate:

a) m^2 to mm^2
b) 0.45 mm^2 to m^2
c) 1 cm^3 to m^3
d) 22.4 dm^3 to m^3

1.02.4

a) What is the electrical quantity Coulomb (C) in base units?
b) 1 Volt (V) = 1 Joule per Coulomb (J C^{-1}). What is this in base units?

1.02.5 (Harder)

In an examination, a student is not sure whether the equation linking power and electrical resistance is:

$$P = I^2R \qquad\qquad P = \frac{I^2}{R}$$

Use base units to check the homogeneity of each of these equations and decide which is the correct one.

Tutorial 1.03 Using Standard Form and Significant Figures

All syllabi

Contents

1.031 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.

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:

$$\mathbf{3.28 \times 10^5}$$

= $3.28 \times 100\ 000 = 328\ 000$

Consider 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.

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

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

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

However, make sure that the units are right, otherwise you will lose a mark for a unit error.

Avoid using expressions like *1 billion*. It is pure journalese.

1 billion can mean 1 thousand million (1×10^9) or 1 million million (1×10^{12}).

1.032 Using a Calculator

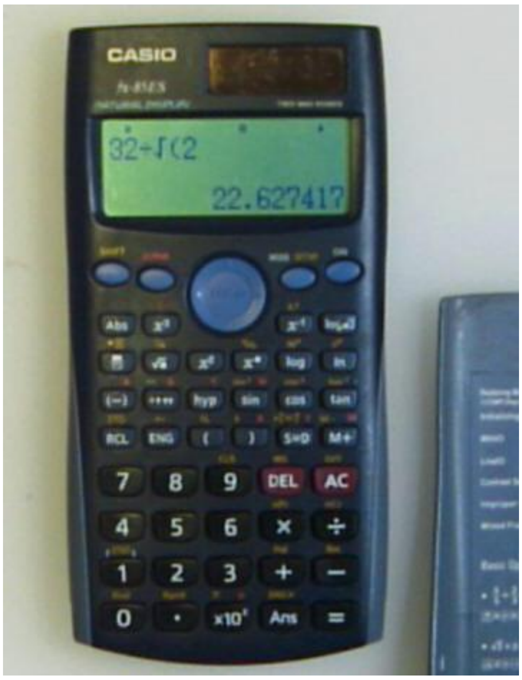

Figure 2 Scientific Calculator

A **scientific calculator** is an essential tool in Physics, just like a chisel is to a cabinetmaker. A calculator geared just to money is fine for an accounts clerk, but quite useless to a physicist.

All physics exams assume you have a calculator, and you should always bring a calculator to every lesson. They are not expensive, so there is no excuse for not having one. It is rather depressing when a student fails to bring a calculator and says, "Forgorrit."

The calculator should be able to handle:

- **standard form**
- **trigonometrical** functions
- **angles** in **degrees** and **radians**
- **natural logarithms** and **logarithms to the base 10**.

Most scientific calculators have this and much more.

There are no hard and fast rules as to what calculator you should buy:

- Get one that you are happy with. I used to use an ancient thing that was nearly thirty years old, but it worked. Then I lost it.
- Make sure it is accurate; I have known some calculators to get an answer plain wrong! This usually happens when the batteries are failing.
- Avoid machines that need a hefty instruction manual.
- For the exam, there are certain types of calculator that are NOT allowed, for example those with QWERTY keypads. Make sure that your calculator is an allowable type.

Some Points

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

[2] [.] [3] [1] [EXP] [7]

Do NOT key it in like this:

[2] [.] [3] [1] [×] [1] [0] [EXP] [7]

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

Do NOT write 2.31^7. This means "2.31 to the power 7" (= 351). This will get a mark deduction because it's an arithmetical error.

Different calculators use slightly different ways of keying in inputs. You need to be careful with the use of brackets.

Consider this calculation:

$$\frac{23.6 - 6.2}{4.6 \times 1.6}$$

The correct way to do this is:

$$(23.6 - 6.2) \div (4.6 \times 1.6) = 2.36$$

This is wrong:

$$23.6 - 6.2 \div 4.6 \times 1.6 = 21.4$$

There is no excuse for such calculator errors.

1.033 Significant Figures

Suppose we have a measurement of 5 m. We could say that it's 5.0 m, 5.00 m, or 5.000 m. All of these suggest a difference in precision:

- 5 m suggests a precision of the nearest metre;
- 5.00 m suggests a precision of the nearest cm;
- 5.000 m suggests a precision of the nearest mm.

To find the number of significant figures, you have to count the total number of digits, starting at the **first non-zero digit**. 0.000034 is to **two** significant figures.

Rounding is done in the usual way that you will have done in Maths. So, 4.73 is rounded to 4.7 to 2 significant figures, and 5 to 1 significant figure.

Do not confuse significant figures with places of decimals.

2.3 is two significant figures but one decimal place.

0.0023 is to two significant figures but four decimal places.

0.0023 = 0.00 to two decimal places.

Consider this calculation:

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

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

There is no reason at all in A-level Physics to write any answer to any more than **3 significant figures**. The use of 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. Before calculators were common, **slide rules** were used extensively. They would give answers to two significant figures, three at a push.

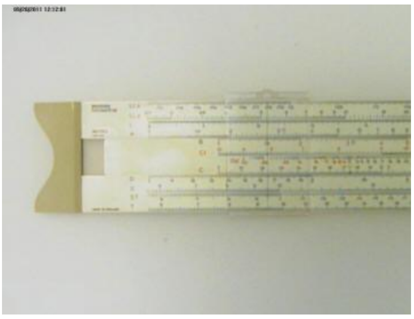

Figure 3 Slide Rule

Your grandparents might recognise one of these from their school days.

The **examination mark schemes** give answers that are no more than 2 significant figures. So, our answer becomes:

$$V_{rms} = 9.62 \text{ V (3 s.f.)}$$

$$V_{rms} = 9.6 \text{ V (2 s.f.)}$$

Do any **rounding** up or down at the **end** of a calculation. If you do any rounding up or down in the middle, you could end up with rounding errors.

Many questions tell you to write your answer to an appropriate number of significant figures. The rule is:

The answer should be to the same number of significant figures as the quantity with the lowest number of significant figures.

For a question that quotes these data (don't worry about what they mean at the moment):

- $h = 6.63 \times 10^{-34}$ Js
- $e = 1.6 \times 10^{-19}$ C
- $m = 9.11 \times 10^{-31}$ kg
- $V = 1564$ V

The answer will be to no more than 2 significant figures, as the quantity *e* is to 2 significant figures.

Some other tips on use of calculators:

- On most calculators the number is keyed in before the function (sin, cos, log)
- Take one step at a time and write down intermediate results.
- It is easy to make a mistake such as pressing the × key rather than the ÷ 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; 2×10^{-10} N is most certainly not.

Note that if you have a formula that contains an integer (a whole number), such as:

$$A = \frac{\pi D^2}{4}$$

You ignore the integer as far as significant figures are concerned.

Mathematicians often write answers in **surd** form, e.g. $5\sqrt{8}$. You need to express an answer like this as a proper number, 14.1 (to 3 significant figures) in this case.

Calculators may express a number as a fraction, e.g.:

$$\frac{245}{37}$$

Again, this needs to be written as a decimal number:

6.62 (to 3 significant figures)

1.03 Questions

1.03.1

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) 2800 000 000 000
d) 0.000000000000341

1.03.2

Convert the following numbers into standard form:

a) 86
b) 381
c) 45300
d) 1 500 000 000
e) 0.03
f) 0.00045
g) 0.0000000782

1.03.3

Use your calculator to do the following calculations. Write your answers to no more than three significant figures.

a) $\frac{3.4 \times 10^{-3} \times 6.0 \times 10^{23}}{235}$
b) $\frac{27.32 - 24.82}{\sqrt{38}}$
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

1.03.4

A runner runs a 100.0 m race in a time of 13 s. Calculate his average speed, giving your answer to an appropriate number of significant figures.

Tutorial 1.04 Relationships between Quantities and Transposition of Formulae	
All syllabi	
Contents	
Relationships between quantities	Direct Proportionality
Inverse Proportionality	Inequalities
Approximations	Change in
Transposing Formulae	Transposing Simple Formulae
Formulae with Four Terms	Equations with + or -
Dealing with Squares	

The **transposition** (or **rearrangement**) of formulae is a skill that is essential for successful study of Physics. A wrong transposition of a formula will lead to a **physics error** in the exam, and you will lose all the marks available in that part of the question. (However, if you use your incorrect answer correctly in subsequent parts, your error will be carried forward and you will gain the credit.)

Some students find rearrangement very difficult. It hampers their progress and enjoyment of the subject. They try to get round it by learning all the variants of a formula, which is a waste of brain power.

Before we go on to look at rearranging formulae, let us look at how quantities are related in physics. Mostly they are equal, but sometimes they are less than, or greater than. One quantity may vary as another. You need to understand the relationships, otherwise physics will not make sense.

1.041 Relationships between quantities

Physics studies how different physical quantities are related to each other. The most obvious relationship is when one variable is **equal** to the product of a number of different variables. We call this an **equation**. For example:

$$\lambda = \frac{ws}{D}$$

Again, don't worry about what this means now. It will be studied later.

1.042 Direct Proportionality

Equations are the result of proportionalities, where one quantity varies in a predictable way with another. In a resistor we know that if the voltage doubles the current doubles. So, we can say that voltage is **directly proportional to current**.

We can write:

$$V \propto I$$

The symbol $\propto$ means "varies as".

To make an equation out of this we have to use a constant of proportionality, which is usually written as k.

$$V = kI$$

From GCSE, Actually we know that in this case, the constant of proportionality is resistance, R, so we write:

$$V = RI$$

Or more conventionally:

$$V = IR$$

If two quantities are directly proportional, then the graph of one plotted against the other is a **straight line of positive gradient which passes through the origin**.

See Figure 4.

We will look at this later.

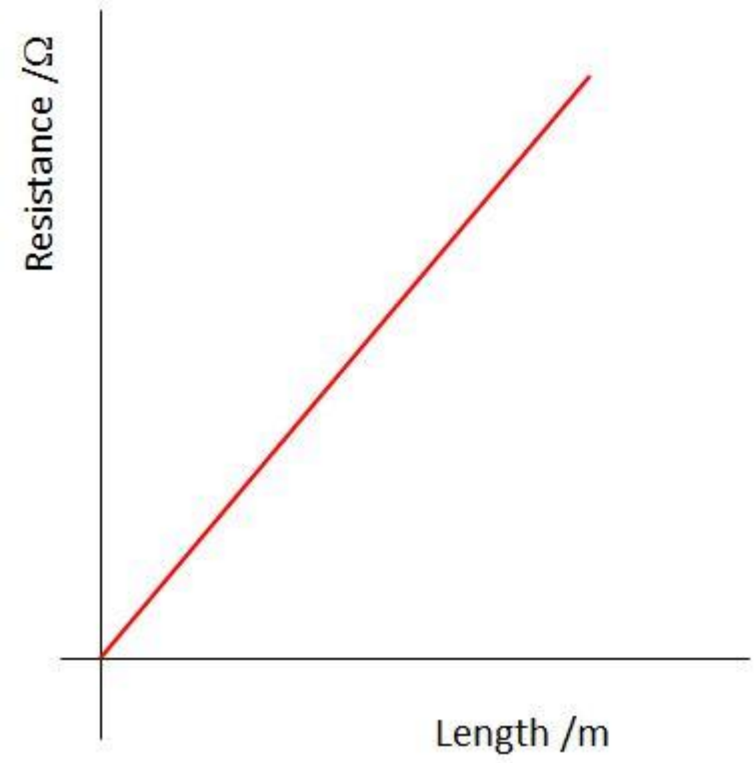

Figure 4 Graph showing direct proportionality

Not every straight line results in direct proportionality.

A straight-line graph that does not pass through the origin tells us that the two quantities are not directly proportional.

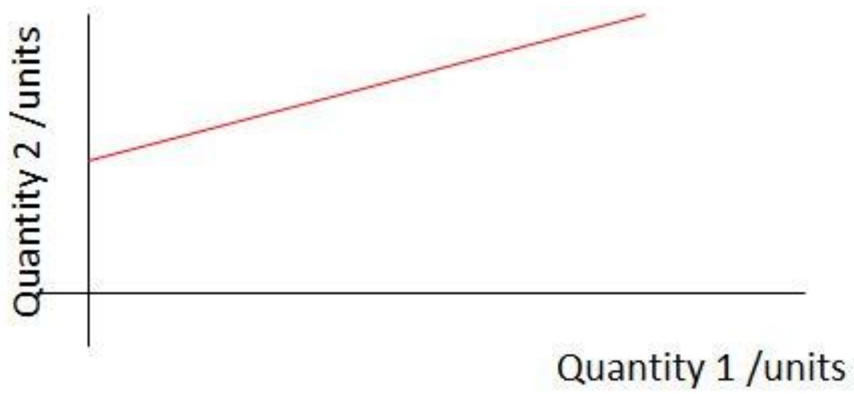

Figure 5 Straight line graph, but not directly proportional

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1.043 Inverse Proportionality

Not every relationship shows direct proportionality. If the relationship is of **inverse** proportionality, we will see:

$$a \propto \frac{1}{b}$$

The graph looks like this:

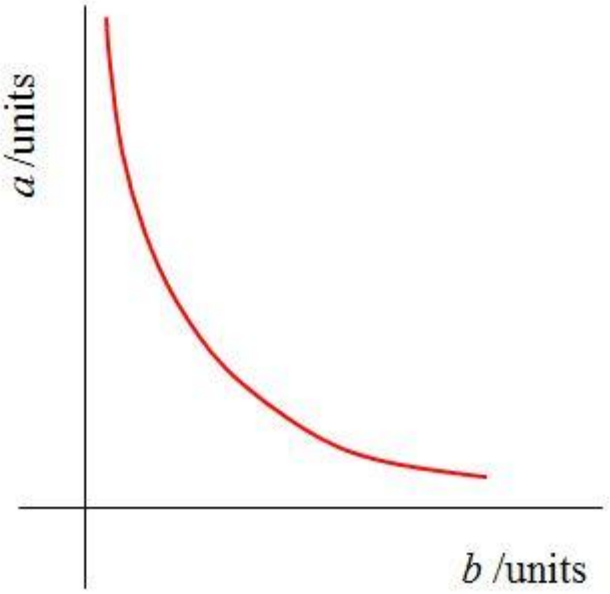
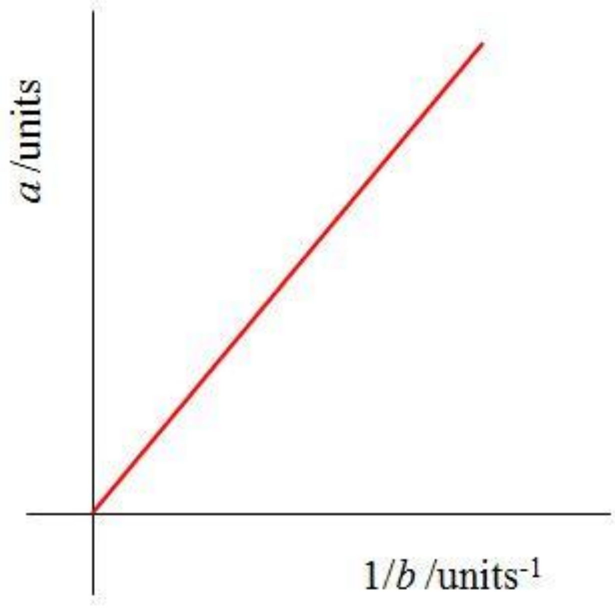


Figure 6 This graph shows inverse proportionality

$$a \propto \frac{1}{b}$$

If we plot *a* against 1/*b*, we get a straight line:



Plot a against $1/b$ to get a straight line.

The gradient gives us the constant of proportionality, *k*.

So, we can bring in our constant of proportionality:

$$a = \frac{k}{b}$$

One example of this is the relationship between pressure and volume in a gas. Double the pressure, the volume will go to half.

Figure 7 Graph more clearly inverse proportionality

1.044 Inequalities

It is possible that some quantities are not equal to the product or sum of the other variables.

We denote that with these symbols, with which you are familiar from GCSE Maths (aren't you?).

- < - less than;
- << - much less than;
- > - greater than;
- >> - much greater than.

1.045 Approximations

Sometimes it is not possible to get an exact answer. For example, the circular number π is what mathematicians call an **irrational** number. This means that however many significant figures you write it to, you will never get to the exact value. We can get an **approximation** (close to) to the value of π by writing:

$\pi \approx 3$

$\pi \approx 3.14$

$\pi \approx 3.1415$

$\pi \approx \frac{22}{7}$

Sometimes correct calculations in Physics will give answers that are only approximations to the true answer. This is because the equations used may not take into account variables that will affect the answer in real life. For example, if you ignore air resistance when calculating the trajectory of a falling object, you will get an approximation to its path, but in reality, the object will not follow that exact path.

This leads to the important concept of **uncertainty**, in which measured values may not be the true values. We will learn how to handle uncertainties later.

1.046 Change in

Quantities can change. For example, acceleration is defined as the change in velocity per unit time. The change in a quantity is denoted by the symbol Δ, (Delta, a Greek capital letter 'D').

Δ value = value at end – value at the start

1.047 Transposing Formulae

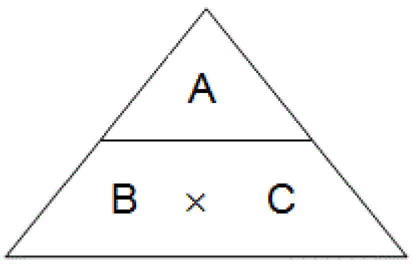
It is far better to get into the habit of rearranging formulae from the start. The best thing to do is to practise. Key Points:

- 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.
- $x/x = 1$

1.047.A Transposing Simple Formulae

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

A simple trick is to use the **formula triangle**. Some physics teachers sneer at this method. I don't, as long as you are aware that it only works for three term equations.



You put your finger over the term you want to be **subject** of the formula (what you want to find) and then the rest follows:

$$B = A/C$$

However, it is better that you follow a more orthodox method. Suppose we are using the equation $V = IR$ and wanted to know I.

We want to get rid of the R on the RHS (right hand side) 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* terms on the RHS *cancel* out because *R/R* = 1. So, we are left with:

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

1.047.B Formulae with Four Terms

Triangle methods will not work with these. Nor is there a magic square. Instead use the same method as above. Consider this formula:

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

Make ρ the subject.

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:

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

The *A* terms cancel to give us our final result:

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

1.047 C Equations with + or -

If there are terms which are added or subtracted, we need to progress like this. Again, do not worry about what this equation means. You will meet it in Tutorial 2.

$$E_{\mathrm{k}} = hf - \Phi$$

We want to find h.

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

$$E_{\mathrm{k}} + \Phi = hf - \Phi + \Phi$$

$$E_{\mathrm{k}} + \Phi = hf$$

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

$$\frac{E_{\mathrm{k}} + \Phi}{f} = \frac{hf}{f}$$

Which gives us our final result of:

$$h = \frac{E_{\mathrm{k}} + \Phi}{f}$$

1.048 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:

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

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

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

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

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

1.04 Questions

1.04.1

In the equation

$$P = I^2 R$$

the power is proportional to the square of the current.

What is the constant of proportionality?

1.04.2

The equation

$$E = \frac{V}{d}$$

suggests an inverse proportionality. Write down the inverse proportionality using the varies as symbol, $\propto$. What is the constant of proportionality?

1.04.3

Use your calculator to show how close an approximation the value 22/7 is to the calculator value of π.

1.04.4

Use the delta notation to write an equation for acceleration.

1.04.5

Rearrange these equations:

	Equation	*Subject*
a	$V = IR$	R
b	$p = mv$	v
c	$r = m/V$	m
d	$Q = CV$	C

1.04.6

Rearrange these equations:

	Equation	*Subject*
a	$pV = nRT$	V
b	$E_{\mathrm{p}} = mg\Delta h$	Δh (Δh is a single term)
c	$V = -\frac{GM}{r}$	G
d	$\lambda = \frac{ws}{D}$	D

1.04.7

Rearrange these equations:

	Equation	Subject
a	$v = u + at$	t
b	$E = V + Ir$	r

1.04.8

Rearrange these equations:

	Equation	Subject
a	$E_k = \frac{1}{2}mv^2$	v
b	$T = 2\pi\sqrt{\frac{m}{k}}$	k
c	$f = \frac{1}{2\pi\sqrt{(LC)}}$	C

1.04.9

(Challenge) Make t the subject of this formula:

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

Tutorial 1.05 Experimental Uncertainty

All syllabi

Contents

Many of the most significant scientific discoveries are the result of meticulous work and record keeping. They have been accepted because not only are the results **reproducible** but have been collected using methods that are considered to be reliable.

You need to do experimental work in which the data can be considered to be reliable. While there is no practical assessment in the AS syllabus, there will be questions in the examination about certain practical work that you will have to do. Since you will need to pass the AS year (depending on your centre) to progress to A-level, there will be practicals that you will have to do to include in your portfolio which is to be submitted to the Board for your A-level exams.

These notes will look at many common terms and concepts that are used in practical work.

1.051 Variables

These are the items that are being studied in a scientific investigation. In physics, the variables are almost always **quantitative**, i.e. have a value that is a number.

- **Categoric** variables are those that are described by words, for example, ants, bumble bees, butterflies. There is no cross-over between the different classes. You can't have a half-way version of an ant and a bumble bee.
- **Ordered** variables are not numerical but are in a **ranked** order, for example, thin, medium, thick.
- **Discrete** variables are those that are in whole numbers. You can have 1, 2, 3, ..., but you cannot have 1.2 or 3.5.
- **Continuous** variables have a numerical value of any value, e.g. 3.64 W.

These variables are used in three ways in experiments:

- The **independent variable** is the one that we change (e.g. by changing the length of resistance wire).
- The **dependent variable** changes in response (e.g. the resistance increases).
- The control variable, which is kept constant to make sure that it's a fair test. If you were measuring temperature rise with the power of a heater, you would keep the start temperature the same, use the same volume of water, etc.

Any type of variable can be the independent or dependent variable.

1.052 Errors in measurement

Errors affect the reliability of your data, and it's important that you are aware of the sources of these errors. Errors arise from:

- Wrong technique, for example holding a ruler in your hand to measure something that you are holding in the other hand. The ruler will wobble...
- Positioning your eye to read the scale. **Parallax** errors can occur.
- Reaction time in stopping a timer.
- Uncertainty in a reference point. It is worth having a clear reference point when something is moving. This is often called a **fiducial** or **fiduciary** mark.

Figure 8 A mirror to reduce parallax error

Parallax errors can be minimised by use of a **mirror** behind the pointer. When you cannot see the image of the pointer, you can be sure that you are reading the correct result. A parallax mirror can be seen on the meter in the picture.

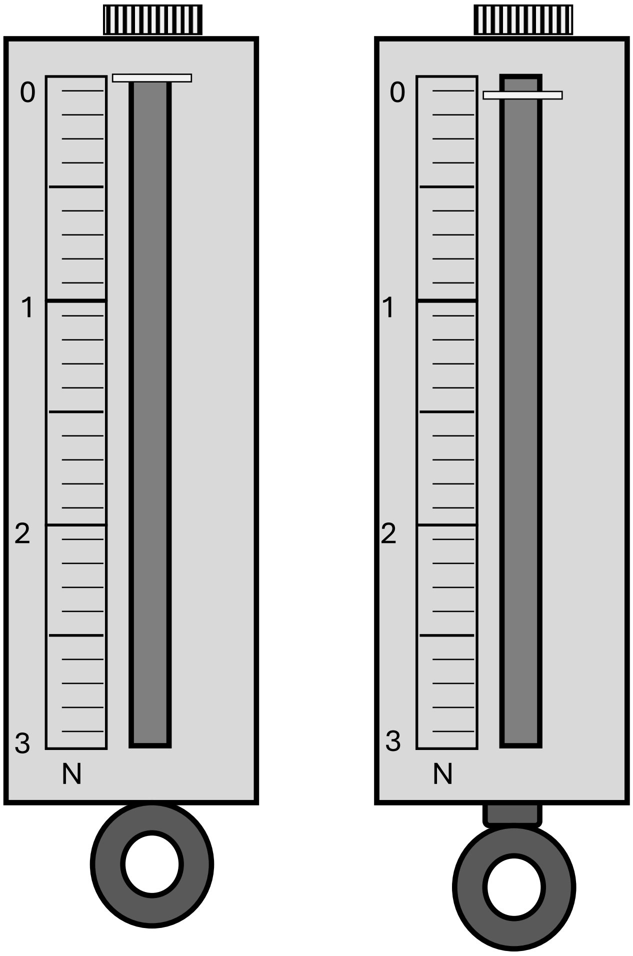
All these errors are **random**. Random errors arise from faulty technique or faults in the equipment.

Sometimes random errors are called **human error**. Do not use this term in the examination as no credit is given. This is because the phrase *human error* is too vague and covers not only faulty technique, but also a whole range of other human frailties, e.g. the pilot who stalls his aeroplane on take-off, or "having one's fingers in the till", or "playing away from home".

To err is human, to forgive divine.

Random errors can be reduced by taking **repeat readings**.

Systematic errors result in readings all being shifted too high, or too low. This can be the result of the wrong calibration of the instrument, or a change in the zero point of the instrument.



Notice how the calibration on the right-hand meter is wrong. It is not correctly zeroed.

Figure 9 Zero error on the right-hand newtonmeter

The zero point on many instruments can be adjusted, for example, this voltmeter.

Figure 10 Adjusting screw to reduce zero error

1.053 Improving Accuracy of Measurements

A **fiducial mark** is a **reference point**. Suppose you are timing a swinging pendulum. You want to know when one swing finishes and the next starts, so you place a pointer on the bob and one on the clamp stand, like this:

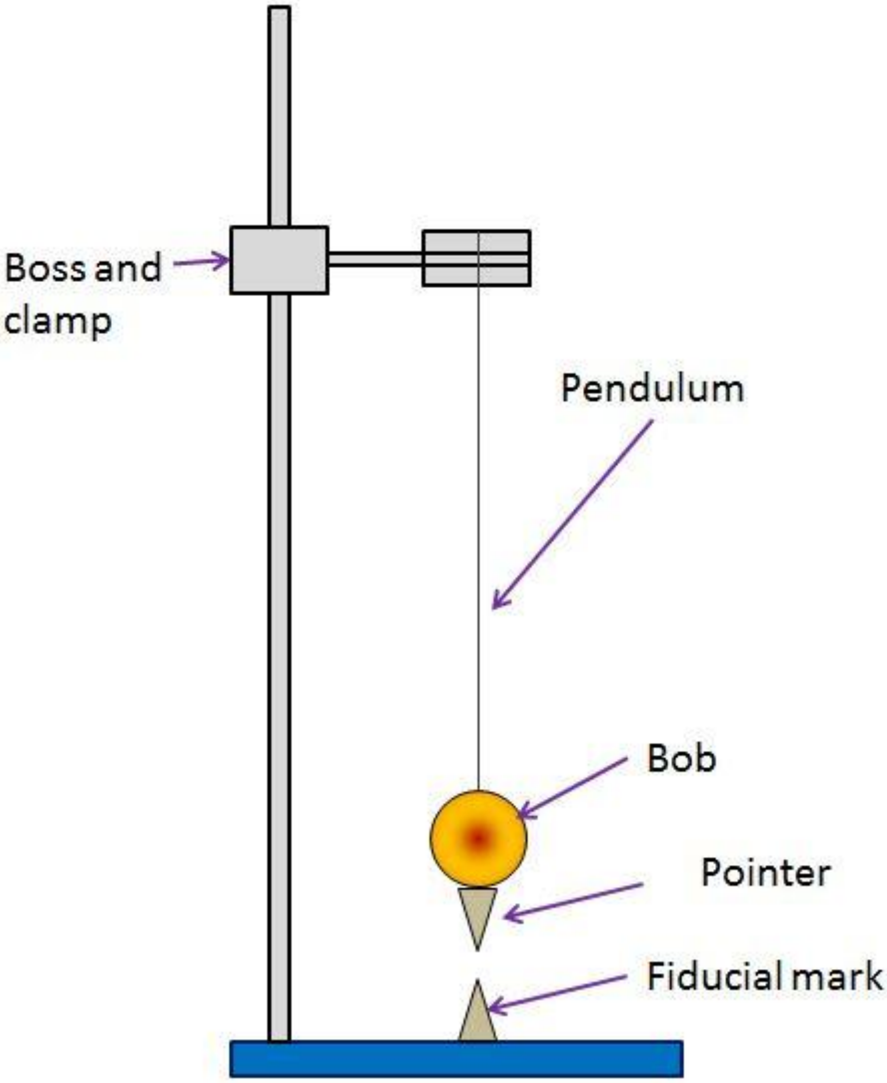


Figure 11 Use of a fiducial mark

You count each time the pointer passes the fiducial mark from, say, left to right. You start timing when the pointer first passes the fiducial mark from left to right. A whole swing is when the pointer passes the fiducial mark the next time from left to right. This fiducial mark is in the middle of the swing, so that it doesn't matter if the amplitude of the swings gets less. You need to count **multiple** swings (say 10) to reduce the uncertainty in the timing. The period of the swing is the time for 10 swings ÷ 10.

When a fiducial mark is used to indicate a **zero** point, it is called a **datum** point.

Using a **set square** is a valuable way to check that you are reading a scale correctly:

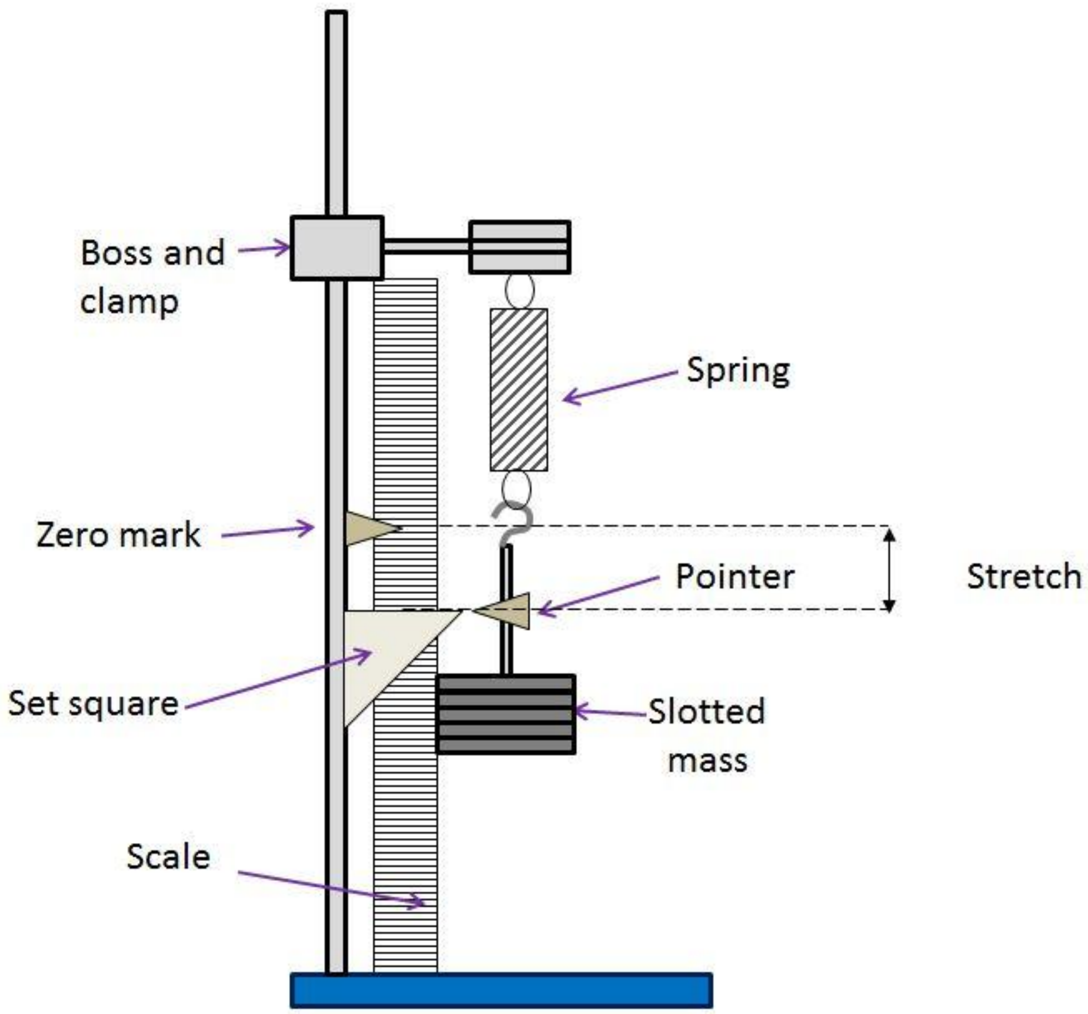


Figure 12 Using a set square to read a scale accurately

You place a pointer onto the slotted mass. When there is no force from the slotted mass, you set up the zero mark using the set square to make sure it is exactly opposite the pointer. As you load this spring, you can measure the stretch using the set square to make sure you are reading from the pointer. This reduces uncertainty.

A **plumb line** is a thin piece of cotton with a small weight on it. It always hangs vertically. You will use one when finding the centre of mass of an irregular sheet of material.

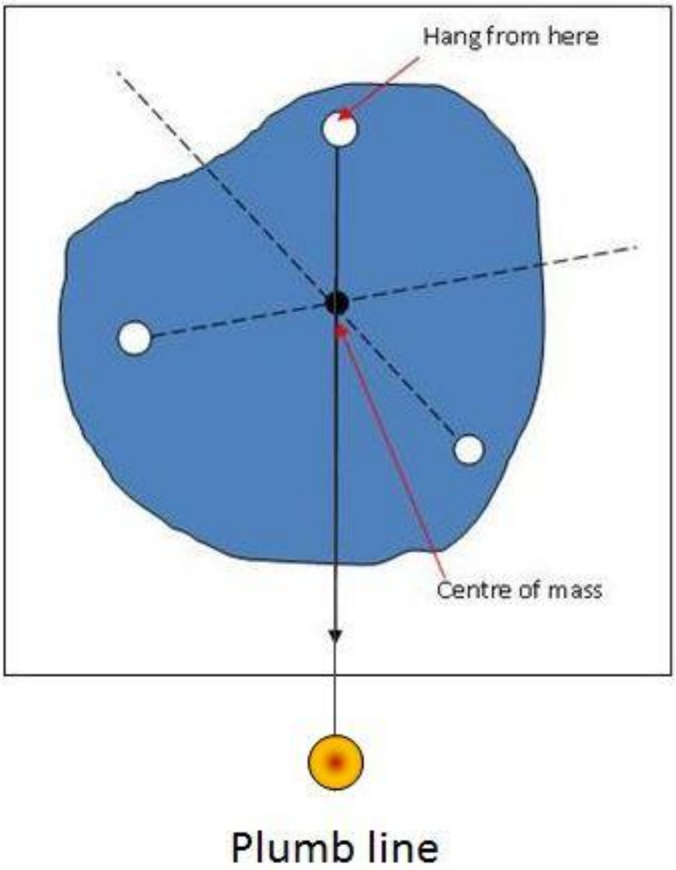


Figure 13 Using a plumb line

Decorators use plumb lines for making sure that wallpaper hangs vertically.

1.054 Accuracy and Precision

When you take a measurement, you want the measurement to be both **accurate** and **precise**. However, it is important to understand the difference between the two words:

- **Accurate** measurements are close to the true value.
- **Precise** measurements arise from the smallest scale reading that the instrument can give. A digital voltmeter can give a precision of 0.001 V (the minimum reading that it can take).

If the voltmeter is not properly calibrated, it may be precise, but not accurate. Similarly, a watch with a precision of 10^{-6} s per day is not accurate if it's telling the wrong time. The diagram shows the idea by using airgun shots around a target (Figure 14).

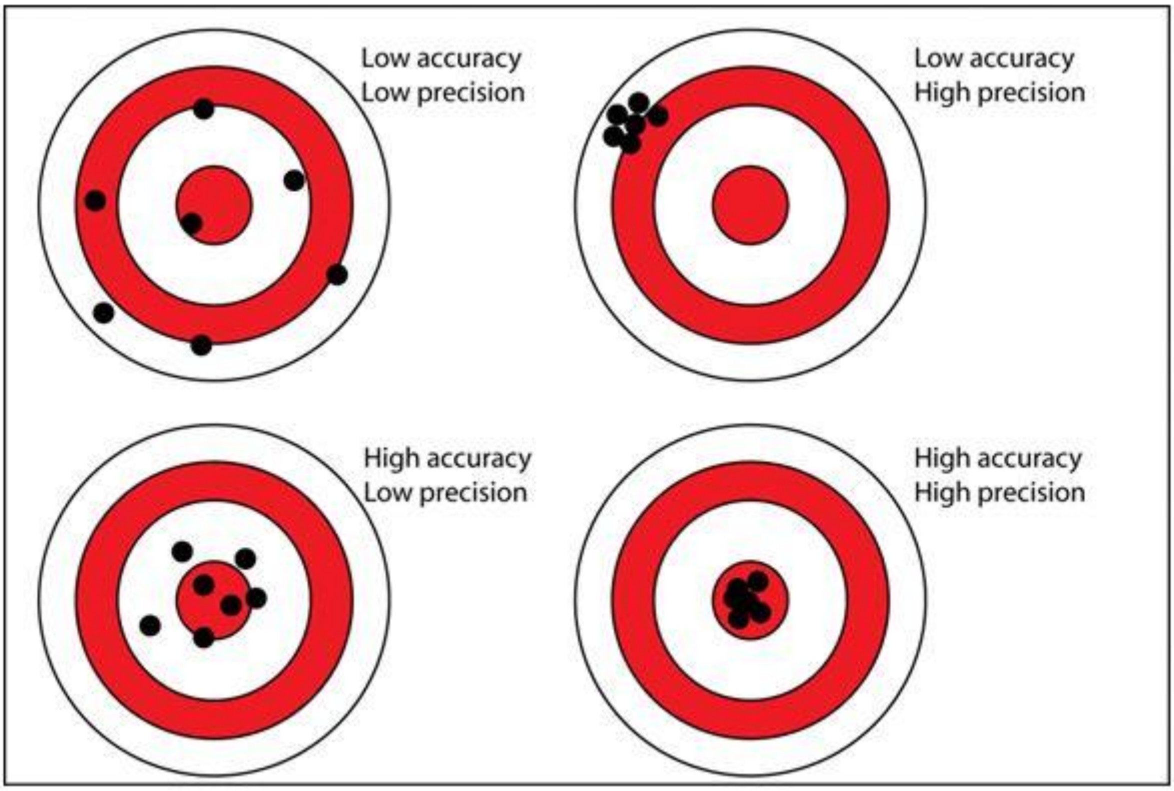


Figure 14 The difference between accuracy and precision

If the shots are on the bullseye, they are **accurate**. If the shots are close together, they show high **precision**. A tight group of shots may be precise but are not accurate if they are not on target.

When measuring length with a metre ruler, you can measure to a precision of ± 1 mm.

The AQA definition for precision that is used in the examinations is the **smallest division that can be read**. Yes, I know you can read it to about half a division, but that is what the AQA have decided.

An electronic thermometer that can read to ± 0.1 °C is more precise than an alcohol thermometer that reads to ± 0.5 °C.

Look at this voltmeter, which is reading 244 V (Figure 15).

However there is more to precision than the above:

A **precise** instrument gives consistent readings when taking the same measurements. For example:

A beaker is weighed 3 times on balance A. The readings are 73 g, 77 g, and 71 g. The range is 77 – 71 = 6 g.

The same beaker is weighed on balance B. The readings are 75, 73, and 74 g.

1.055 Taking Measurements

Note that the word *data* is a **plural** word. The singular, *datum*, is used in the context of a reference point from which measurements are made. A single measurement is best referred to as a *data item*.

When you read your instruments, you are recording **data**. The data that you record are then processed in a certain way to get:

- A graph.
- Processed data items, (e.g. resistance from voltage and current).
- Or both.

Data are made **reliable** by taking **repeat readings**. Whenever you take a set of repeat readings, there is always going to be a certain amount of **variation**. A free-fall experiment involving dropping a ball bearing through a viscous (gooey) liquid may give these results:

10.1 s, 10.2 s, 9.9 s, 10.0 s; 10.3 s; 10.6 s

There is **variation** because there are **reaction times** in operating the stopwatch.

The **range** of the results can be worked out:

Range = maximum value – minimum value.

To get a value that we can plot on a graph, we need to take an **average** (or **mean**):

Average = (Sum of the readings) ÷ total number

Note that the average is not necessarily the midpoint of the range.

You can also test for the reliability of your data by checking the results obtained by other students in your class. If they are close, you can be confident that your data are reliable.

1.056 Processing Data and Quantification of errors

We have looked at how errors can arise. Now we need to see how we can quantify the errors, i.e. turn the errors into numbers.

Suppose several students measured the diameter of the same ball bearing with a micrometer. The results were:

1.21 mm; 1.20 mm; 1.18 mm; 1.25 mm; 1.24 mm; 1.19 mm

The average of these readings is:

$$\frac{1.21 + 1.20 + 1.18 + 1.25 + 1.24 + 1.19}{6} = \mathbf{1.21\ mm}$$

The range of these readings can be worked out using:

Range = maximum value – minimum value

Range = 1.25 – 1.18 = **0.07 mm**

The error (or uncertainty) is found by taking **half the range**:

Uncertainty = 0.5 × range = 0.5 × 0.07 = **0.035 mm**

So, we can write:

Diameter = **1.21 ± 0.04 mm**

The diameter of the ball bearing can be confidently measured as:

1.17 mm to 1.25 mm

When you write down such an error remember to write in the units.

If you have repeat readings that are all **identical**, then you need to work out the uncertainty from the **precision** of the meter. The same applies if you have not done repeats.

If we have several different variables, we need to combine the errors for each one. Clearly it does not make sense to combine quantities of different units, e.g. millimetres, amps, ohms.

However, we can work out the **fractional error** for all quantities. These are numbers, so they can easily be combined.

We can work out the fractional error as:

Fractional error = error in the measurement ÷ average value

In this case:

Fractional error = 0.035 ÷ 1.21 = **0.029**

You can convert that to a percentage. In this case, it's 2.9 %.

In AQA exams, the **fractional** uncertainties are always expressed as percentages. If an overall or **absolute** error is asked for, you need to write:

Resistance is 6.3 ohms +/- 0.2 ohms

When combining errors, the following rules apply:

- When quantities are added or subtracted, the **absolute** errors are added together.
- When quantities are multiplied or divided, the **fractional** (percentage) errors are added together.
- If a quantity is squared, the error is multiplied by 2. If it's cubed, the error is multiplied by 3.
- If a square root is taken, the error is halved.

1.056 A Adding Quantities together

Here are two resistors in series. We know that:

$$R_T = R_1 + R_2$$

In this case we simply add up the resistances and add the **absolute uncertainties**.

Do not add the percentage uncertainties.

The percentage uncertainty of the 25 Ω resistor is (1 ÷ 25) × 100 = 4.00 %

The percentage uncertainty of the 45 Ω resistor is (1 ÷ 45) × 100 = 2.22 %

The total percentage uncertainty would be 6.22 %. This translates into an absolute uncertainty of:

$$0.0622 \times 70 = 4.44\ \Omega$$

This is over twice what it actually is.

1.056 B Multiplying or Dividing

The majority of calculations involve the multiplication and/or the division of several numbers. In this case the **percentage uncertainties** add together.

Let's look at what happens in a calculation. Suppose the voltage has an error of 2.5 %, and the current has an error of 3.6 %. If we calculate the resistance using $R = V/I$, the error will be:

Error = 2.5 % + 3.6 % = **6.1 %**

And if we calculate the power, we use $P = IV$:

Error = 2.5 % + 3.6 % = **6.1 %**

Do not put the error into a formula in this way:

Error in the resistance = V/I = 2.5 % ÷ 3.6 % = 0.64 %. Wrong

Error in the power = VI = 2.5 % × 3.6 % = 9 %. Wrong

If we have a lot of quantities with different uncertainties, it can be helpful to use an equation to sum them:

$$\Delta W = \sqrt{(\Delta X^2 + \Delta Y^2 + \Delta Z^2)}$$

Where:

- ΔW is the overall **fractional** uncertainty
- ΔX is the uncertainty in quantity X.
- ΔY is the uncertainty in quantity Y.
- ΔZ is the uncertainty in quantity Z.

We can also write for a similar equation for the absolute uncertainty:

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

1.057 Reliable and valid evidence

Evidence is data that are considered to be **relevant** to the investigation. When investigating resistivity, the lengths of the resistance wire are relevant data; they are evidence. The colours of the connecting wire or the manufacturers of the meters are not. They are not evidence.

We want our evidence to be **reliable**:

- Reliable evidence stems from data that you can trust.
- If other students did the same experiment using the same equipment and method, they would get the same result.

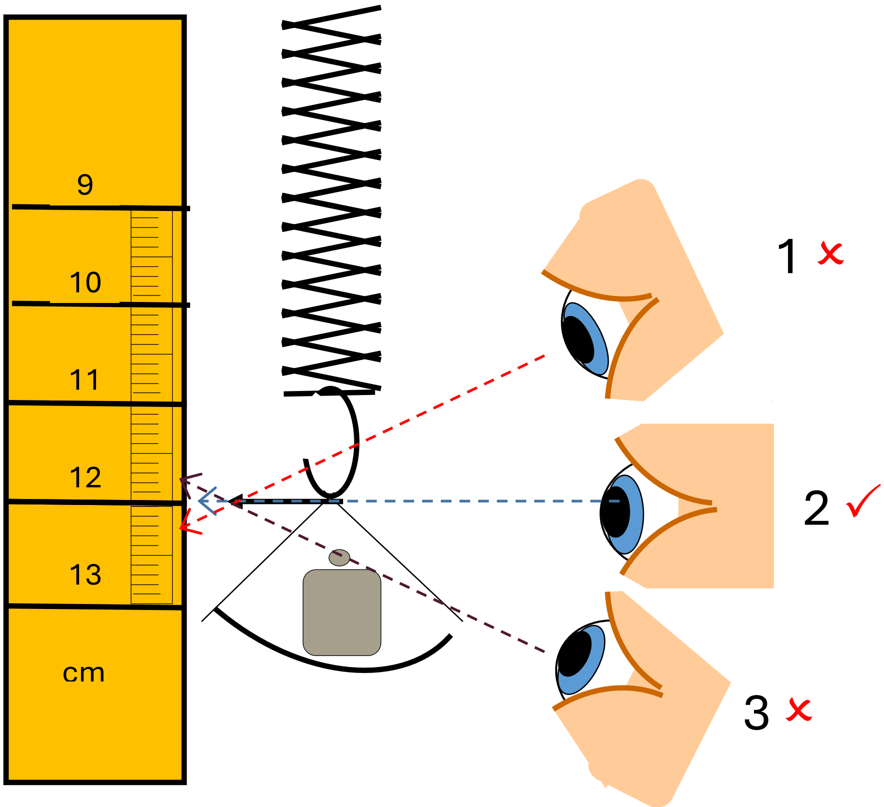
The evidence must be **valid** as well. **Valid** evidence is **reliable** and **relevant**. For example:

- Measuring the extension of a spring to find the force pulling on it. This is relevant, so the evidence is valid, provided that the data are reliable.
- Measuring the volume of a resistor to investigate the resistance. This is not valid evidence, as the volume is not relevant to the resistance.

You can check the validity of your data by using **secondary evidence**, e.g. someone who has done the experiment before, and observed the same things.

Questions

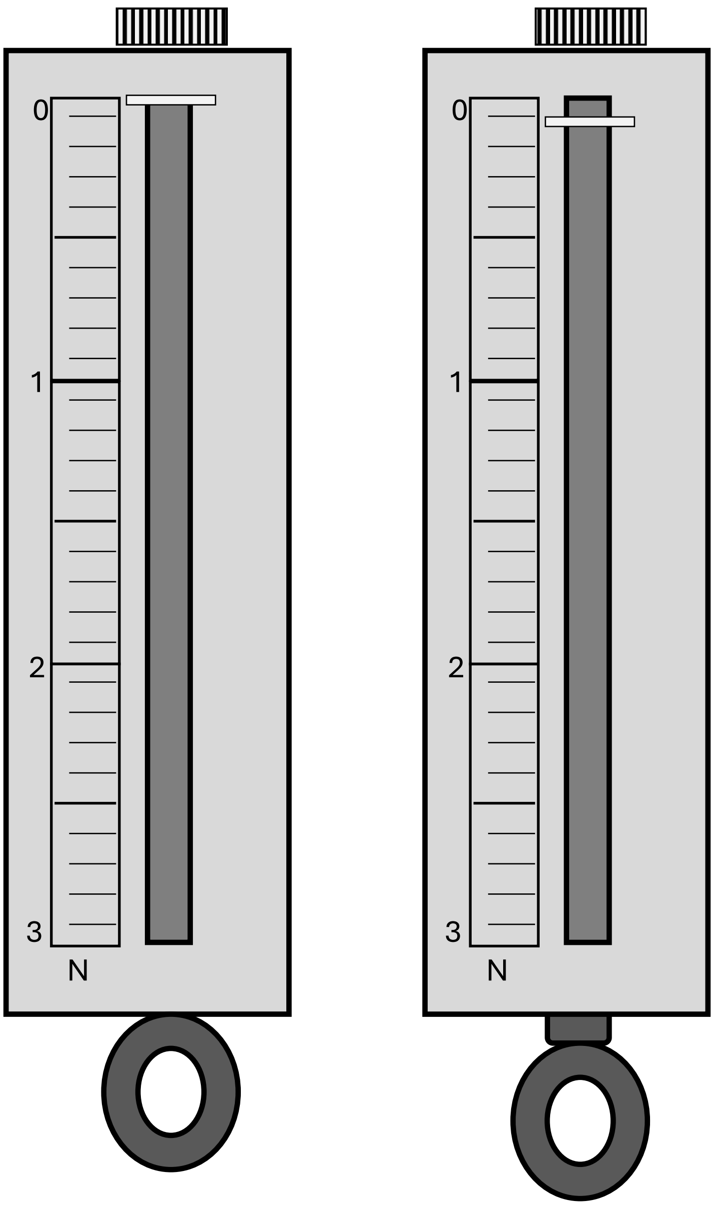
1.05.1



Write down the reading shown by positions 1, 2, and 3 in the picture above.

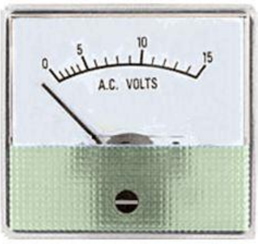
1.05.2

How would you take into account the error from this newtonmeter?



1.05.3

How would you fix the zero error on this meter?



1.05.4

(a) What is the precision of this voltmeter?
(b) What is reading on this voltmeter including the precision?

1.05.5

A beaker is weighed 3 times on balance A. The readings are 73 g, 77 g, and 71 g. The range is 77 – 71 = 6 g.

The same beaker is weighed on balance B. The readings are 75, 73, and 74 g.

(a) What is the range for balance B?
(b) Which instrument is more precise?

1.05.6

Three students are asked to determine the capacity of a box for storing ball bearings. Each of them uses a different ruler and only one takes care doing it. Here are their results:

Name	Width (cm)	Height (cm)	Depth (cm)	Capacity (cm^3)
Andy	10	9	7	
Bill	11	8	6.5	
Cass	10.8	7.9	6.4	

(a) Calculate the capacity that each student works out and complete the table.

(b) The true value is 545 cm^3. Which is the most accurate result?

1.05.7 and 1.05.8 use these data:

A free-fall experiment involving dropping a ball bearing through a viscous (gooey) liquid give these results:

10.1 s, 10.2 s, 9.9 s, 10.0 s; 10.3 s; 10.6 s

1.05.7

What is the range of the data above?

1.05.8

What is the average of the data above?

1.05.9

What is the total resistance and what is the total uncertainty of these two resistors?

1.05.10

Here are some data for a resistivity calculation. The formula for resistivity is:

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

(The symbol ρ is rho, the Physics code for resistivity).

- The uncertainty in the area is 8.5 %.
- The uncertainty in the Resistance is 6.3 %.
- The uncertainty in the length is 0.86 %.

(a) Calculate the uncertainty in the resistivity.

(b) What are the units for resistivity?

Tutorial 1.06 Basic Graphical Skills

All syllabi

Contents

1.06.1 Recording Results

The chances are that you were told how to present data in **tables** when you were in Year 7 (1st Year). It is clear that many students weren't listening, because the **presentation** of tables of data causes many problems and lost marks in the practical assessments. It shouldn't; it is dead easy. Even if you know no physics, you can still pick up several marks for making sure that your data are presented well.

- Make sure you make a **table**.
- It should be **boxed in** with **ruled** lines, please.
- There should be **headings** for each column.
- With **units**.
- Data should be to no more than three significant figures.

In an experiment you should get into the habit of taking two or three repeat readings. This helps to reduce anomalous results (those that don't fit into the pattern). Show these in your table and do an **average**.

In an experiment all students are expected to have their own copy of the results.

It is depressing how often the excuse is made that "Zack's got my results."

Dealing with Uncertainty

We dealt with this in Tutorial 4. In experimental there is always a certain amount of **uncertainty**. Some books call it **error**, but error implies operator carelessness, which is not always the case. Uncertainty can be:

- **Random**, where there is no pattern. For example, a digital meter takes readings every 0.2 s. Was the result caught exactly as the stopwatch read 10 s?
- **Systematic**, where there is uncertainty in the calibration of an instrument. A school voltmeter may read 3.45 V, but the real voltage could be 3.41 V.

1.062 Results

In general, a school physics experiment will produce at best accuracy of one part in 100. Therefore, it makes no sense mindlessly to reproduce all ten digits from a calculator.

The writing up of practical reports is an essential skill in physics. You might have got brilliant results in a required practical, but that's no good if you don't tell anyone about them. I have written at length about practical reports in the induction notes in Tutorial 7. There is more stuff about graphs in the induction notes Tutorials 1.06 and 1.07

A sure-fire way of getting data that are unreliable is to jot them down on a scrap piece of paper with no semblance of order. While you may know what the data items refer to when you are taking them, it is very easy to forget. Or the bit of paper gets lost. It is depressing to hear the excuse for an experiment not being handed in, "Sean's got my results".

Data are recorded on a table of results, and each student must have its own set of data. This should be drawn up before you start your experimental work. The picture below shows a neat table of results. While it may not be of an experiment at AS level, it still shows the principle:

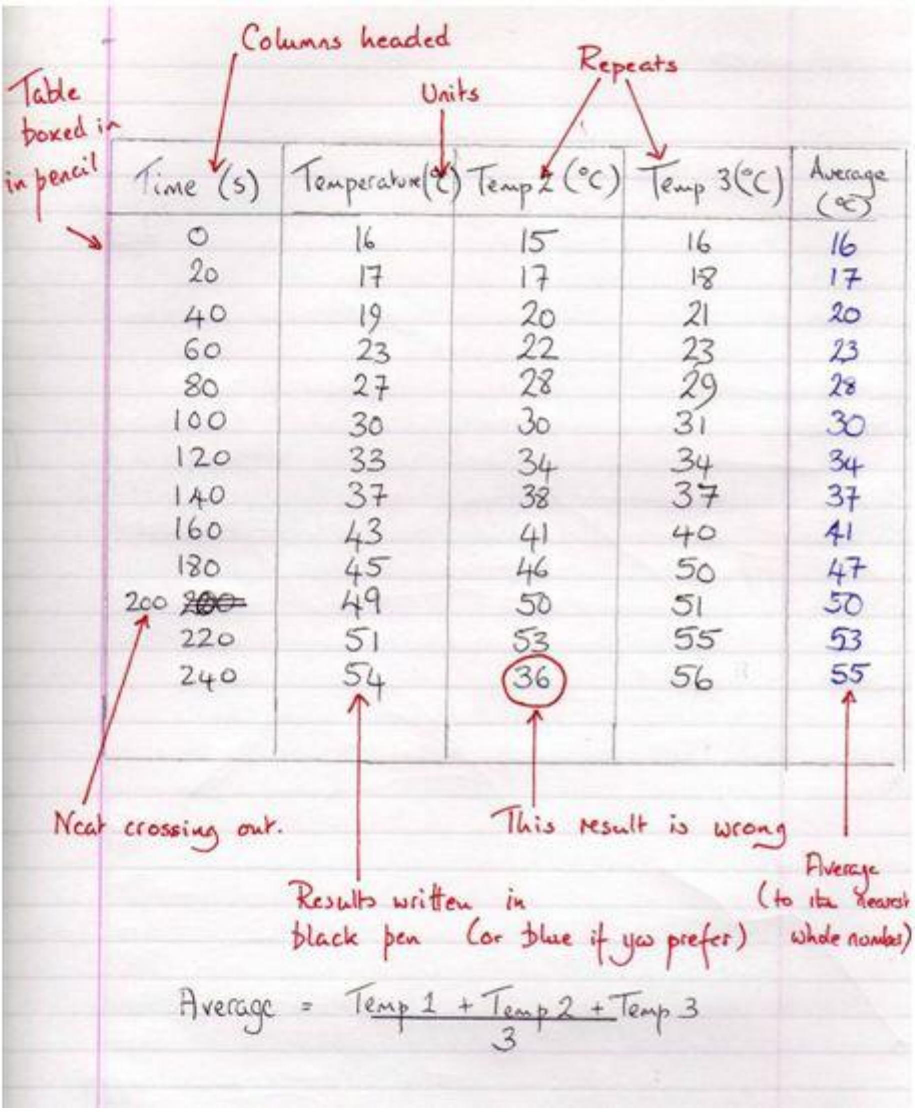


Figure 15 A table of results

Your data must be recorded to the precision of the instruments. The averages from repeat readings must be recorded to the same number of significant figures as the data.

If you process data, the number of significant figures must be no more than the minimum number of significant figures. Let us look at the resistance of a length of resistance wire:

Length / m	Current / A	Potential difference (V)			Average / V	Resistance / Ω
		Reading 1	Reading 2	Reading 3		
0.100	0.25	2.30	2.25	2.32	2.29	9.0
0.200	0.25					
0.300	0.25					
0.400	0.25					
0.500	0.25					
0.600	0.25					
0.700	0.25					
Etc…						

- The p.d. readings are consistent with the readout of a digital voltmeter.
- The current was kept constant at 0.25 A. The number of significant figures is consistent with the precision of an analogue ammeter.
- The average is consistent with the number of significant figures of the p.d. readings.
- The resistance is calculated to two significant figures. It calculated to 9.04 Ω but is written as 9.0 Ω to make it consistent with the current which is recorded to two significant figures.

1.063 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.

You have harvested data, done repeats, etc. But what then? A table of numbers is not very helpful. So, we need to represent the data as a picture which shows us a great deal of information that we could not pick up from the data in the table.

- Whether one quantity is proportional to another.
- What the proportionality is.
- How a derived quantity is obtained from the gradient.

All **graphs** in physics are line graphs. This is because quantities in Physics tend to be continuous. A set of results is not very easy to use to judge the way quantities are related to each other. The graph shows it instantly.

Size

Graphs should always:

- Be **large** – they should occupy the whole of a side of A4 paper.
- Have a **title** to tell the reader what the graph is about.
- Have **sensible** calibration of axes, with **simple** scales.
- Have both axes labelled with the quantity and units.

Note that sometimes the points are compressed to one side of the graph.

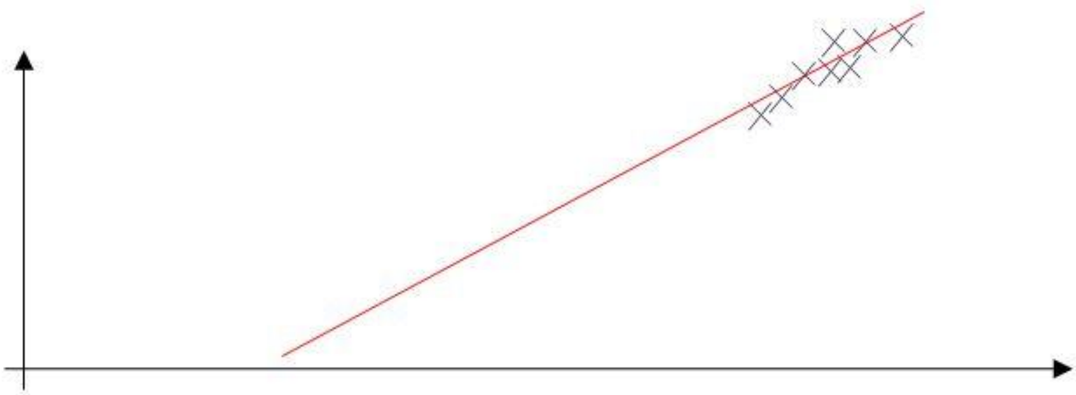


Figure 16 This graph needs to have its scales reconsidered

You really need to consider the scale of your graph to stretch out the points. As such the graph would not get any marks for its size.

You can draw a graph in **portrait** (long side vertical), or **landscape** (long side horizontal). Sometimes it's quite clear which way it should go. Other times it's a matter of what seems best.

Just a reminder of the rules for drawing a graph:

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 2* on the horizontal axis.
5. Look for the highest value in each range. You **calibrate** (put numbers on) your axes to the nearest convenient step above your highest value.
6. Use a sensible scale.
7. **Plot** your points with **crosses** (+ or ×). Points get lost.
8. Join your points with a line, but not dot-to-dot!

The table below shows some data to plot:

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

The graph below is nonsense. Can you see why? Although graphs drawn like this are quite useless, they are depressingly common.

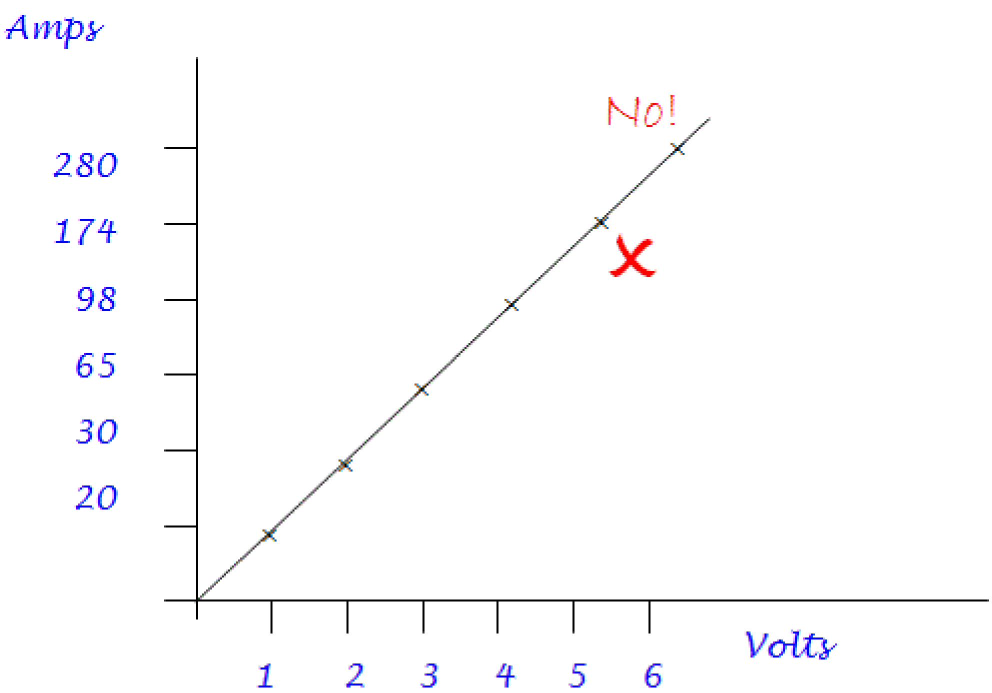


Figure 17 This graph is useless

The correct graph is shown below:

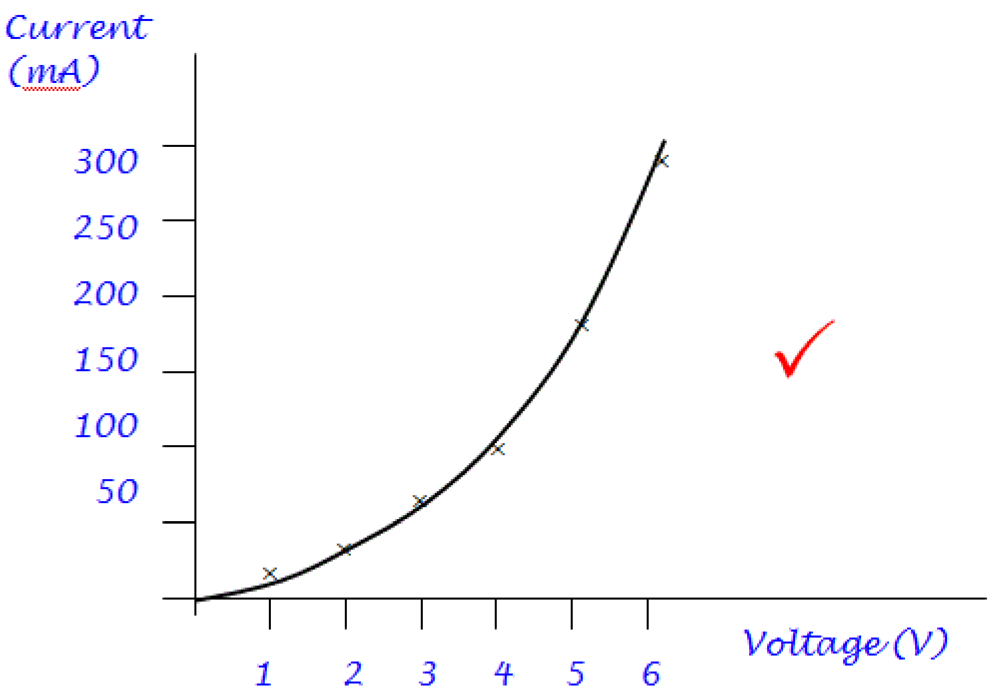


Figure 18 This is a correctly drawn graph

Notice:

- Axes labelled with quantities and units.
- Scales are sensible.
- **Line of best fit** drawn through the points. No dot-to-dot, please.

In the coursework, you will get marks for a graph that is big enough (more than 1/2 the size of A4). You will get marks for labelled axes and sensible scales.

1.064 Axes and Scales

In general, the **independent** variable goes on the **horizontal** axis (the *x*-axis, or **ordinate**), and the **dependent** variable on the **vertical** axis (*y*-axis or **abscissa**). When you are told to plot quantity 1 *against* quantity 2, quantity 2 goes on the horizontal axis.

Sometimes the scales go the other way round, for example voltage (independent variable) against current (dependent variable). This enables us to work out the resistance from the **gradient**.

Your scales should go up in multiples of 1, 2, 5, or 10. Do not use multiples of 3.

The quantity should be separated from its units by a **solidus** (**/**), for example you would label the velocity axis **velocity /m s^{-1}**. In effect you are dividing the quantity by its unit to give a pure number. It is "less scientific" to put the units in brackets, but you would not lose marks in the exam.

1.065 Plotting and Lines of Best Fit

It goes without saying that data need to be plotted accurately. Your scales should allow you to do this. In AQA examinations, the tolerance is within 1 mm of the true position.

A **line of best fit** needs to be drawn, because the data points will always be slightly out.

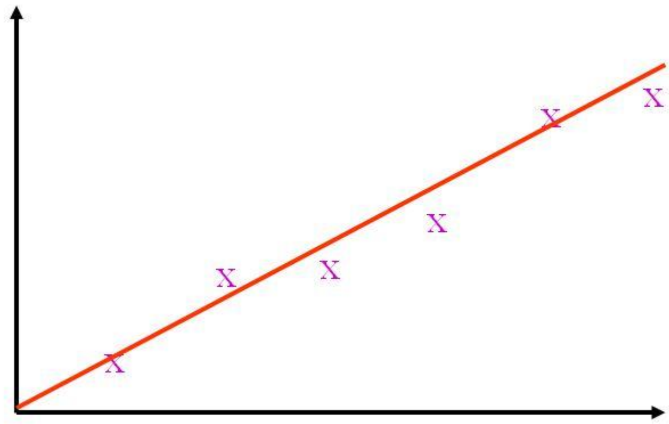


Figure 19 This graph is a straight line of best fit

Consider whether the **origin** is a valid data point. For example, at zero volts, we get zero amps. So' in a voltage-current graph, the origin is a data point in its own right.

It is important to draw a line of best fit so that goes through the middle of a scatter of points. Roughly half should be above, and half below, unless the outlying points are clearly anomalous.

Sometimes the data form a **curve**. Draw a smooth curve, not doing dot-to-dot.

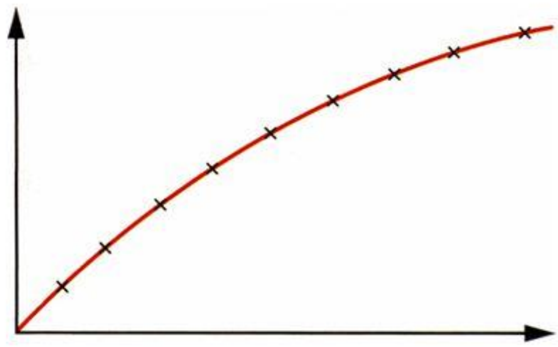


Figure 20 This graph is a curved progression

Do not force a straight line through the curved progression.

Decide whether the origin is a valid data point. If it is, include it.

Sometimes it is not at all easy to decide whether the graph is a curve or a straight line. In this case, you should take more data points. 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. A flexi-curve can help you with this.

You may well get a data point that does not fit in with the rest of the data. This is called an **anomalous** result.

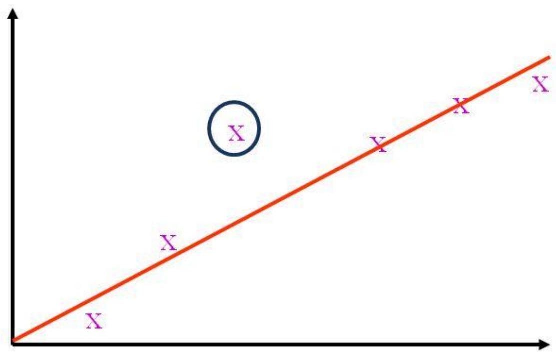


Figure 21 This graph shows an anomalous result

If possible, check out anomalous results by doing a repeat. Your new data will most likely fit in with the other points, and the anomalous data can be discarded.

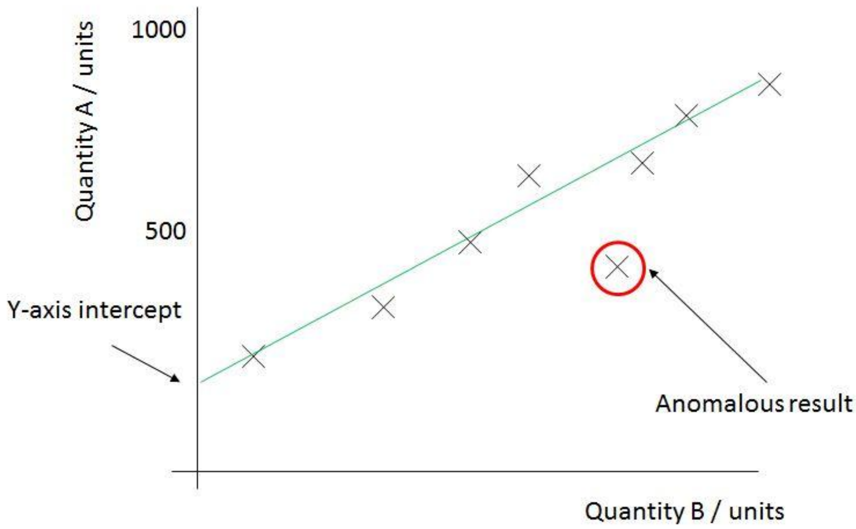


Figure 22 Another anomalous result

Not all graphs are a straight line. When the progression is clearly curved, do not force a straight line through the points.

Sometimes it can be quite hard to decide. Look at these data on the graph:

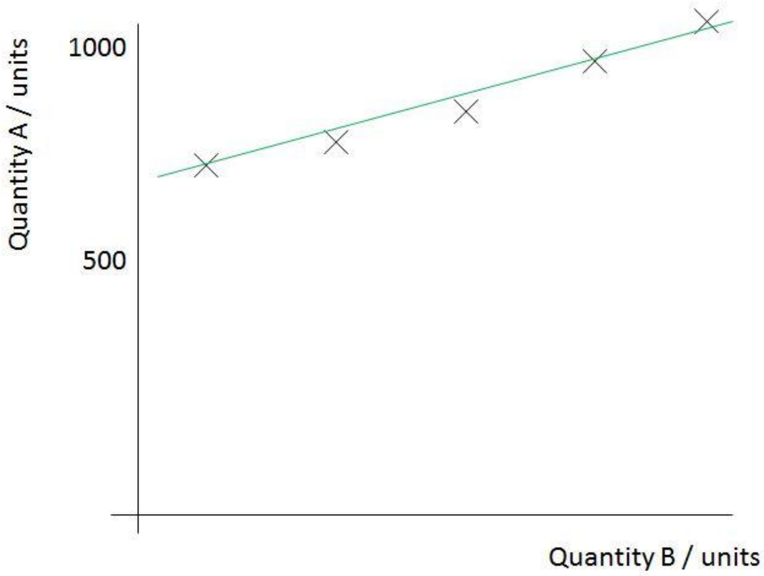
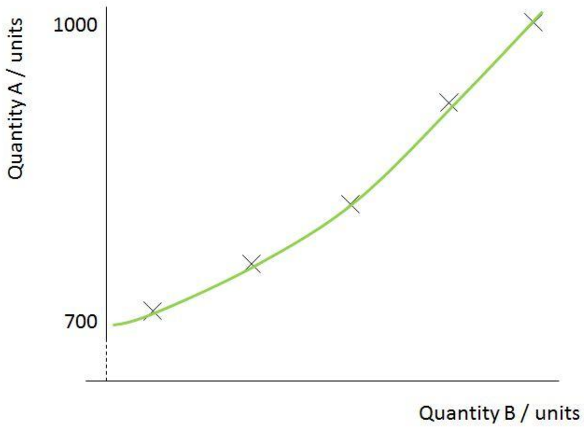


Figure 23 Sometimes it's hard to see if the progression is straight or curved

You can see how hard it is to decide whether these data form a straight line or curve. It might be worthwhile starting the scale for Quantity A at a **non-zero** value. Suppose your minimum value is 700 units and your maximum value is 1000 units. The data now form the graph like this:



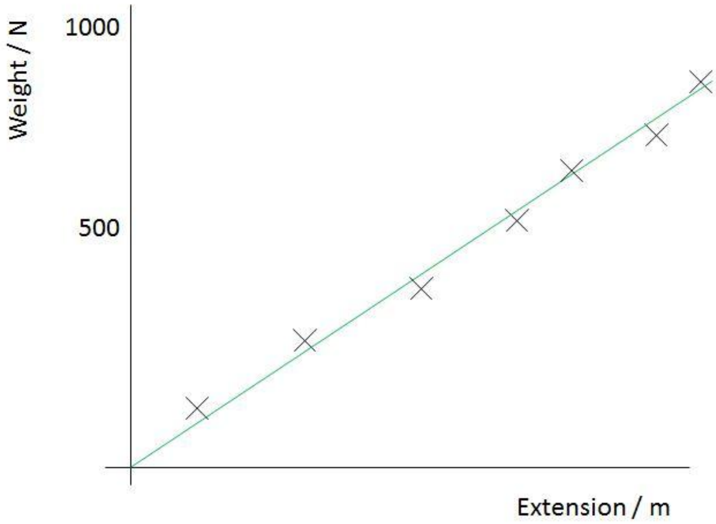
The progression is clearly a curve. Make sure that it's clear where you are starting the scale.

It is clear that in this case the data do not pass through the origin. Therefore, do not include the origin as a data point.

Look carefully at your range of values and choose an appropriate scale. You will lose marks if you don't.

1.065 A Direct Proportionality

A graph that is **straight-line of positive gradient** and **goes through the origin** shows that the two quantities are **directly proportional**.



In this case:

- If the force is doubled, the extension is doubled.
- If there is zero force, there is zero extension.

$$y = mx$$

Figure 24 Direct Proportionality

The term *m* is a **constant**.

Descriptions like *"...if weight increases, the extension increases..."* are too vague and will not gain any credit.

You need to say, "*The extension is directly proportional to the weight (*1 mark*), as the line is straight (*1 mark*) with a positive gradient (*1 mark*) and passes through the origin (*1 mark*).*"

1.065 B Other Proportionalities

It is possible for a relationship to show **inverse proportionality**:

$$y = \frac{k}{x}$$

The graph is a **hyperbola** and looks like this:

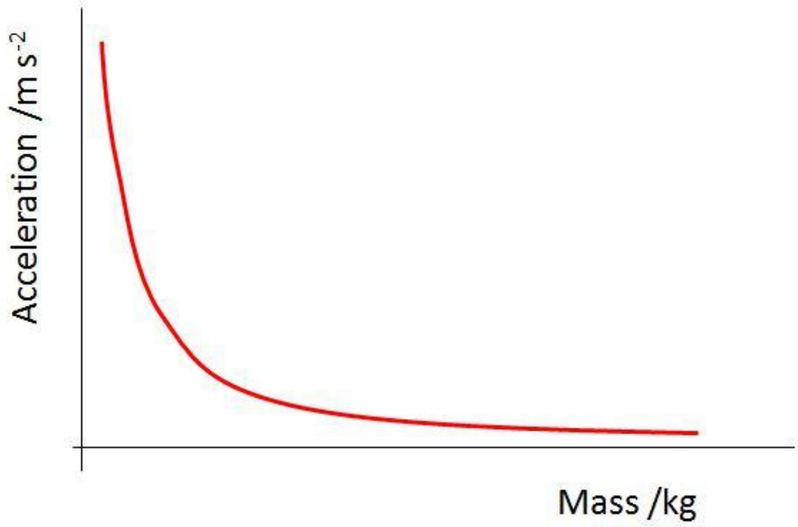
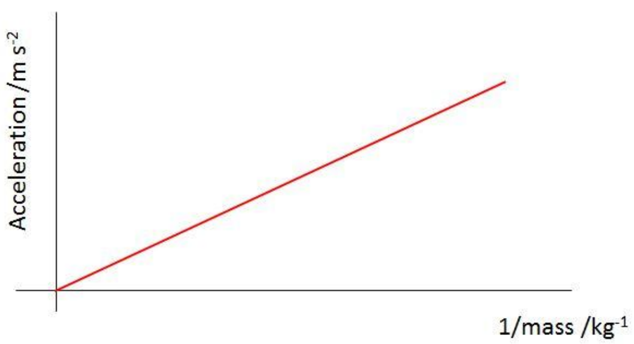


Figure 25 This graph is a hyperbola

Note that the line is **asymptotic** for both axes, which means that it never touches the *x* or the *y* axis.



If we plot **acceleration** against **1/mass**, we get a straight line.

If we plot **1/acceleration** against **mass**, the two would also be proportional.

Make sure that, when you invert a quantity, that you invert the units.

You will lose marks if you write **1/mass** / kg. You must write it as 1/mass / kg^{-1}.

For the **1/acceleration**, the units would be $s^2\ m^{-1}$, NOT $m^{-1}\ s^2$. Note the change in order.

Suppose we have a relationship like:

$$P = I^2R$$

We can say that:

$$P \propto I^2$$

The graph of power against current looks like this and is called a **parabola**

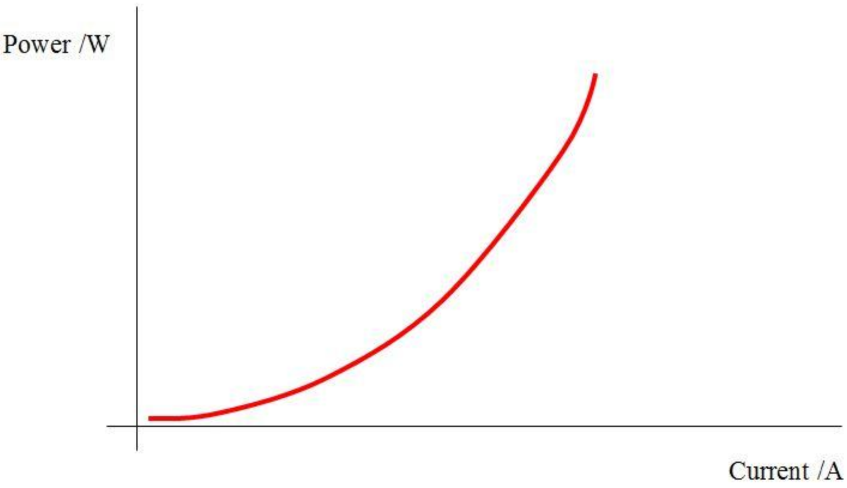


Figure 26 A parabolic graph

We could plot a graph of power against current^2. This would give a straight line that passes through the origin.

1.065 C Linear Graphs that are not proportional

This graph does NOT go through the origin.

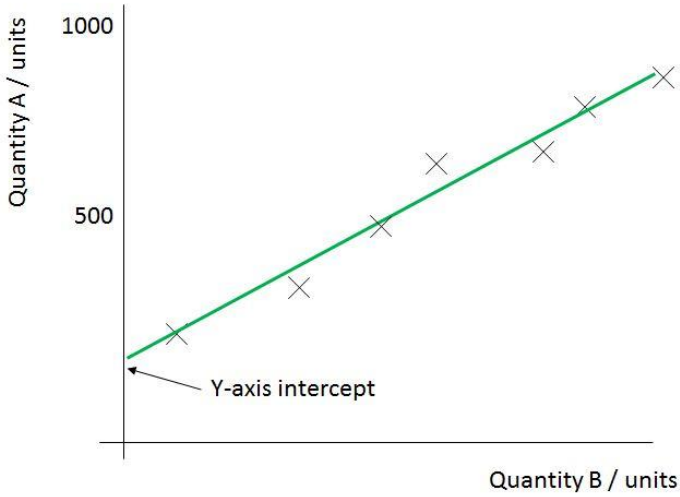


Figure 27 A straight line graph may not show proportionality

This is a **linear** progression (i.e. it's a straight line) but is NOT proportional. If the *x*-value is doubled, the *y*-value is not doubled._The general equation for this graph is:

$$y = mx + c$$

The term c is the value of the **intercept**, which is the point at which the graph crosses the y-axis. You can have an x-axis intercept, of course.

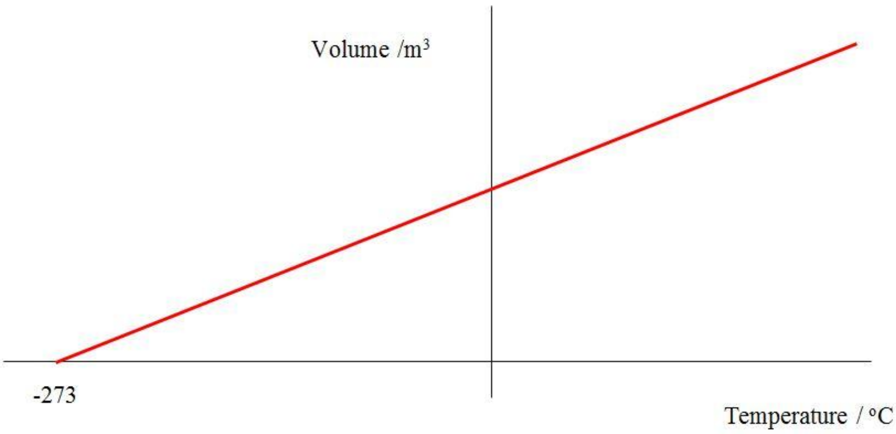


Figure 28 x-axis intercept

1.066 Reading data from the graph

Reading values off the graph is called **interpolating**, which you did in Question 1.06.5.

The graph above that you will have plotted in 1.06.5 is a straight line. The reactance is **directly proportional** to the frequency, as the line goes straight through the origin. No frequency, no reactance. In a directly proportional relationship, if Quantity A doubles, Quantity B doubles as well.

Remember that straight-line graph has the general equation where *m* is the gradient and *c* is the **intercept**, the point at which the line cuts the vertical axis. A function with a graph of this type is NOT directly proportional. If Quantity *A* doubles, Quantity *B* does not double

When we extend the graph to read a value outside the range of plotted data, we are **extrapolating**.

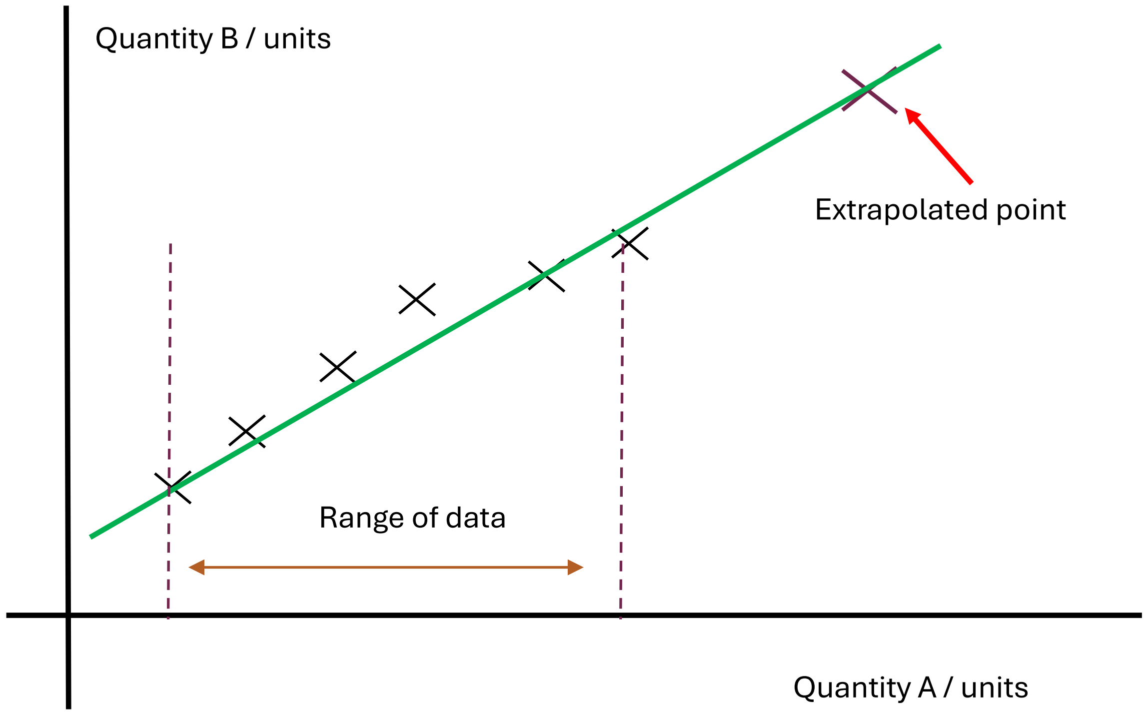


Figure 29 Extrapolating from a graph

1.067 Calculating the Gradient

To determine the **gradient** (or slope) of your graph, you work out the **rise** and the **run**.

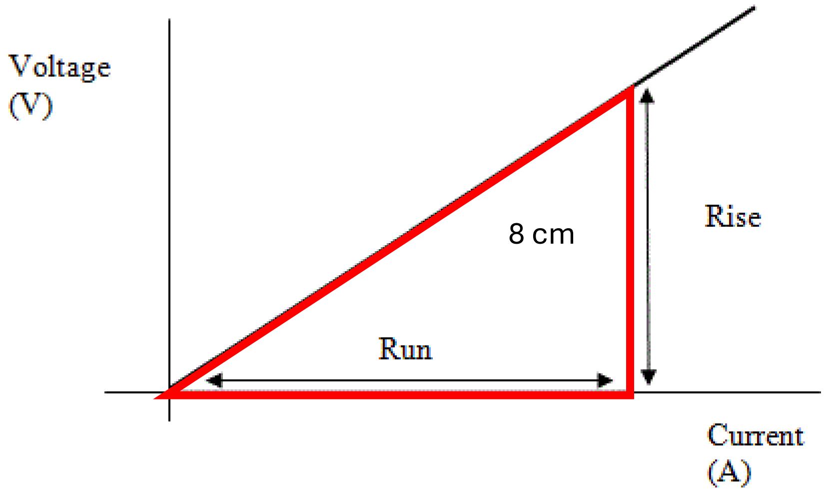


Figure 30 Determining the rise and the run

Don't just use a pair of values to calculate the gradient. In most cases the answer will be wrong, especially if the graph does not go through the origin.

The values should be from the line of best fit.

When you work out the gradient in the exam, you must have a large triangle. **In the exam, the minimum length must be 8 cm**.

$$\text{Gradient} = \text{rise} \div \text{run}$$

Rise is worked out by:

$$\Delta y = \text{highest } y - \text{lowest } y$$

Run is worked out by:

$$\Delta x = \text{highest } x - \text{lowest } x$$

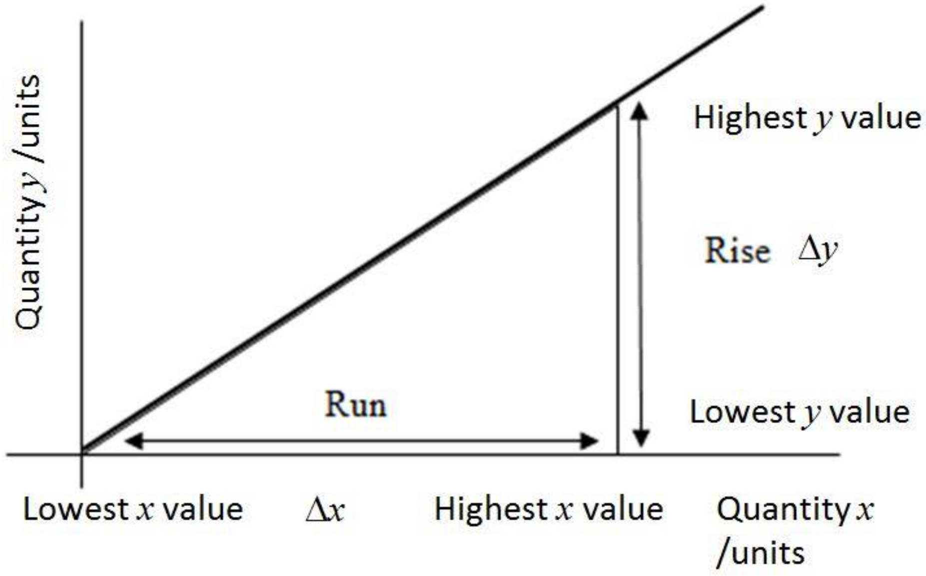


Figure 31 Working out the gradient from a straight-line graph

The gradient will give a reading that could be used directly, for example resistance is the gradient of the graph of voltage against current.

In a **directly proportional** relationship, if Quantity *A* doubles, Quantity *B* doubles as well. The graph of this function goes through the origin.

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.

A function with a graph of this type is NOT directly proportional. If Quantity *A* doubles, Quantity *B* does not double.

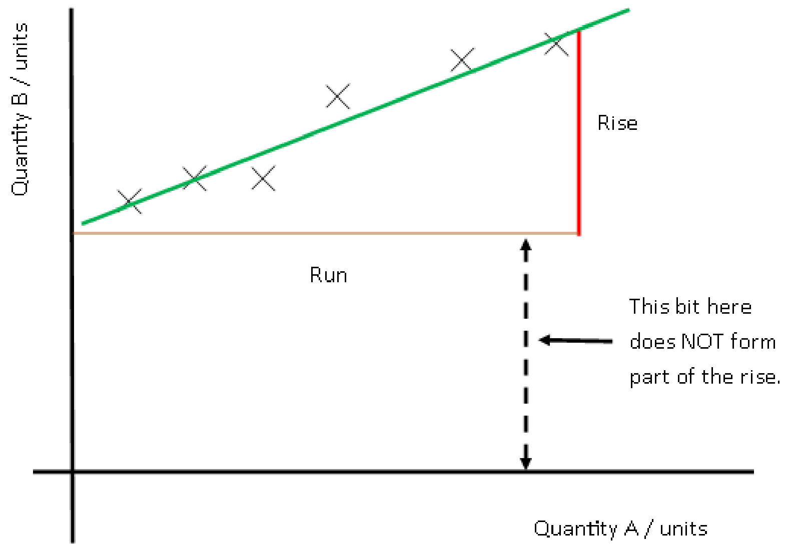


Figure 32 Finding the gradient from a linear graph that is NOT proportional

You must set the **run** line first from the lowest part of the line of best fit and draw it to the highest part of the line of best fit.

The **rise** is the distance from the run line to the line of best fit. See Figure 32.

The minimum side of the triangle must be 8 cm.

For other relationships, you may need to do some further **processing** to get the value that you want.

Consider this graph that shows the relationship between resistance and length of a resistance wire:

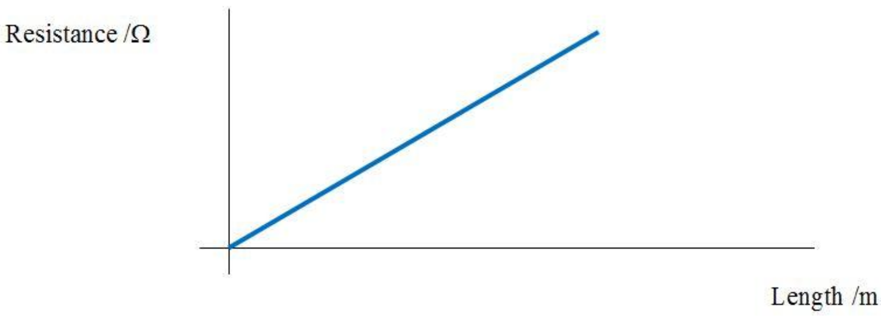


Figure 33 Graph of resistance against length

The formula for resistivity is:

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

R - resistance (Ω)

ρ - resistivity (Ω m).

l - length (m).

A - area (m^2).

You will meet resistivity when you do electricity. It's a property of the material the wire is made from.

The gradient does not in itself give you the resistivity; you have a little more to do.

To get the area, we would need to measure the wire with a **micrometer** which gives us the diameter. To work out area, we then need to use the formula:

$$A = \frac{\pi d^2}{4}$$

The value of the gradient will be ρ/A. To get the resistivity, you need to multiply the value you get by A. Hopefully it will correspond to the value given in a data book.

Sometimes a graph has a **negative** gradient. See Figure 34.

When you do electricity, you will learn how to find the **internal resistance** of a cell (battery). This is done by measuring the voltage of the battery in open circuit (the EMF), when no current is drawn. Then a variable resistor is connected, and a range of readings is taken at different resistances.

Voltages and currents are noted and (what a surprise) a graph is plotted. It looks like this:

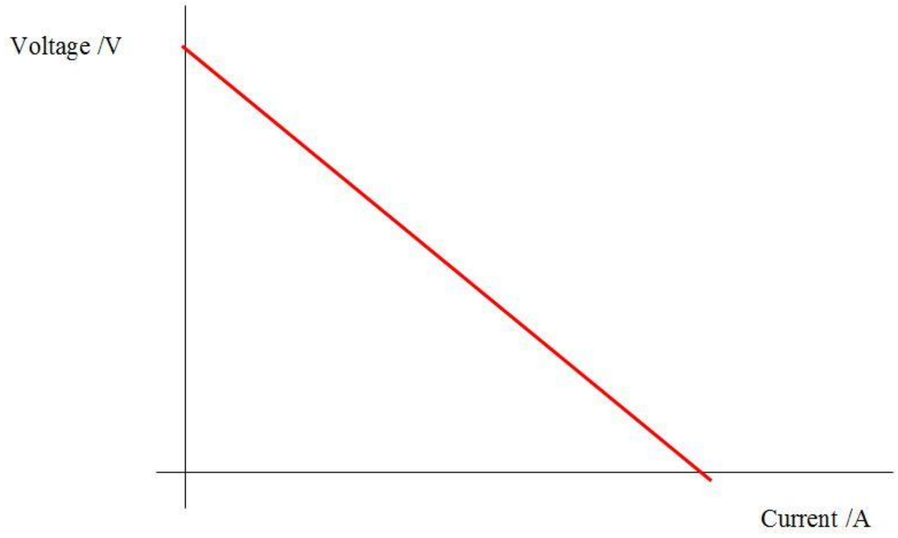


Figure 34 Graph with a negative gradient

The equation for this graph is:

$$V = \mathcal{E} - Ir$$

where:

V – voltage (V)

ε - EMF (V)

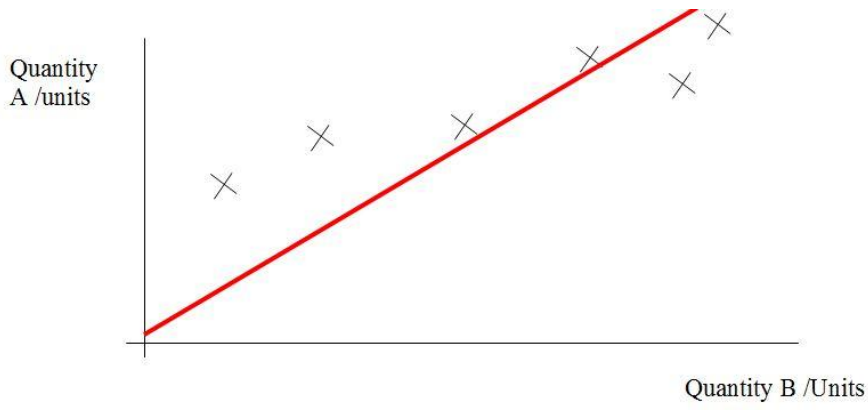
I – current (A)

r – internal resistance (Ω)

1.06 Questions

1.06.1

A student draws a graph like as below and joins the points with a "line of best fit" as shown.



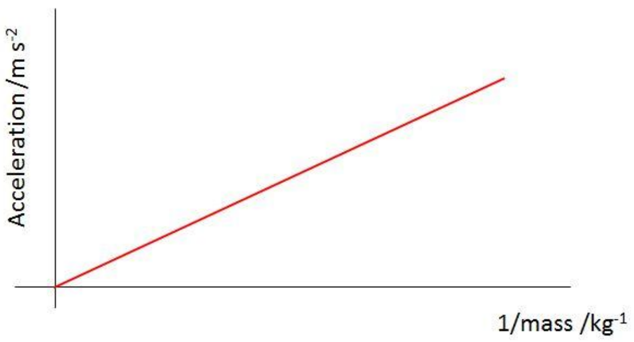
(a) The title of the graph is ____________________ against ________________.

(b) What is wrong with this line of best fit?

(c) Draw the correct line of best fit.

(d) In the exam, he writes that *Quantity A is directly proportional to Quantity B*. Discuss how you would mark his answer.

1.06.2



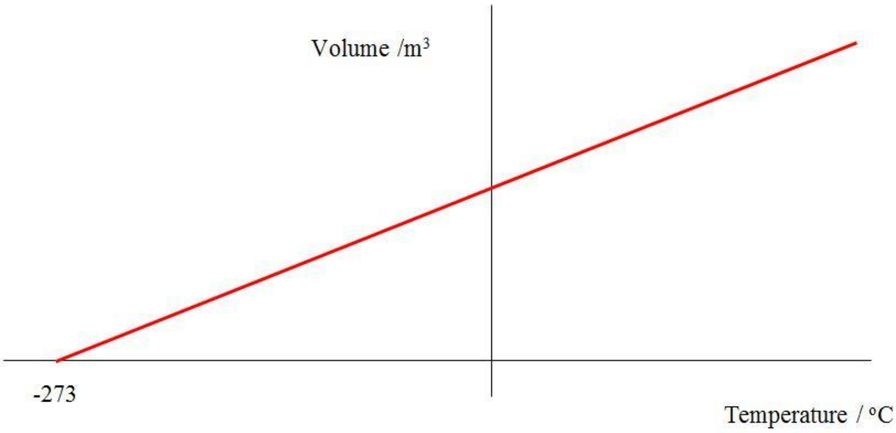
Explain how this graph shows that acceleration is directly proportional to 1/mass.

1.06.3

We could plot a graph of power against current^2.

What would the graph look like? What units would you put in for current^2?

1.06.4



Use $y = mx + c$ to give a general relationship for the x-axis intercept.

1.06.5

Reactance is a kind of resistance found in electrical circuits that use alternating currents. Use the data below to plot a graph of Reactance against Frequency. Remember the rules!

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

a) What is the value of the reactance at a frequency of 4200 Hz?
b) What frequency gives a value of reactance of 700 ohms?

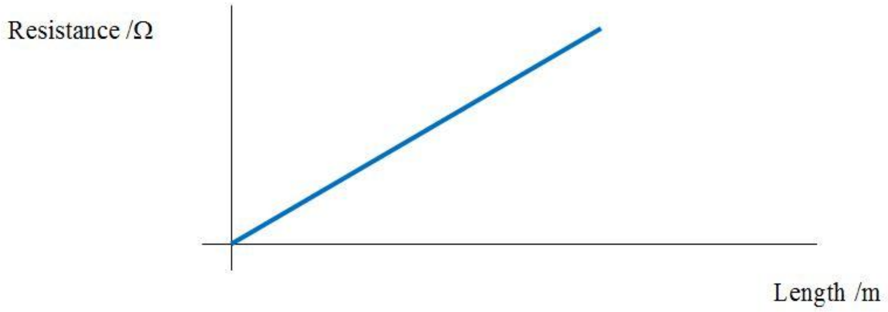
1.06.6

Work out the gradient of your graph in question 5. Show on your graph how you got the gradient.

Write down the units you think the value of gradient should have.

1.06.7

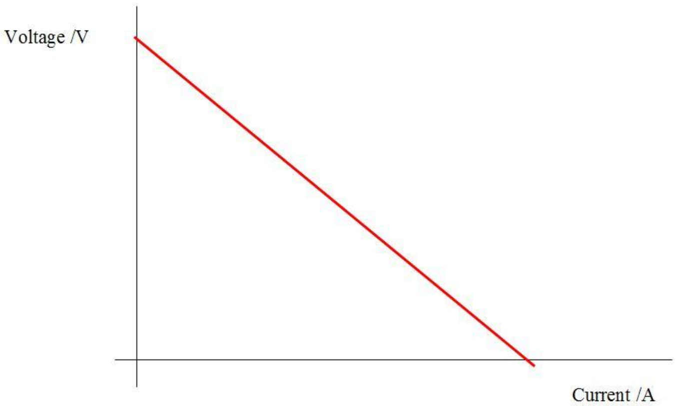
This is the graph of resistance against length of a wire.



How would you work out the resistivity from the graph of resistance against length?

1.06.8

This graph shows the results of an experiment to show internal resistance of a cell.



(a) Match up the symbols with $y = mx + c$.
(b) What does the y-axis intercept represent?
(c) What does the x-axis intercept represent?
(d) How would you find the internal resistance?

Tutorial 1.07 Further Graphical Skills

All syllabi

Contents

1.071 Curved Graphs

Not all graphs are a straight line, as in the following example. When the progression is clearly curved, do not force a straight line through the points.

The graph below is a curve:

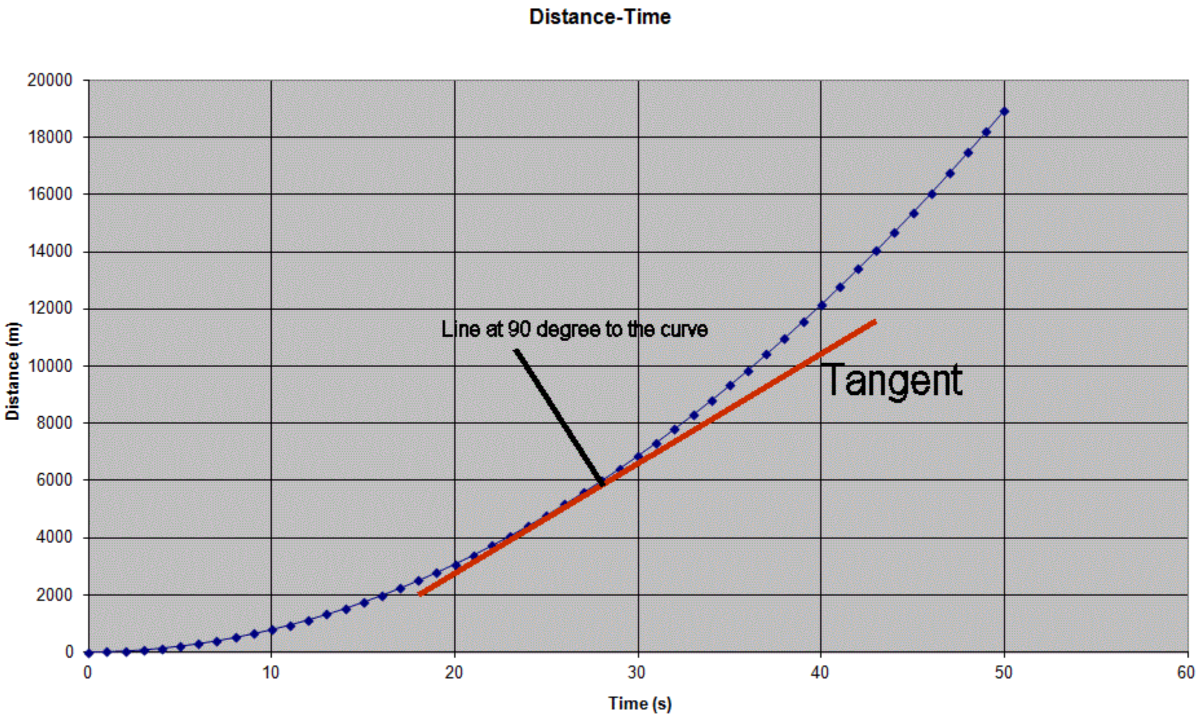


Figure 35 A curved graph

The gradient is worked out by taking a **tangent** to the curve. You need to make a line perpendicular to the curve at the point you are interested in. Then you draw a line at 90 degrees to that line, which will give you the tangent. You work out the **gradient** of the **tangent** using the **rise** and **run** in the normal way. Your triangle is at least 8 cm in its shortest dimension (of course).

The tangent gives us the **instantaneous rate of change** at that point.

Consider a speed-time graph of a car accelerating:

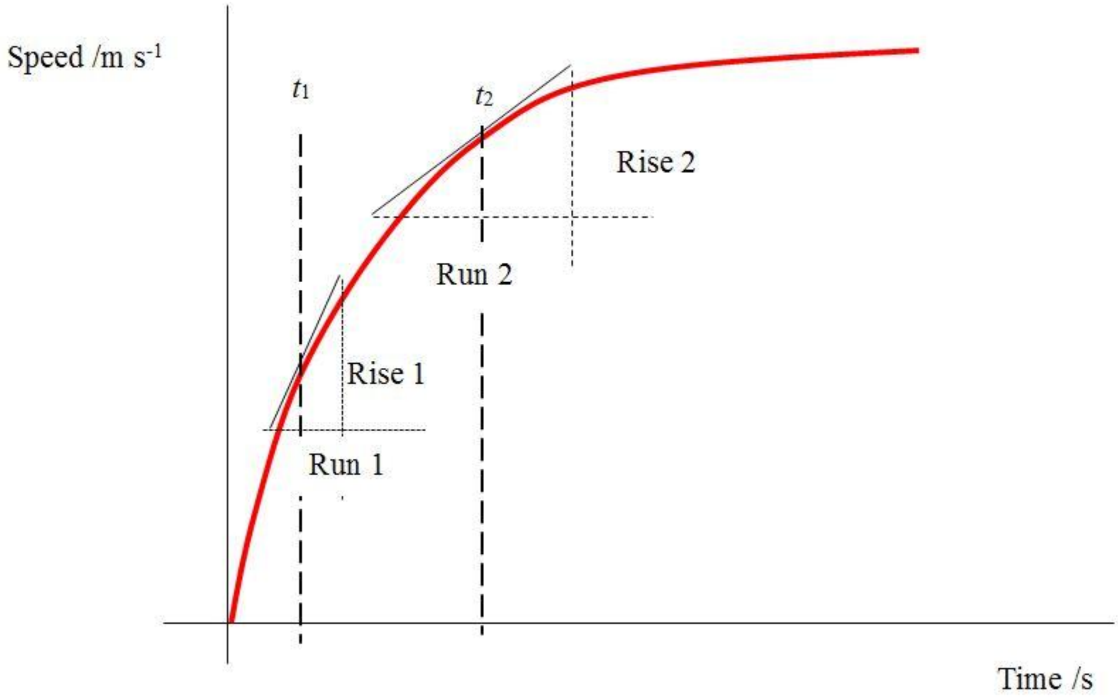


Figure 36 Speed-time graph of a car accelerating

In this graph you can see that two tangents have been drawn to work out the accelerations at times t_1 and t_2.

The gradient of a curved graph is changing all the time.

So do not do this:

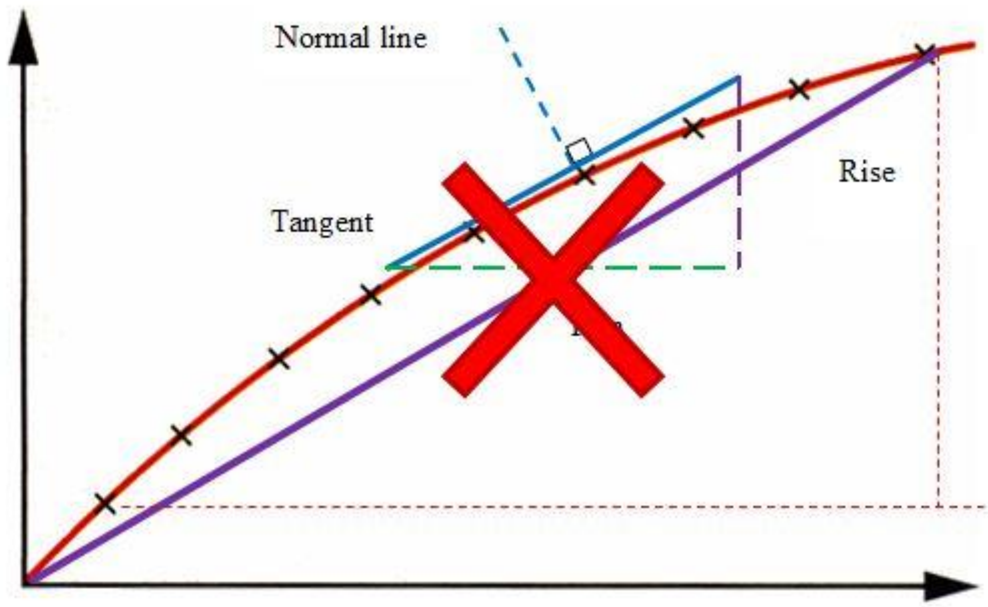


Figure 37 How NOT to find the gradient of a curved graph.

When calculating quantities that are represented by the gradient, it is important to use the graph, not just the values at a given point. These will give you the **average** gradient, which is not the same as the **instantaneous** value of the gradient.

The graph below shows the difference between the **instantaneous** gradient and the **average** gradient.

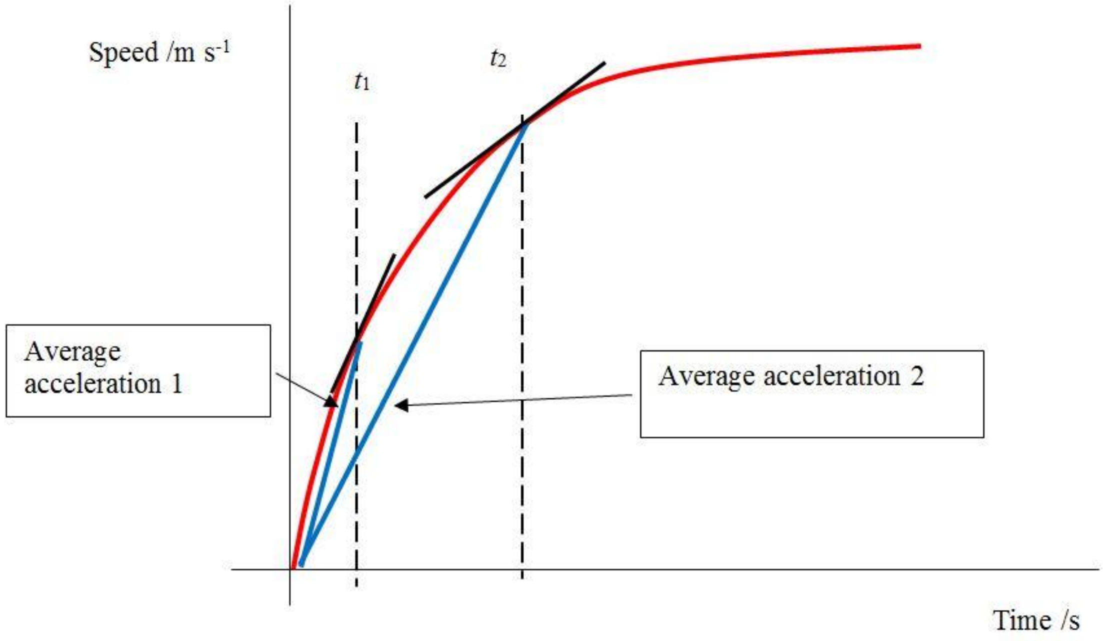


Figure 38 Difference between instantaneous and average accelerations.

1.072 Finding the area under the graph

At GCSE, you will have been asked to work out the distance travelled from the speed time graph. You did this by finding **the area under the graph**. To get the units for the area, you multiply the **units for Quantity 1** by the **units for Quantity 2**.

If the graph is a simple shape like a straight line, finding the area is really simple; you find the area of the triangle:

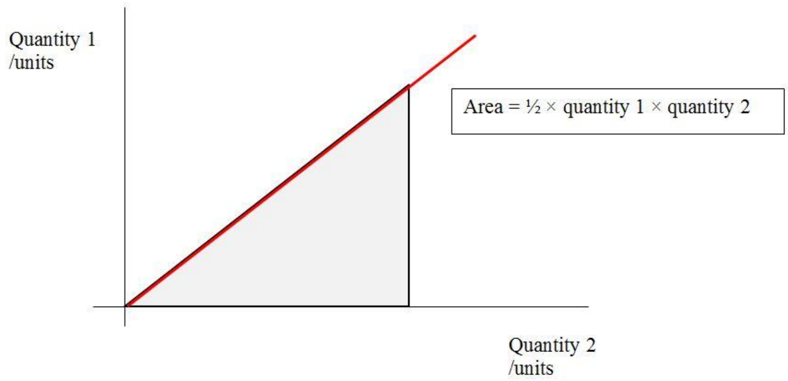


Figure 39 Finding the area under a straight-line graph from the origin

An example of this is the energy stored by a spring:

$$E = \frac{1}{2}Fe$$

E – Energy (J)
F – Force (N)
e – extension (m)

You may have come across this while doing Hooke's Law.

If the graph consists of simple shapes, you can find the area by working out the area of each shape and adding them (Figure 40).

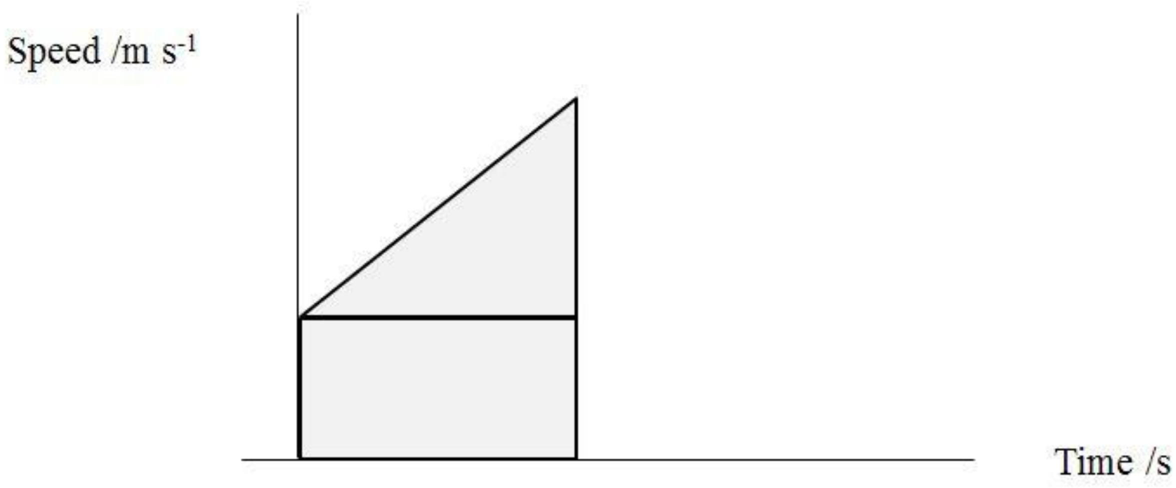
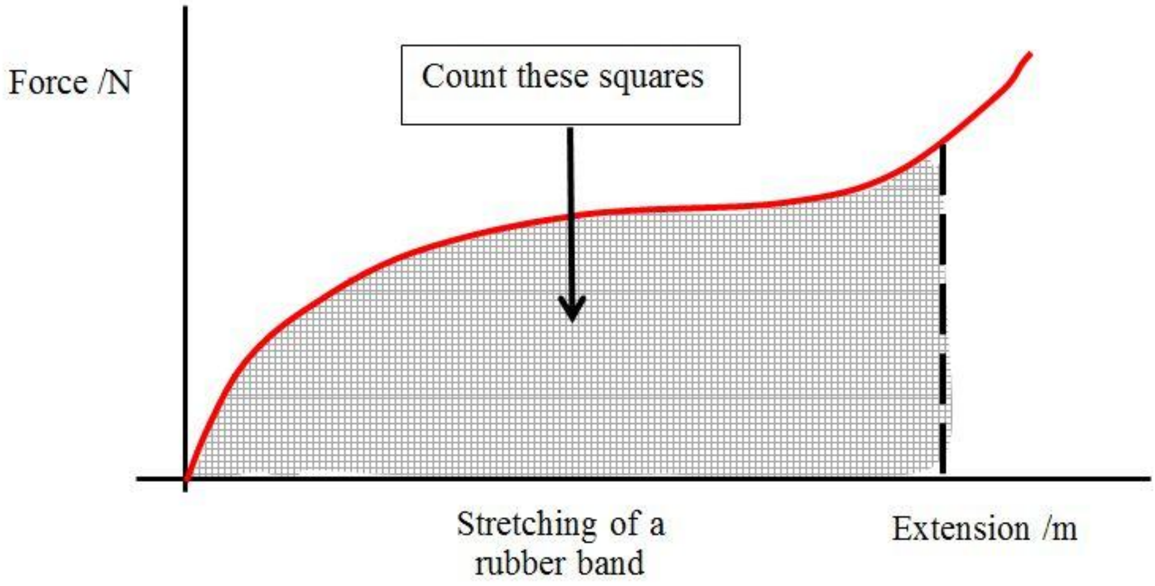


Figure 40 Working out the area of a linear graph that does not go through the origin

To find the distance travelled, you find the area of the rectangle and the area of the triangle and add them together.

Sometimes the graph is a more complex shape. If the graph has a known function for example $y = x^2$, then the **calculus** procedure of **integration** can be used. This is widely used by mathematicians but is not expected for Physics A-level. (It is for Scottish Advanced Highers.) You will need to be able to do calculus at university level.

If the graph is a weird shape, then the area under the graph is worked out by **counting the squares** of the graph paper. This can only give an approximation.



But there are a couple of rules to make sure that the approximation is not too far out:

- If the area fills more than half the square, count it in
- If the area fills less than half the square, ignore it.

1.073 Representing Uncertainty in a Graph

Uncertainty can be represented graphically using **error bars**. They help you to decide how your line of best fit will go and reduce the guess-work that can happen when you are trying to decide a **line of best fit**. This is especially true if the data are scattered about.

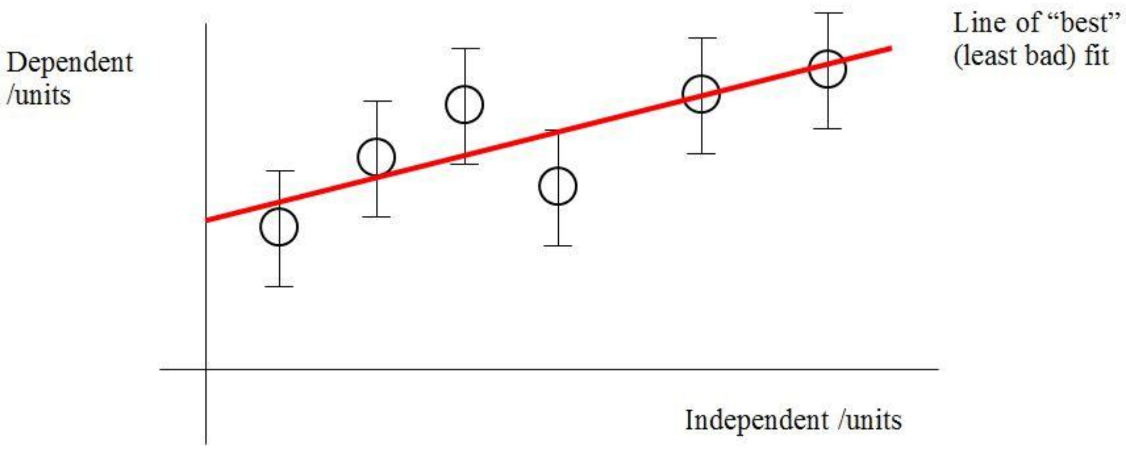


Figure 41 Error bars

If your line of best fit goes within the error bars, it means that the answer lies within experimental uncertainty and can be considered to be reliable.

Unless the uncertainty is so small that error bars cannot be seen, we should always use error bars for **both** axes. This graph shows the error bars for both axes:

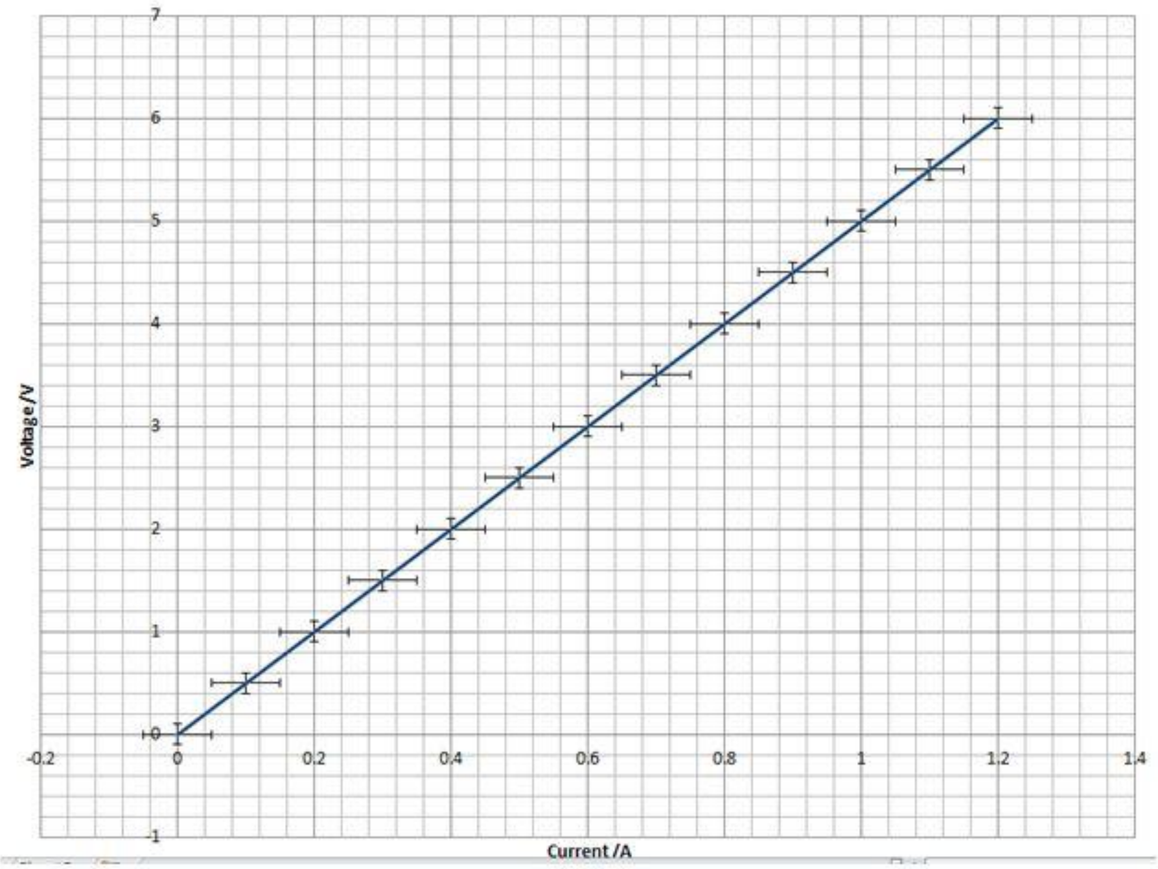


Figure 42 Showing error bars for both axes

The vertical bars are smaller. Since the horizontal scale has larger steps, the error bars are longer. In Physics at A-level, **absolute** uncertainties are used when error bars are shown. More sophisticated statistical methods are used with research.

The **lines of worst fit** are like this:

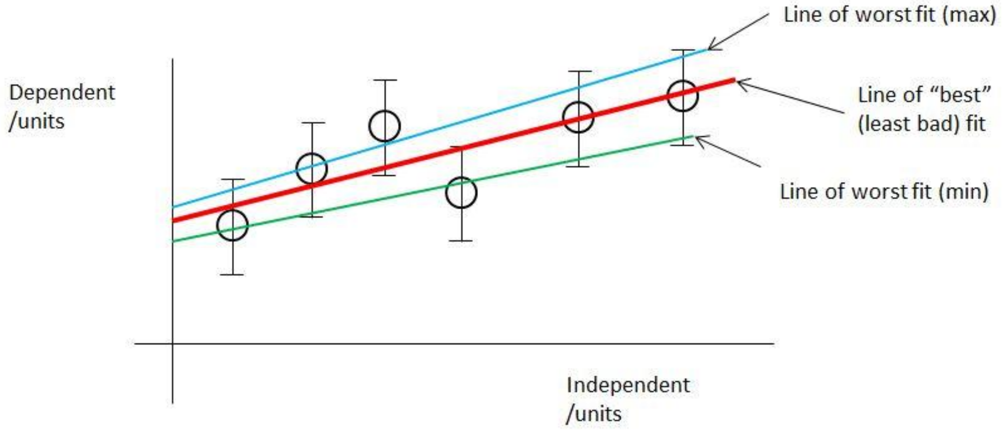


Figure 43 Lines of worst fit

If we did percentage error bars, we would get a pattern like this:

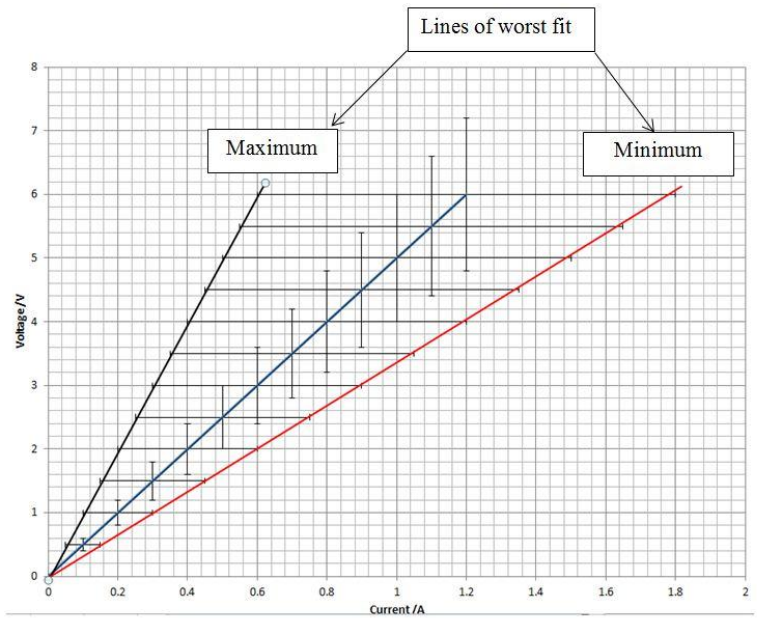


Figure 44 What happens if we use percentage error bars

You can see the way that the uncertainty for each value gets bigger. Therefore, we can see the different slopes it is possible to get.

- The line of best fit gives a gradient of 5.0 V A^{-1} (or Ω).
- The maximum value is 10 V A^{-1}.
- The minimum value is 3.3 V A^{-1}.
- The difference is 6.7 V A^{-1}.

This range is very large. Therefore, the uncertainty in the answer is so large that it is almost meaningless.

1.074 Using Absolute Errors to Measure Uncertainty

Consider an object that is moving at constant speed. The uncertainty in the timing is 0.3 s and the uncertainty in the measurement of distance is 0.1 m. Here are the data.

Time /s	Distance /m
0	0
1	0.4
2	0.8
3	1.2
4	1.6
5	2
6	2.4
7	2.8
8	3.2
9	3.6
10	4

Since the speed is constant, it doesn't take a genius to see that the speed is 0.4 m s^{-1}. You can plot these data as a linear graph (question 1.07.7). Note that the **origin does not have any uncertainty**. The lines of best fit and worst fit still pass through the origin.

Notice that we have used more significant figures than is appropriate.

In Physics at A-level, **absolute uncertainties** are used when error bars are shown. More sophisticated statistical methods are used with research.

In your practical work, you need to get into the habit of drawing error bars as a matter of routine.

1.075 Finding the uncertainty from a gradient

We have now worked out the gradient from our line of best fit and got an answer. But what is the uncertainty? A natural way would be to add the percentage uncertainty from the terms that make up the gradient. However, it is not done like this.

Instead, we draw a line of **worst** fit.

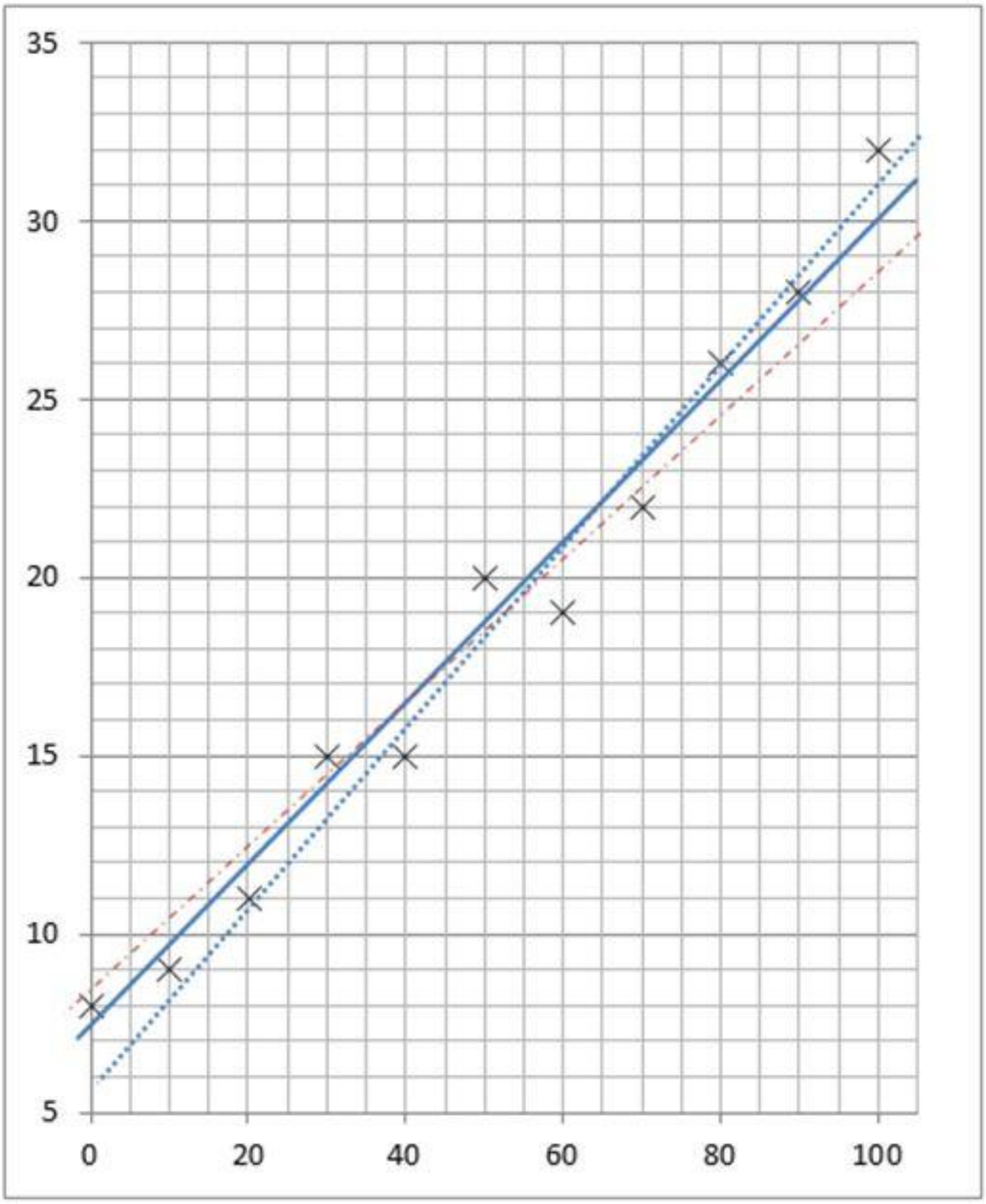


Figure 45 Lines of best and worst fit

This could be the steepest gradient, or the shallowest gradient. The percentage uncertainty is given by the relationship:

$$\textbf{Uncertainty} = \frac{\textbf{best gradient} - \textbf{worst gradient}}{\textbf{best gradient}} \times \textbf{100 \%}$$

If we have an intercept, its uncertainty can be found in a similar way:

$$\textbf{Uncertainty} = \frac{\textbf{best intercept} - \textbf{worst intercept}}{\textbf{best intercept}} \times \textbf{100 \%}$$

The uncertainty of the gradient is not worked out by adding the percentage uncertainty in the rise and the run.

Remember that the origin has no uncertainty.

1.07.1

These data show the power dissipated by a resistor as voltage increases:

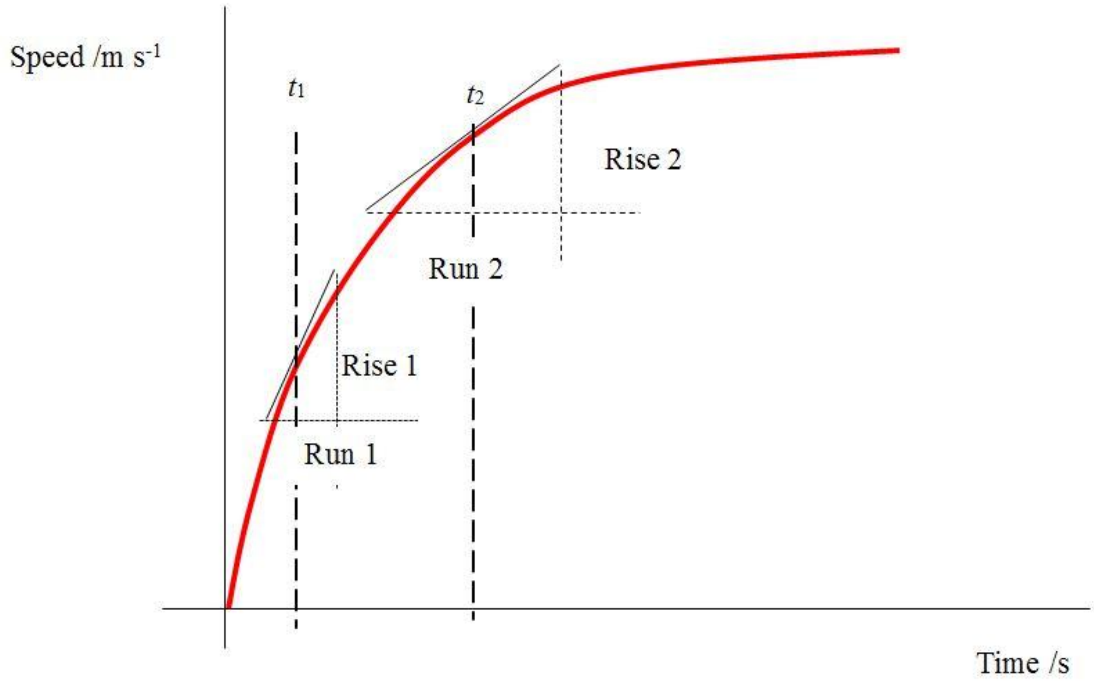
Voltage (V)	***Power (W)***
0	0
2.5	2.0
5.0	4.1
7.5	18.4
10.0	31.8
12.5	52.1
15.0	72.6
17.5	100
20.0	128

(a) Plot these data and join the points with a line of best fit. Note that there is an anomalous result.

(b) Which is the anomalous result? What would you do to avoid anomalous results?

1.07.2

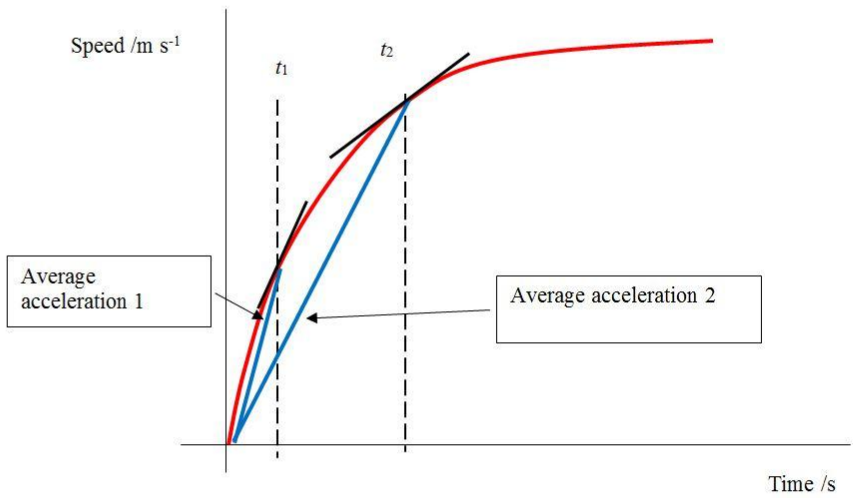
This is a speed time graph of an accelerating car (see Figure 36).



Use your graph to state what is happening to the acceleration of the car at times t_1 and t_2.

1.07.3

Look at this graph (See also Figure 38).



Compare the average accelerations shown in the graph above with the true accelerations shown by the tangents.

1.07.4

For a graph showing the energy in a spring obeying Hooke's Law, where:

$$E = \frac{1}{2}Fe$$

(a) What are the axes that would be plotted on the graph?

(b) What would the units be?

1.07.5 and 1.07.6

Let's suppose that we are doing a voltage-current measurement. The voltage range is from 0.5 V to 6.0 V. The precision of the voltmeter is ± 0.1 V. The current range is 0.10 A to 1.2 A with a precision in the ammeter of ± 0.05 A.

1.07.5

Calculate the percentage uncertainty for the voltage and the current, using the smallest value for each.

1.07.6

Comment on the quality of the instruments that have provided these data.

1.07.7

Time /s	Distance /m
0	0
1	0.4
2	0.8
3	1.2
4	1.6
5	2
6	2.4
7	2.8
8	3.2
9	3.6
10	4

Plot these data on a graph. Time on the horizontal axis, distance on the vertical axis.

Draw the line of best fit.

Include the error bars on both axes.

1.07.8

Now add the lines of worst fit to your graph.

1.07.9

Work out the gradients of the lines of worst fit.

Tutorial 1.08 Presentation	
All syllabi	
Contents	
Presentation	Presentation of Written Work
Calculations	Exam Words
Why do Practical Work?	Key Practical Skills in Physics
Practical Assessment for AQA	Writing Reports
Further Experimentation	

1.081 Presentation

Physics is a technical subject in which you are communicating your knowledge to others. In your career, whatever you do, you will need to communicate in such a way that people understand. There is no point in having the solution to a big problem unless you can tell others about it, in a way that others can understand.

As a teenager, I studied Thomas Hardy for English Literature. His Victorian writing style was impenetrable to my immature fifteen-year-old mind. Forty-five years later, I tried reading *The Woodlanders* again. It was just as impenetrable and really got in the way of what should have been a good story. Sorry, Mr B. I did try. What I did get out of it was the picture of squalid little thatched cottages in Dorset, which are nowadays no longer the homes of agricultural or forestry workers. Now they appear on *Escape to the Country* with large sports utility vehicles outside them. Everything is tiny and twee, except the prices which are many hundreds of thousands of pounds.

This tutorial should give you some ideas about how you should present your work in a way that will help you to achieve your potential. Good communication skills are vital not only in Physics, but also to sell yourself at interview.

Key points:

- Keep the language simple. This means short sentences. You are not writing for a literary prize.
- Keep your paragraphs short.
- Use good English, including spelling, punctuation, and grammar.

We will look at the various aspects of communication in Physics.

1.082 Presentation of Written Work

Communication

In the exam, there will be at least one question which asks you to give an account of a **phenomenon** (something that happens) in Physics. In this, they will assess your written English, as well as the content of your account. Whatever the career that you chose, the skill of writing good English is essential. The standard of written English in many answers is not good. While some people may dismiss the need for good English and clear presentation as elitist, the exam boards do not. Nor do employers. Follow this advice, and you will keep your written English clear:

- Keep your sentences simple. Do not write lots of sub-clauses, as the sentence will get complicated. Remember that you are not out to get a literary prize.
- Watch out for common errors. See below.
- Sentences always end with a full stop. They never end with a comma. Keep the punctuation simple and you will not go far wrong.
- If you can't spell a word, look it up in a **dictionary**.
- Never use text-messaging or phrases such as *24/7*.

Some common grammatical confusions are:

- *It's* (it is) and *its* (of it).
- *There* (in that place), *their* (of them), and *they're* (they are).
- *It could have,* NOT *It could of*.

- Misuse of the apostrophe. *Resistor's* means *of a resistor*; *resistors* is the plural of resistor.
- *Advice* is what you get from your tutor who *advises* you.
- *Practice* makes perfect. You get good by *practising* the problems.
- Data is a **plural** word, e.g. *These data show*, NOT *this data shows*.

A badly word-processed document looks awful. Plurals always end in 's' without an apostrophe. There are spell checkers to check your spelling. Make sure that it's set to UK English.

Never use text-messaging. The latter is fine for a mobile telephone, when messages were charged by the character. It has no place in technical English (or any other language).

This may sound a bit rich from my English teacher's worst pupil. My written English is not perfect, but I try to write well. So should you.

I have written "English" here, as most of my readers use the English Language. If, for example, you are doing your Physics course in German, your German needs to be well written (or any other language, for that matter). I have had students whose native language is not English. What I have noticed is that often their spelling, punctuation, and grammar is better than that of native speakers, although occasionally the structure of the English reflects that of their native language. The same would apply to English speakers doing their studies in another language.

In universities, reports are expected to be **gender neutral**. However, this can give rise to inconsistent constructions like:

"*The student wrote their results in a table*". The singular is mixed with a plural here.

Perhaps a better way to write the sentence:

"*The students wrote their results in a table*" or even "*The student wrote its results in a table*".

The impersonal pronoun ("*one*") in English is not very good and can sound stilted and pompous. Impersonal pronouns in German ("*man*") and French ("*on*") tend to work better in those languages.

Alternatively reports can be written in the **passive voice** ("*The results were written in a table*".). At university reports are expected to be written in the **passive** voice.

If you are keen on writing really good English, you can always read *Strictly English* by Simon Heffer.

1.083 Calculations

Calculations need to be set out logically; otherwise, it is easy to get lost. Follow this advice and you will not go far wrong:

- Write the equation appropriate to the problem.
- Make a shopping list of the quantities and their units.
- Keep each step separate.
- Write the number to the **least number** of significant figures. If one data item has 2 significant figures, while others have 3, then you answer to 2 significant figures.
- Include the units for the answer.
- Consider whether a value is appropriate. An acceleration of 3.5 m s^{-2} is right for a car. 3500 m s^{-2} is not.

Avoid writing stuff that is not mathematically correct, e.g.

s = ((20 + 30) × 10) ÷ 2 = 250 ÷ 10 = 25. This is nonsense.

Write it as:

$$s = ((20 + 30) \times 10) \div 2 = 250 \text{ m}$$

$$v = 250 \div 10 = 25 \text{ m s}^{-1}.$$

1.084 Tips for Calculations

1. Write down a formula or equation using standard symbols if possible.

$$s = ut + \tfrac{1}{2}at^2$$

2. You may wish to write a "shopping list" for the quantities in the formula/equation but this gets **no marks**.

- s = 4.5m
- u = 0
- v = (not needed)
- a = ?
- t = 0.90s

3. Substitute values into the formula/equation **without rearranging first** (unless you know you won't make daft mistakes).

$$4.5 = 0 + \tfrac{1}{2}a \times 0.90^2$$

4. Rearrange and calculate your final answer.

$$4.5 = 0.405a$$

$$a = \frac{4.5}{0.405}$$

5. Write the answer using sensible **significant figures** and, if necessary, standard form. Add the proper **units**.

Check that you have answered what the question actually asked for. This may sound obvious, but many students give an excellent answer to a different question!

If you have done all this underline your answer:

$\underline{a = 11.1 \text{ m s}^{-2}}$

1.085 Exam Words

You need to understand the special meaning of the following words in exams:

- **Calculate** Work out a numerical answer, showing the steps in your working.
- **Define** Write down a "textbook-type" statement explaining the word or symbol. You can sometimes get the marks if you write a defining equation **provided you explain each symbol used.**
- **Describe** Simple list of the steps you would carry out in, say, an experiment. (Use numbered steps and short sentences.) A labelled diagram would also be expected.
- **Evaluate** Work out the mathematical value of an equation for example. Assess the evidence/results from an experiment.
- **Explain** Write down a brief statement of the meaning of the concept or words. You can sometimes get the marks for an answer using standard symbols perhaps in an equation.
- **Prove/derive** Use algebra to obtain a given equation. (All proofs required are stated clearly in the notes or course syllabus.
- **Ratio** When asked to find the ratio of **a** to **b** you have to calculate the answer to the fraction *a/b* as a number.
- **Show that** Use maths to calculate a value that has been given to you.
    - (Remember that you can use the given value in the next bit of the question anyway.)
    - Use algebra to prove/derive an equation/formula.
- **Sketch** Draw, without graph paper the general shape of a graph. Label the axes and mark any special values or show the ranges. Include the origin unless you have a good reason not to do so.
- **State** Write down a name, phrase, numerical value or equation without any explanation.
- **Suggest** Give your ideas about a new problem or situation based on physics you already know. (Often asked at the end of a practical question.)

1.086 Why do Practical Work?

In many schools, students' experience of practical work is limited. Perhaps this is why:

Figure 46 Chaos Theory in a school laboratory

For most physicists, experimental work is as important as theoretical work. There were exceptions of course. Ernest Rutherford was a brilliant experimenter, but not very good at maths. Werner Heisenberg was a brilliant theoretical physicist but was hopeless at even the most elementary practical work.

Practical work:

- Illustrates many of the concepts met in the theory.
- Gives you practice at making measurements.
- Gives you practice at recording and presenting your data.
- Gets you to think about how your results fit in with the theory.
- Helps you to take responsibility for your own learning.
- Improves your skills at using equipment.
- Helps you to work with others.
- Gets your backside off an uncomfortable stool.

All of these give evidence for employability skills as well.

Physics experiments have a reputation for not working properly and being rather difficult to interpret as a result. This need not be the case, if you do the following:

- Read the instructions carefully.
- Do exactly what you are asked to do, no more, no less.
- Record data to an appropriate precision.
- Plot them on a graph.
- Think about your data to assess whether they are reliable.
- Discuss the physics behind the experiment.

1.087 Key Practical Skills in Physics

There are certain skills that you will learn as you do your practical work. You have probably done them anyway without thinking about putting a name to them. But here they are anyway.

Follow instructions and Work with others

- A **standard** procedure might be to set up a circuit to measure voltage and current in a circuit.
- A **complex** procedure would require a number of steps to set up the apparatus. An example of this may be to measure the energy supplied by a heater and measurement of temperature of water, possibly with a data-logger.
- Working with others means just that.

Some students find it hard to work with others. However, it is essential to do so, both at university and in employment.

This is NOT working with others:

- Chattering about Nick's new girlfriend (or Samantha's boyfriend), how various teams got on in last night's footy, etc.
- Sharing a personal stereo.
- Testing each other on the Highway Code.
- Watching someone else do the work.

Nor is this:

Figure 47 Study in indolence

This study in indolence, taken from my car, was observed a few years ago on the A6 in Cumbria.

This IS working with others:

• It means that each student takes responsibility for getting part of the experiment set up and data recorded.

• You need to work co-operatively so that the task gets done quickly, and effectively.

• While it's most comfortable to do it with friends, you may find yourself having to work with someone you might not necessarily get on with socially. Tough.

• Groups that get right idea about working together get the work done quickly and effectively.

Select and Use Equipment

This skill area concerns the choice and use of equipment for a procedure.

At AS level, you use standard laboratory equipment such as a digital multimeter and select the appropriate range.

In this picture, the 600 volt AC range has been chosen. You can see that there are a lot of other ranges that can be chosen.

Needless to say, the equipment has to be used correctly, safely, and appropriately.

Figure 48 Using a multimeter on the correct range

Organisation and Safety

Parkinson's Law, coined by Cyril Northcote Parkinson (1909 – 1993), tells us that:

Work expands so as to fill the time available for its completion.

In other words, a lot of time can be wasted. And this happens frequently in practical work. One person (if that) does the work, while others watch.

Here are some guidelines for effective organisation:

- Read the instructions carefully.
- Set tasks for each member of the group.
- Set up the apparatus exactly as shown.
- Prepare a table for the results, including repeats.
- Make sure that each member of the group does one of the sets of results.
- Swap roles.
- **All students must have their own copies of the results.**

Safety of all students must be the first priority. There is no observation that is so important that students are put at risk to obtain it. The risks in a school or college physics laboratory are very low, but students still have a responsibility to look after their own safety and that of others.

Risks in physics experiments include:

- Breakages of glassware - the most common risk.
- Burns from heaters or resistive elements - these can be painful.
- Falling weights - drop a 1 kg mass on your foot and you will know about it.
- High voltages - a shock can kill.
- Implosion of vacuum tubes - shards of glass could end up in your face.

Safety should always be considered before carrying out any experiment.

If equipment is faulty, it must be reported to the teacher. It should go without saying that no action should be taken to compromise safety by abusing equipment or doing unauthorised experiments.

You should get into the habit of making your own **risk assessment**, even though your teacher will have carried out a risk assessment previously. In this, you should consider:

- Is the equipment in good condition?
- What would happen if the wrong ranges were used?
- What happens if too big a voltage was used?
- How can you stop something heavy falling off the bench?
- What damage could be done if the equipment failed?
- Any shout of "ouch!" means that you are not working safely.

It is also worth remembering that laboratory equipment is **very expensive**. And you could end up being billed for it...

1.088 Practical Assessment for A-level Physics (AQA)

For the new linear A-level syllabus, you will have to hand in a **portfolio** (file) of your laboratory work when you reach the end of the second year of A-level. There is no such requirement to pass AS level. In your centre, the policy may be that you will have to pass AS level to progress to A-level. Therefore, you will be expected to maintain the practical skills portfolio during the AS year and do the first year set practicals. There will be examination questions that are based on data analysis that involve the set practicals. They may well cover material from other experimental work.

The six set experiments for **AS** are:

Experiment	***Activity***
1	Variation of the frequency of stationary waves in a string depending on length, tension and mass per unit length of the string.
2	Interference effects – Young's slit and diffraction grating.
3	g by free-fall.
4	Determination of Young's modulus.
5	Determination of the resistivity of a wire.
6	Investigation of the e.m.f. of a cell.

The six set experiments for **A-level** are:

Experiment	***Activity***
7	Investigation into the simple harmonic motion of a mass on a spring and a simple pendulum.
8	Investigation of Boyle's and Charles' Law.
9	Investigation of the discharge of a capacitor, including log-lin analysis to determine the RC time constant.
10	Use a top pan balance as a force-meter to show how the force on a wire varies with the current and flux density.
11	Use a search coil and oscilloscope to investigate the relationship between angle and flux linkage.
12	Investigate the inverse square law for gamma radiation

If your centre does the two-year linear syllabus without doing AS level, you may find that you do these set practicals in a different order. It depends how your tutors organise their scheme of work.

This is NOT the only practical work you will be doing. Practical work is an important part of your classwork and will form much of your class-work mark (depending on the policies in your Physics Department).

Note that other syllabuses have different arrangements. Your tutor will advise you.

1.089 Writing Reports

In your portfolio, you will need to write reports in the traditional way. The idea of this is to:

- Get you to write reports in a professional manner, just like the experts.
- Give you a simple structure to use.
- Make you think about what you have done.

There are frequent questions in the examinations on practical techniques, so if you can remember them, you are at a strong advantage.

You should aim to enable your reader to follow your instructions and get the same results that you did.

Introduction

You should give a brief explanation of what you are setting out to do, and how it links in with the theory. For example, if you were finding the resistivity of a piece of wire, you would explain that the gradient of the graph can be found from the formula:

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

Therefore, the gradient of a graph of resistance against length is $\rho \div A$, so resistivity can be worked out by multiplying the gradient by A.

Apparatus

This needs to be a list of the equipment that you are going to use. You need to write not only the list, but also the **ranges**. If you were going to measure 6 volts, you will need to state that you were using the **20-volt range** on the multimeter. You should also state the precisions, e.g. +/- 0.1 V.

Diagram

You do not have to be a good artist to draw a good diagram. Diagrams should show the reader **how the equipment was put together**, so that the reader can assemble the equipment to do the experiment. This diagram is taken from a report done by an A-level student:

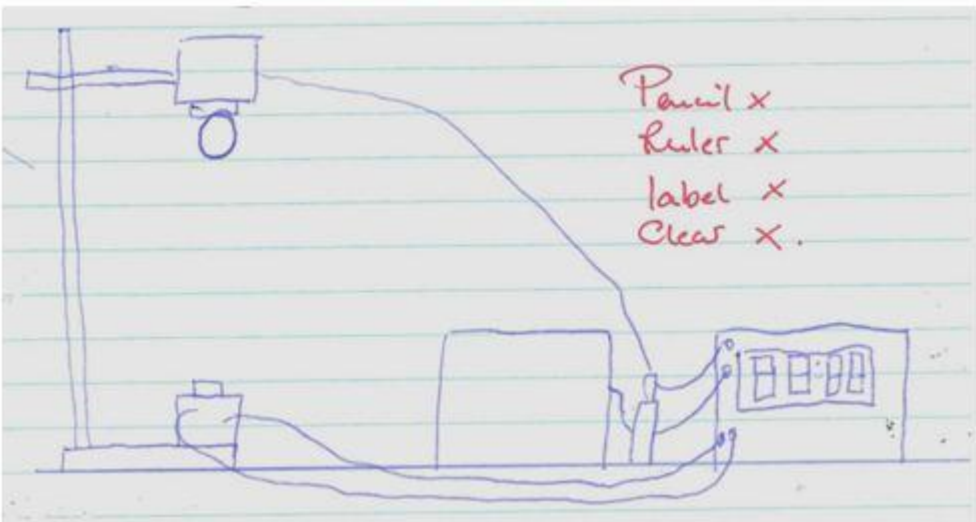


Figure 49 This diagram was submitted by an A-level student

It got zero marks

1. Diagrams should be done in pencil or drawing ink.
2. Use a ruler, please.
3. Make the diagram clear.
4. Label it.

Some students show pictures of each individual piece of apparatus, e.g. a stopwatch. This is meaningless.

If you are doing a word-processed report, you should learn to use graphics. An example of this is shown in Figure 50.

This diagram was made using MS Office graphics. I find that PowerPoint graphics are easier to use than those in Word. Many of my graphics on this site have been put together using PowerPoint. Also, Publisher is good.

If the diagram is complicated, make it large, so that the complex bits can be seen, as in the picture in Figure 50. Do not worry about colouring it in.

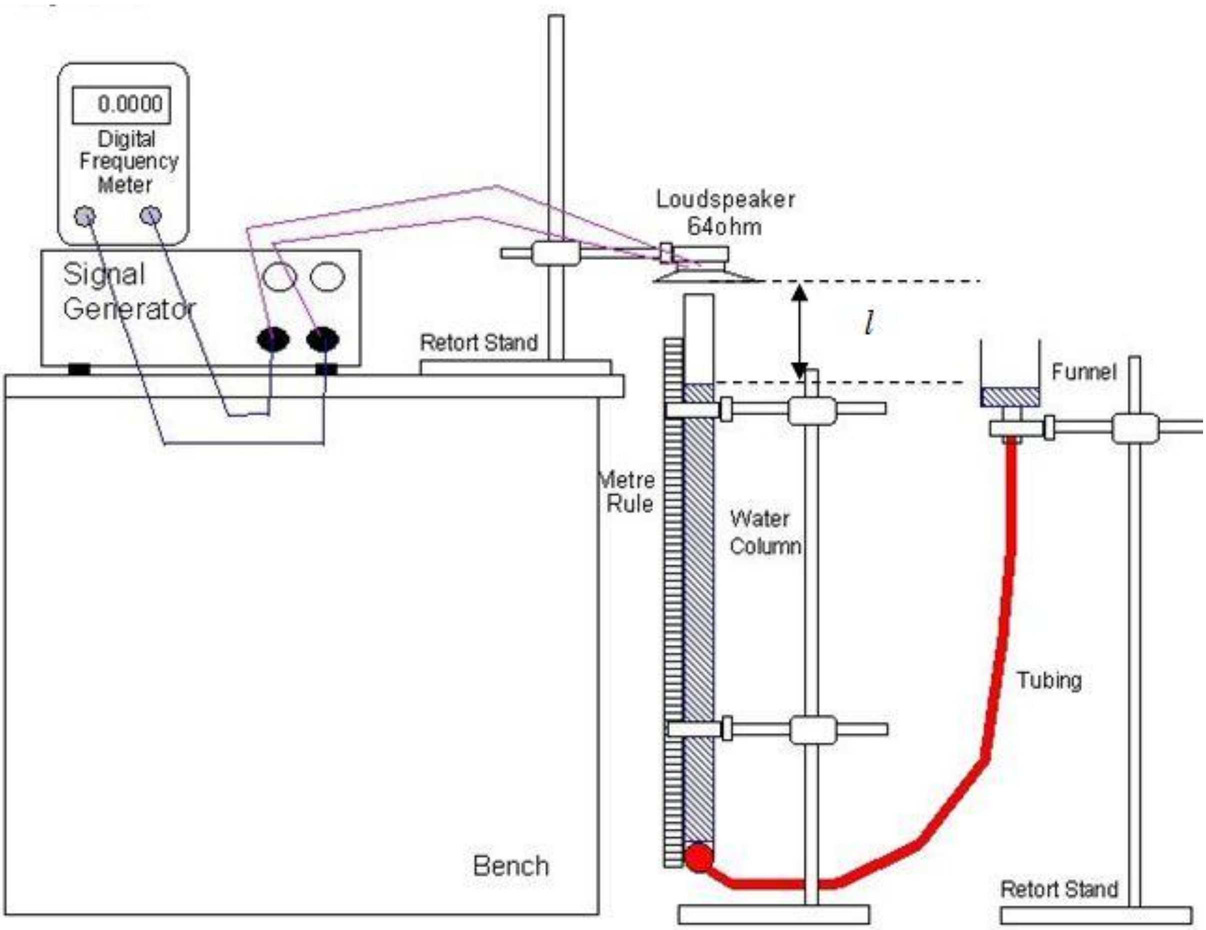


Figure 50 A experiment diagram drawn with graphics

Method

This should be a list of instructions so that the student who missed the lesson can do the experiment following your instructions and get a good set of results. The instructions don't have to be complicated, or a great piece of literature. The best method is a **set of instructions** in your own words, showing your own understanding. You should mention whether there were changes in the original set of instructions. For example, you may have used 4700-ohm resistors instead of 3300-ohm resistors.

It is important to use good English and clear presentation.

A mindless copy of a generic worksheet always got very few marks from me.

Results

You must produce a neat table of results boxed in. There is an example in Figure 51:

x/m	Time for 20 oscillations t_1/s	t_2/s	t_3/s	t_{mean}/s	Time period T/s	$\log_{10}(T/\mathrm{s})$	$\log_{10}(x/\mathrm{m})$
0.300	9.78	9.93	9.99	9.90	0.495	−0.305	−0.523
0.400	11.19	11.07	11.22	11.16	0.558	−0.253	−0.398
0.500	12.82	12.70	12.52	12.68	0.634	−0.198	−0.301
0.600	13.53	13.68	13.71	13.64	0.682	−0.166	−0.222
0.700	14.87	14.74	14.55	14.72	0.736	−0.133	−0.155
0.800	15.78	15.72	15.60	15·70	0·785	−0·105	−0·097
0.900	16.50	16.68	16.62	16·60	0·830	−0·081	−0·046

This one is lifted from a past Physics 6 paper. The student has filled in the data for the last couple of rows. It is here to show how a table is set out with data that have been collected (or **harvested**) and data that have been processed from the harvested data. It shows the way the headings should be set out.

Units are put into the column headings along with the quantity. Note that the quantity is separated from the units by a **solidus** (**/**).

The solidus indicates the **division** (÷) of a physical quantity by its unit, thus what follows is a **pure number.** For example, 'V/ mV = 340' literally means **340** is the value of ***V*** **divided by mV**. Using 'V/ mV 'as a table heading is logical and correct in a way that V (mV) is not. This may seem pedantic, but it's good practice.

Note also that physics codes in word-processed documents are written in Times New Roman font and in *italics*. The units are in normal font. You wouldn't get marked down for not doing this, but it's a good idea to get into the habit. If you are hand-writing the document, it doesn't matter.

There should be sufficient data points to get a straight line. 7 data points is reasonable.

The number of significant figures should represent the precision of the instrument. So, in this case, the ruler to measure x is to the nearest 1 mm, so it is reasonable to put down the data to three significant figures.

Graphical Skills

We have covered these in previous tutorials. Just to remind you:

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 2 on the horizontal axis.
5. Look for the highest value in each range. You calibrate (put numbers on) your axes to the nearest convenient step above your highest value.
6. Use a sensible scale.
7. Plot your points with crosses (+ or ×). Points get lost.
8. Join your points with a line, but not 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. A flexi-curve can help you with this.

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.

Analysis

At A-level you will be expected to carry out some kind of analysis of your data. This will become more searching and in depth as you become more experienced. The sort of things you will almost certainly be asked to do include:

- Determine a gradient.
- Determine the y-intercept or the x-intercept.
- Working out the area under the graph.
- Determining uncertainty.
- Assessing whether your data are reliable.
- Discussion of improvements you could make.

On the worksheet your tutor gives, there will be questions that will get you to discuss various aspects of your experiment. Answer these fully.

Conclusion

The conclusion is a summary paragraph that shows:

- What you have learned.
- How it ties in with the theory.
- Discussion how close any numerical answer is to what you would get in theory.

The table below shows how I would mark a practical report for my students. Your tutor may use something similar. To fit the table in, I have had to reduce the scaling a bit.

Section	Content	Marks	Total	Notes
Introduction	Context of practical	1	3	
	Summary of what will be done	1		
	Theory	1		
Apparatus	List of apparatus	1	3	List needs to be the apparatus actually used.
	With ranges	1		
	Precision stated	1		
Diagram	In pencil/drawing pen	1	4	Diagram needs to be produced by the student.
	With a ruler	1		
	Labels with leader lines	1		
	Clear	1		
Method	Method written in own words...	1	5	A copy of the work sheet will get zero marks. Slovenly work will be penalised.
	...with clear steps...	1		
	...in a logical order...	1		
	...in good English...	1		
	...and with good use of technical terms.	1		
Results	Minimum number of results	1	5	If repeats are not appropriate, marks will be adjusted.
	In a neat table	1		
	With headings and units	1		
	With repeats	1		
	Data recorded to appropriate precision	1		
Graphs	Large graph	1	8	Scales should be in steps of 1, 2, 5, or 10. Graphs to be drawn by hand.
	Axes labelled with quantity and units.	1		
	Sensible scales	1		
	Plot	2		
	Error bars	2		
	Line of best fit	1		

Gradient	Large triangle	1	4	Smallest side of the triangle should be at least 8 cm
	Rise and run values noted	1		
	Gradient calculated...	1		
	...with units.	1		
Analysis	Uncertainties identified...	Questions will be set to discuss these. Marks are variable.		
	...and quantified.			
	Limitations identified			
	Improvements suggested			
Conclusion	What has been learned.	Questions will be set to discuss these. Marks are variable.		
	How it links with the theory.			

The final total mark was always a multiple of 5 (e.g. 45 or 60). I didn't like marking out of a number like 56, but that was just me.

1.0810 Further Experimentation

A classic GCSE experiment is where you investigated the factors that affect resistance:

- Length.
- Area.
- The material.

Most likely you will have investigated resistance against length. You will do a similar experiment in the first year. This time you will find out the **resistivity** and compare the result with the data-book value.

In some exam papers, you may be asked a question on what further experiments could be carried out to investigate a problem. Do NOT write "take repeat readings" or "use more accurate equipment", or "use a data-logger". You will get no marks. The question is asking you to think about other factors to investigate, for example the relationship between area and resistance, or even diameter and resistance.

When you are asked about further experimentation, you need to discuss a **method**. It should use apparatus available in a school or college Physics lab. It should be a set of written instructions that another student could read and use to do the experiment. The best answers show what ranges to use for meters and possibly the specifications of the materials you are going to work with ("I will use constantan wire of 1.5 mm diameter").

For another example, you may have carried out an experiment on the half-life of a capacitor discharge through a resistor (which you will do in the second year). You may have plotted the exponential discharge graph for a start voltage of 6 V. You have found the half-life of the discharge. You may want to investigate whether doubling the voltage affects the half-life. So, you would say that you would use the same capacitor and resistor, but make the start voltage 12 V.

To **improve** an experiment, you need to address how you would reduce uncertainty to get data that are more reliable. For example, in one experiment that you will do in Year 2 (A-level year), you investigate the relationship between pressure and volume (Boyle's Law). One way of doing this is to put weights on the plunger of a plastic syringe:

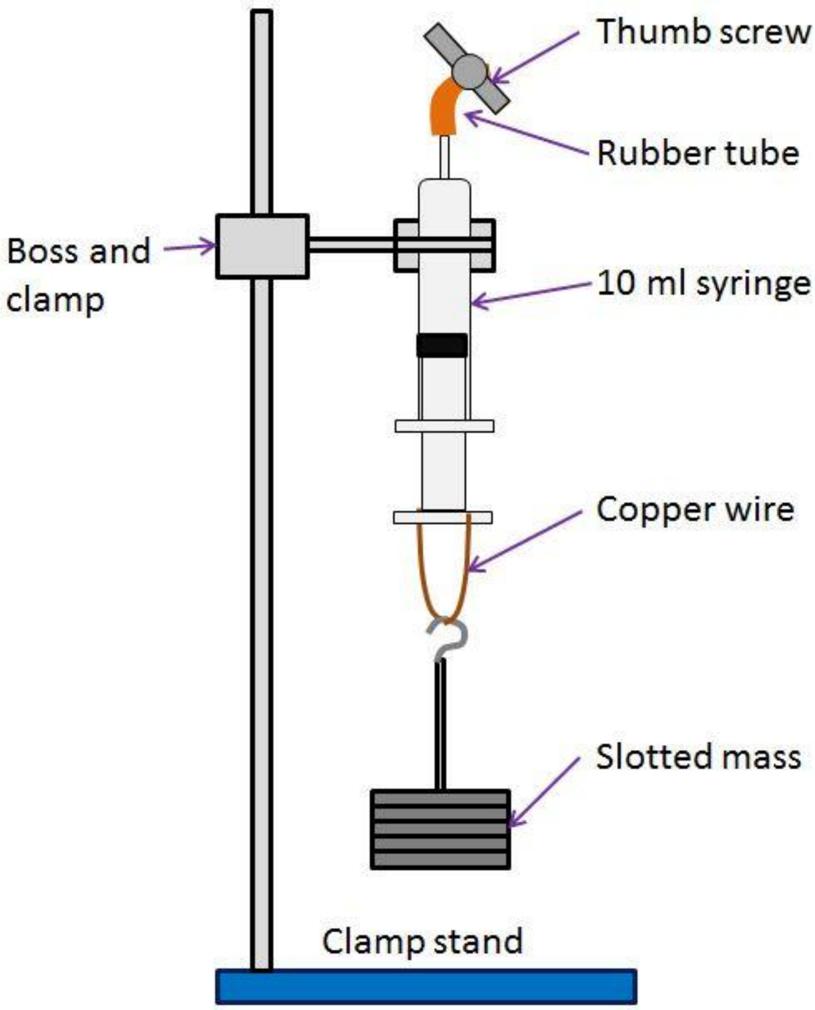


Figure 51Investigating Boyle's Law

The picture shows the set up. Plungers on this kind of syringe have a lot of friction. So, there is considerable **uncertainty** with the force that needs to be applied to pull the plunger out. 10 ml syringes are rather small, so the volume is small. Therefore, there is more uncertainty. Additionally, the syringes are held in clamps and if you screw the clamps too tightly, you will deform the syringe. Too loose, the syringes fall out. An improved experiment would use glass syringes, which have a larger volume, and the friction is lower. You would not want to put a glass syringe into a set up like this, as if they fall out and break, it's expensive. So, an alternative and improved way of doing the experiment is:

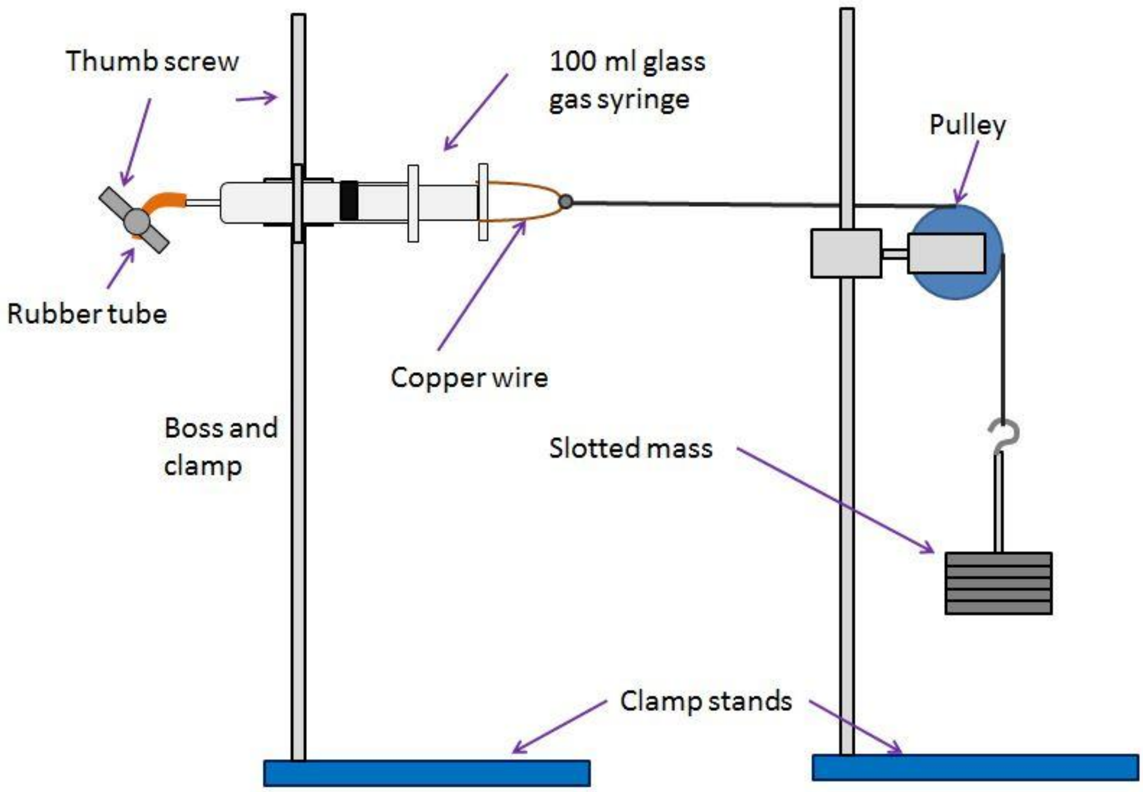


Figure 52 An alternative way to investigate Boyle's Law.

To reduce the risk of breakage, you may want to place a pad underneath the slotted mass.

1.0811 Will this graph get full marks?

Here are some graphs given as examples from the AQA booklet that gives guidance on practical work.

Note that in these examples there are no quantities or units on the axes (which would lose you marks). Nor are there error bars.

This graph is acceptable:

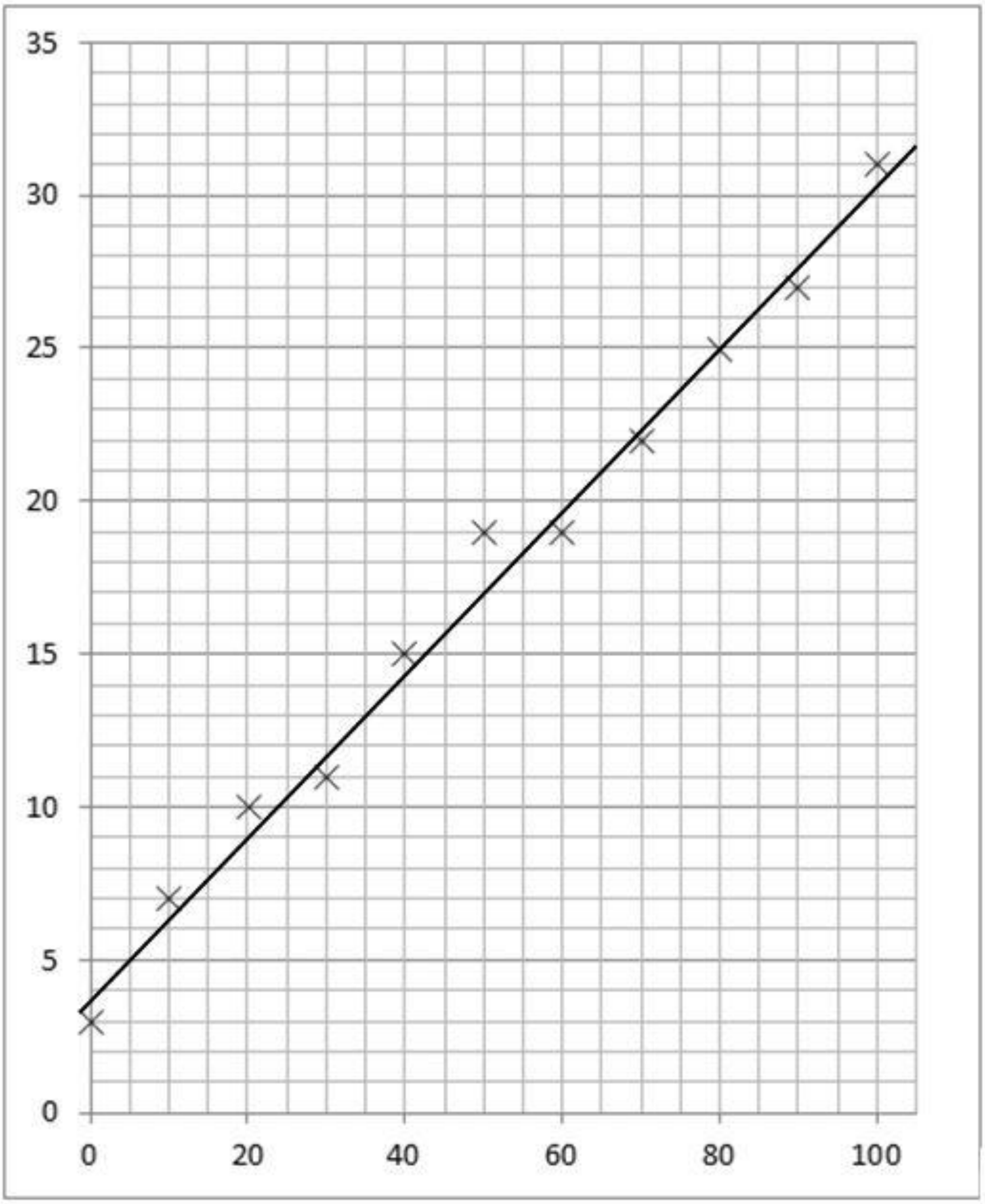


Figure 53 This graph will get good marks. AQA

This graph has well-spaced marking points, and the data fill the paper. Each point is marked with a cross (so points can be seen even when a line of best fit is drawn).

In the questions we will look at some other graphs. Think about these (with a classmate if possible) and come to a decision on whether the graphs will get you the marks. Remember:

• No quantities or units are on the graphs.
• No error bars have been put in.

1.08 Questions

1.08.1

Identify the spelling and grammatical errors in this passage.

When U right sum thing about you're a level physics, you can be tempted 2 deep end two much on yore spell cheque. It dose not pick up every miss steak. Many student's loose lots of mark's coz there righting is pour. Their knot thinking about what they Wright. Sum times they rite rub is.

Physics has lots of technical term's. Its gonna be import ant to make shore that their used prop early, they will bee X-planed during the coarse. 4 example, wait is a fours, while currant is red form an amateur. Chemist's ewes destiny, witch is mess divided by volume.

(Confession here: when I first wrote this, my spell checker did not pick up these misspellings. Spell checkers are much more sophisticated now. Mine has identified no less than 15!)

1.08.2

These data have been completed by a student.

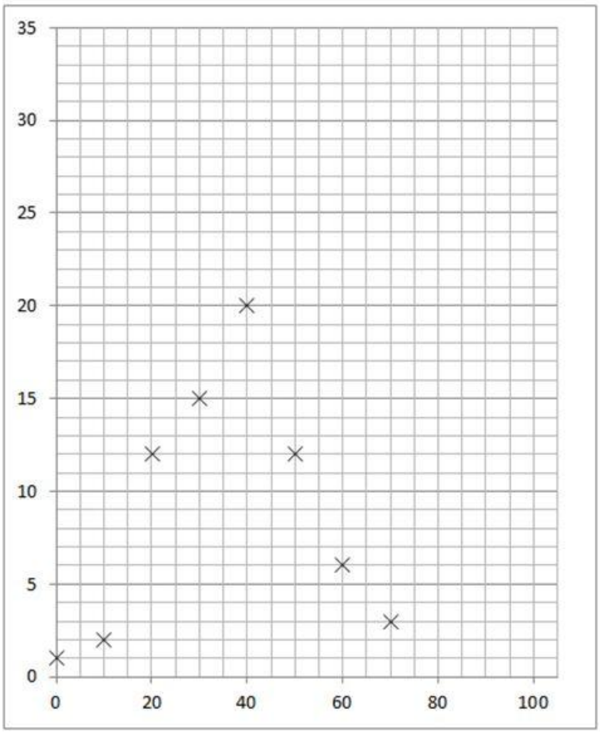
x/m	Time for 20 oscillations			t_{mean}/s	Time period T/s	$\log_{10}(T/\text{s})$	$\log_{10}(x/\text{m})$
	t_1/s	t_2/s	t_3/s				
0.300	9.78	9.93	9.99	9.90	0.495	−0.305	−0.523
0.400	11.19	11.07	11.22	11.16	0.558	−0.253	−0.398
0.500	12.82	12.70	12.52	12.68	0.634	−0.198	−0.301
0.600	13.53	13.68	13.71	13.64	0.682	−0.166	−0.222
0.700	14.87	14.74	14.55	14.72	0.736	−0.133	−0.155
0.800	15.78	15.72	15.60	15·70	0·785	−0·105	−0·097
0.900	16.50	16.68	16.62	16·60	0·830	−0·081	−0·046

(a) Which data have been harvested?

(b) Which data have been processed?

1.08.3

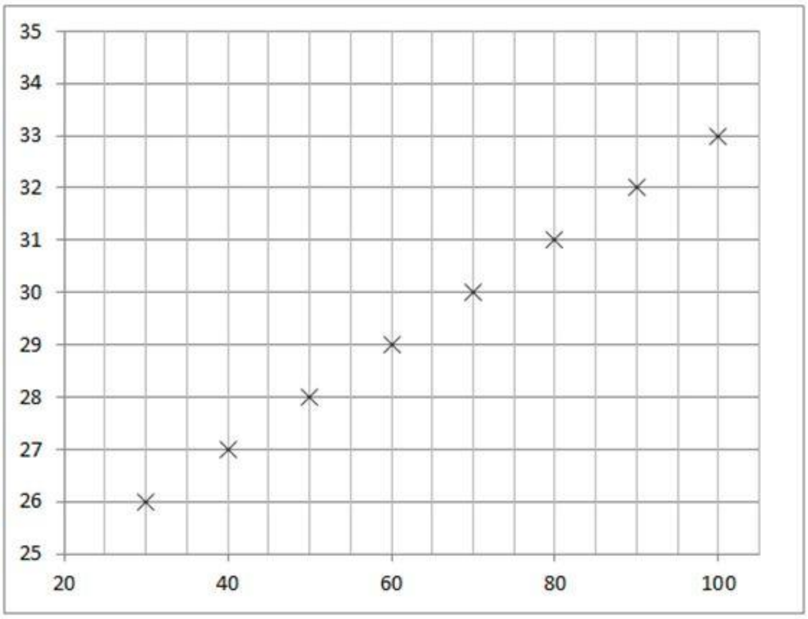
This graph has been used to plot some data.



Draw the line of best fit. Is this graph acceptable for full marks?

1.08.4

What is wrong with this graph?



Tutorial 1.09 Orders of Magnitude

All syllabi

Contents

1.091 Estimating quantities in Physics

When people want a job doing on their house, they get a builder in to give them an estimate. The builder looks at the job that needs doing and uses his (or her) experience to work out in his (or her) mind:

- What materials he needs.
- What techniques he will need to use.
- What, if any, specialist equipment he will need to hire in.
- How many people he will need to help him to do the job.
- How long the job will take to do.

From those mental calculations, he will tell the owners how much, roughly, the job will cost. He has given them an **estimate**. (A **quotation** is a much more detailed affair and gives an exact price that will be charged, which will form the basis of a contract.)

If the builder is not very good at giving estimates, he will find that his price is way out. Either the customer will not be very pleased at having to pay a larger sum than expected, or the job will be done at a loss. Either way the builder won't be in business for very long…

Physicists need to acquire the same skill. They need to use estimates to:

- See if an answer is reasonable.
- Make a comparison.
- Provide data to ask questions.
- To see if a question is worth following.

A good general understanding of physics will allow us to make reasonable estimates. It is a good idea to get used to doing **back of the envelope** calculations, using the physics principles you know and realistic quantities that you may have to look up, for example, the mass of a car being about 1200 kg.

Figure 54 Cheetah (Acinonyx jubatus). Image from Wikimedia Commons

Consider this question from a GCSE textbook about a **cheetah**. The cheetah is the largest of the purring cats and is the world's fastest land animal. It feeds on antelopes in Africa. Here is the question:

A cheetah is running at 30 m s^{-1}. He sees an antelope and accelerates at 4 m s^{-2} for 10 seconds. He then maintains this new speed for a further 500 s.

(a) What is his new speed?

(b) How far does he travel while running at that speed?

The question above appeared in resource materials that were produced commercially and schools paid considerable prices for the photocopy masters. Think about the numbers:

- 70 m s^{-1} is double the motorway speed limit, about 230 km/h. A cheetah can sprint at about 35 m s^{-1}.

- The cheetah can sprint at that speed for about 5 seconds. Although the cheetah runs fast, it can run for no more than 100 m. Most antelopes (which are no slugs) get away.

After 3 seconds, the oxygen debt in the cheetah is so severe that the cheetah collapses in a panting heap and does not feed for several minutes. In that state, it is actually very vulnerable to passing jackals, hyenas, or leopards that would quite happily help themselves to its hard-caught meal, and, quite often, to the cheetah itself.

A wolf, like all dogs, has very high stamina, and will trot at 8 m s^{-1} for hours. It could run 35 km quite easily.

1.092 Fermi's piano tuner problem

Website: https://www.grc.nasa.gov/www/k-12/Numbers/Math/Mathematical_Thinking/fermis_piano_tuner.htm

As a lecturer, Enrico Fermi used to challenge his classes with problems that, at first glance, seemed impossible. One such problem was that of estimating the number of piano tuners in Chicago given only the population of the city.

The population of Chicago was, at the time, 3×10^6 people.

There is now a little problem:

- Chicago is a very run down area. Not many people own traditional pianos.
- If they have a keyboard, it would be electronic. So, it doesn't need tuning.
- So there…

1.093 Making Comparisons

To make sense of the physical world, we often make **comparisons** to things we are familiar with. For example, we could say that London (a city in the South of England) is ten times bigger than Leeds (a city in Yorkshire). Or that a very large animal is the length of two double-decker buses.

We saw how a badly written question compared the sprint speed of a cheetah to the speed of a high-speed electric train, or an aeroplane.

By making comparisons, we come on to the important skill of getting a **scale** of objects.

Using scales, we can represent bigger or smaller objects in a context that is meaningful to us. This is particularly useful when the object is too big for us to handle, for example a full-sized aeroplane, or when the object is far too small for us to see, for example an arrangement of atoms.

1.094 Orders of magnitude

Magnitude is a word that means **size** or **value**.

Journalists tend to use the term *orders of magnitude* as a piece of meaningless padding.

It is a scientific term that means this:

- If an object is ten times greater (or smaller) than another object, it is an **order of magnitude** greater (or smaller).
- The size changes as a power of 10. So, if an object is 4 orders of magnitude bigger than another object, it is 10^4 times bigger (10 000 times bigger). Mathematicians call this a **logarithmic** scale.

Look at this table:

1 m	Human scale – the average British person is 1.69 m
10 m	The height of a house
100 m	The diameter of a city square, like George Square (Glasgow)
10^3 m	The length of an average street
10^4 m	The diameter of a small city like Perth
10^5 m	Distance between Aberdeen and Aviemore or Stirling and Ayr
10^6 m	Length of Great Britain
10^7 m	Diameter of Earth

Of course, this includes things that are bigger than we are, but there is no reason why we cannot go to much smaller things. Also, we are tending to think of distances, but we can apply the same arguments to other quantities, like currents, temperatures, and so on.

The table on the next couple of pages illustrates the orders of magnitude from the very small, to the very large.

Theoretical physics has suggested distances of 10^{-38} m, and particle physics experiments have modelled conditions 10^{-44} s after the Big Bang.

Size	*Powers of 10*	*Examples*
	10^{-18} m	Size of an electron? Size of a quark?
	10^{-17} m	
	10^{-16} m	
1 fm (femto)	10^{-15} m	Size of a proton
	10^{-14} m	Atomic nucleus
	10^{-13} m	
1 pm (pico)	10^{-12} m	
	10^{-11} m	
1Å (Angstrom)	10^{-10} m	Atom
1 nm (nano)	10^{-9} m	Glucose
	10^{-8} m	DNA Antibody Haemoglobin

	10^{-7} m	Wavelength of visible light Virus
1 µm (micro)	10^{-6} m	Lysosome
	10^{-5} m	Red blood cell
	10^{-4} m	Width of a human hair Grain of salt
1 mm (milli)	10^{-3} m	Width of a credit card
1 cm (centi)	10^{-2} m	Diameter of a shirt button
	10^{-1} m	Diameter of a DVD
1 m	10^{0} m	Height of door handle
	10^{1} m	Width of a classroom
	10^{2} m	Length of a football pitch
1 km (kilo)	10^{3} m	Central span of the Forth Road Bridge
	10^{4} m	Typical altitude of an airliner, diameter of Large Hadron Collider, CERN
	10^{5} m	Height of the atmosphere
1 Mm (mega)	10^{6} m	Length of Great Britain
	10^{7} m	Diameter of Earth Coastline of Great Britain
	10^{8} m	
1 Gm (giga)	10^{9} m	Moon's orbit around the Earth. The farthest any person has travelled. Diameter of the Sun.

	10^{10} m	
	10^{11} m	Orbit of Venus around the Sun
1 Tm (tera)	10^{12} m	Orbit of Jupiter around the Sun
	10^{13} m	The heliosphere, edge of our solar system
	10^{14} m	
	10^{15} m	
	10^{16} m	Light year. Distance to Proxima Centauri, the next closest star
	10^{17} m	
	10^{18} m	
	10^{19} m	
	10^{20} m	
	10^{21} m	Diameter of our galaxy
	10^{22} m	
	10^{23} m	Distance to the Andromeda galaxy
	10^{24} m	
	10^{25} m	
	10^{26} m	
	10^{27} m	Distance to the next galaxy cluster
	10^{28} m	
	10^{29} m	Distance to the edge of the observable universe

1.09 Questions

1.09.1

Refer to the question in1.091. Show that the answer to (a) is 70 m s^{-1} and (b) is 35 000 m.

1.09.2

Do you think that these answers in 1.09.1 are reasonable?

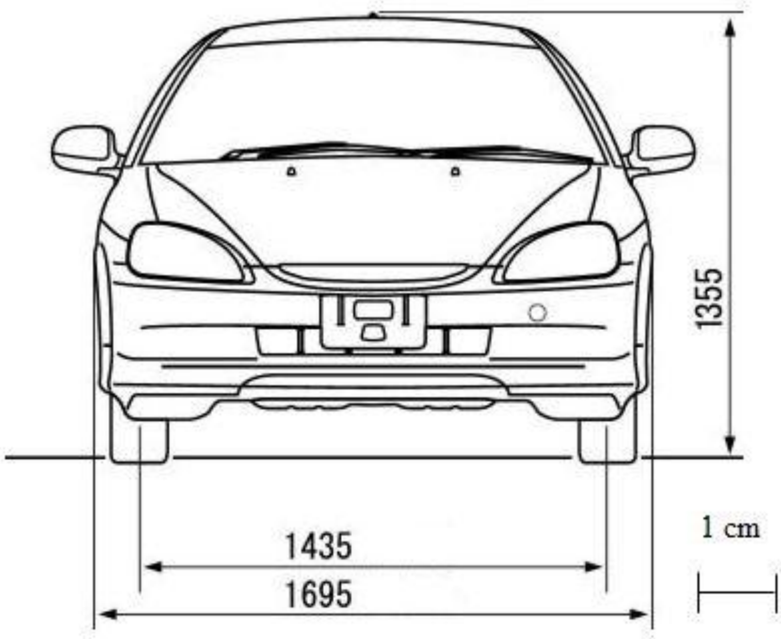
1.09.3

Look at the picture of this young man with his head on a bed:

What is wrong here? How high would you estimate the room to be?

1.09.4

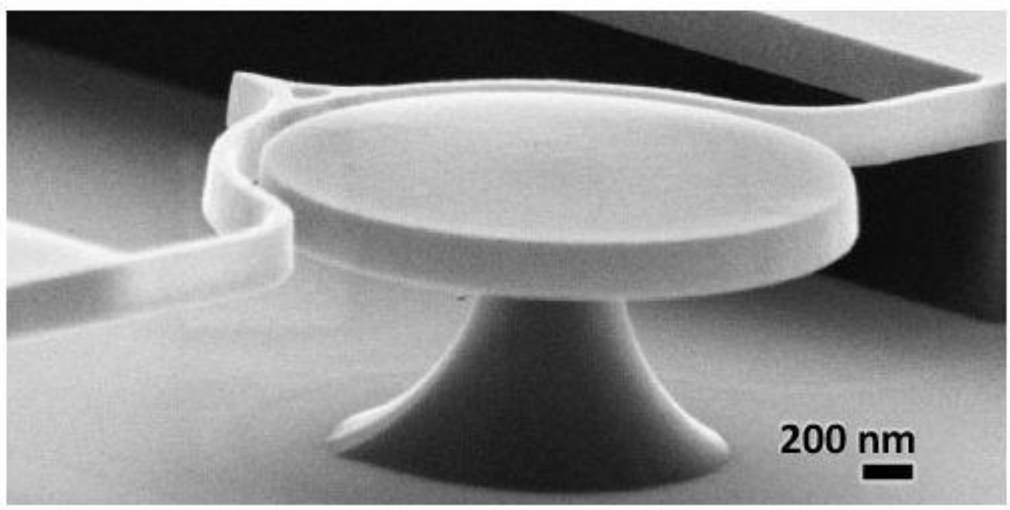
Here is a scale drawing of a car.



What is the scale?

1.09.5

How wide is this shape?



Does it matter that the view is at an angle?

1.09.6

In the following table the words represented by the letters A, B, C, D, E, F and G are missing. They are at the bottom.

Order of magnitude/m	***Object***
10^{-15}	A
10^{-14}	B
10^{-10}	Diameter of hydrogen atom
10^{-4}	C
10^{0}	D
10^{3}	E
10^{7}	Diameter of Earth
10^{9}	F
10^{13}	Diameter of solar system
10^{21}	G

Match each letter with the correct words from the list below.

diameter of nucleus; diameter of proton; diameter of Sun; distance to nearest galaxy; height of Ben Nevis; size of dust particle; your height.

1.09.7 (Challenge problem for A-level students)

Here is a back of the envelope calculation.
When a car doesn't start, it is possible to move it a few metres by putting it in gear and moving it with the starter motor.

Assuming:

- you have a 32 amp-hour battery.
- the battery has a voltage of 12 V.
- the car moves at 1 m s^{-1}.

How far will the car go before the battery goes flat?

Tutorial 1.020 - Using ICT in Physics	
All syllabi	
Contents	
ICT	Data-Logging
Drawbacks of Data-Loggers	Examples of Experiments
Data-Modelling	Internet
Animations	A I

1.0201 ICT

Computers are used widely in Physics, not only in research, but also teaching. They initially came into teaching in schools and colleges about thirty years ago with the BBC microcomputer. There may be some schools that still use them for data-logging. Programs came on large floppy discs. Operating them was simplicity itself. A program was started by pressing SHIFT + BREAK. There was a range of sensors and interface boxes that worked with the BBC. Laughably crude nowadays, they were effective data loggers, although they printed out graphs on dot-matrix printers with tractor feeds. (Ask your tutor - there is probably one hidden in a corner of the prep-room).

ICT should play a central role in much of your learning, regardless of what subject you are doing. In this tutorial we will look at how you can use ICT enhance your studies. However, you should be aware that no computer can be a substitute for a teacher, and you still need to use the old-fashioned low-tech approach to study, such as:

- Writing notes.
- Using a textbook (very reliable, doesn't crash, and can be used anywhere).
- Hand-written assignments (setting out equations on a computer is time-consuming. It can be done much faster by hand).

In the exam, you will still need to hand-write your answers. Some people think that legible handwriting is over-pedantic and old-fashioned. It is also part of you. Examiners and employers do not. My own handwriting is not the best in the world, but I try to make it legible. (It is worse now after I suffered a bad stroke a couple of years back that has left my right hand very stiff and weak.)

Computers can be used for:

- Data-logging.
- Mathematical modelling.
- Research on the Internet.
- Animations to illustrate concepts.

We will look at each of these in turn.

1.0202 Data-Logging

In a **data-logging experiment**, you will use:

- a **sensor** which detects some kind of change, e.g. temperature;
- a **sensor** unit which translates the output of the sensor into digital form.
- a **data-logging** unit.

The picture below shows a **probe** with the **sensor unit** that connects it to the **data-logger**.

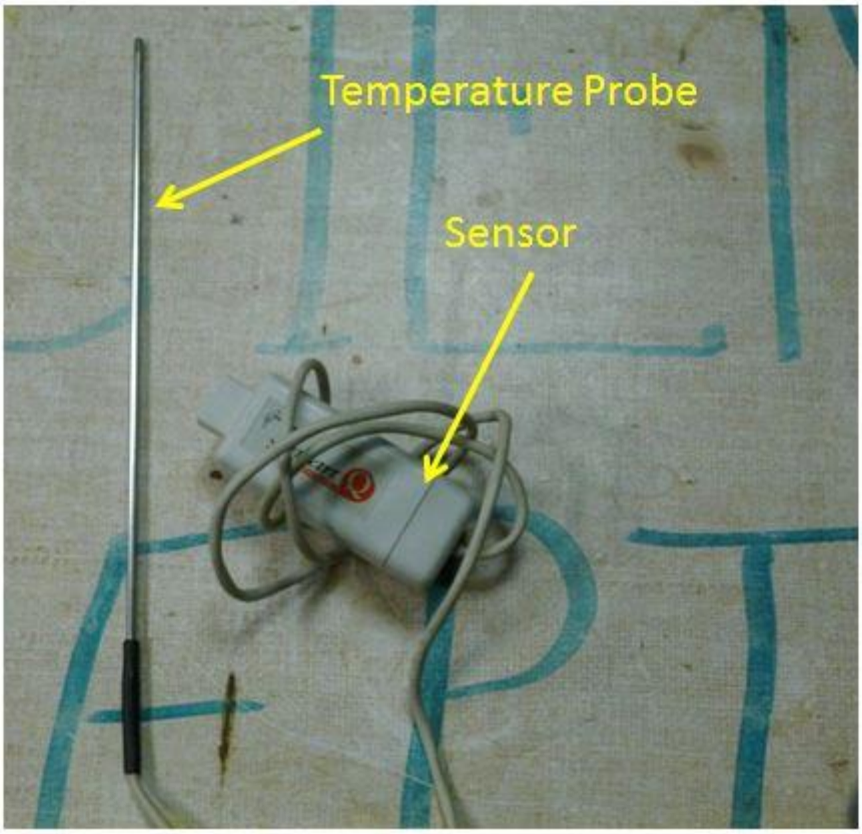


Figure 55 A data-logging sensor.

The data-logger is shown below:

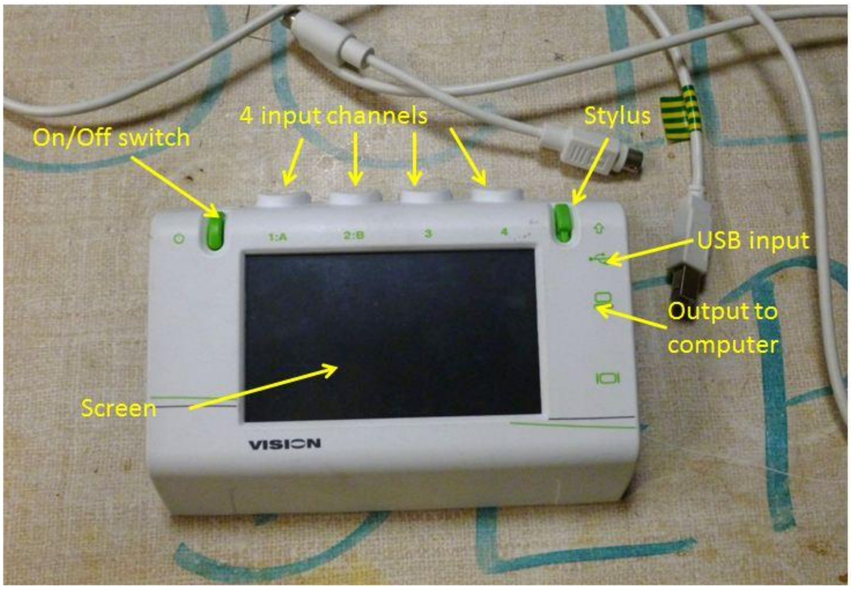


Figure 56 A typical data-logger

Other models are available and will have a different layout. This one has a screen that will display the data in a table or a graph. There is a **stylus** that allows the user to change settings on a dialogue screen. The screen is small, so fingers are too fat and clumsy!

There are four **input channels** which can be connected to different sensors of the same kind (e.g. 4 temperature probes) or of different kinds (e.g. voltmeter and ammeter). Channel 1 and Channel 2 are also marked A and B. This is to allow for **light gate** sensors in two different positions. The picture shows a pair of light gates:

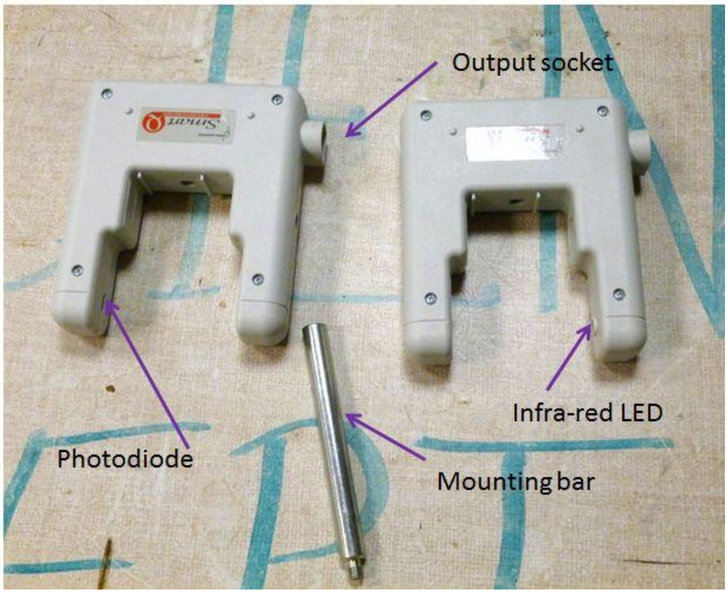


Figure 57 Light gates for measuring speed, acceleration etc,

There are sensors for a whole range of applications:

- Voltage sensors, that are wired into a circuit just like a voltmeter.
- Current sensors, which are wired in like an ammeter.
- Temperature sensors that are used like a thermometer.
- Magnetic field sensors.
- Light level sensors.
- Position sensors.

The list goes on. In biology, there are oxygen sensors. In chemistry there are pH sensors.

The most obvious way of using a data-logger is to measure some variable (like voltage) against **time**. The data-logger can be set to record every millisecond, or second, ten seconds... This is called the **sample rate**. This means that the time period for a recording can be from a fraction of a second up to several days. There is much reduced uncertainty compared with a stopwatch (reaction time is about 1/3 second), and the instrument does the recording unsupervised, so you can get on with something else.

Time is, of course, not the only independent variable.

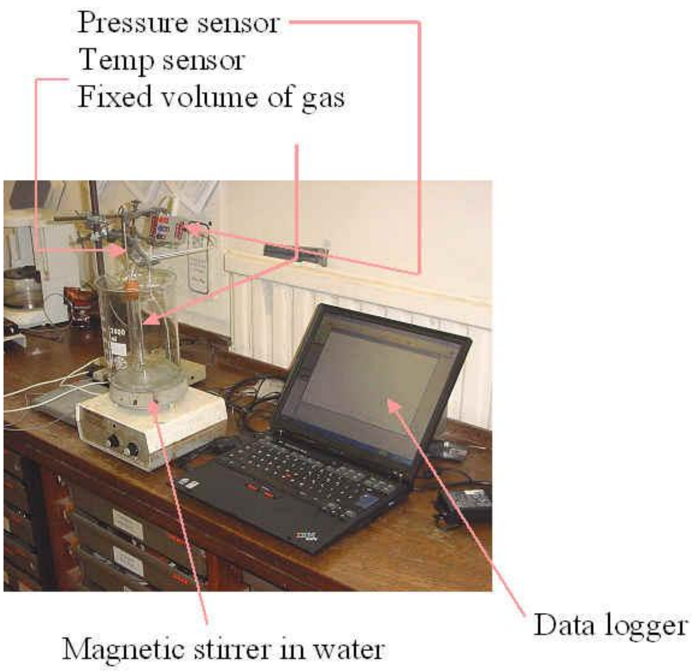


Figure 58 A (rather old) laptop used as a datalogger.

This apparatus shows a data-logging experiment in which the pressure of a fixed volume of gas is measured against the temperature. The computer is set to measure the pressure for each increase of temperature of 1 °C. In other experiments, the data of the independent variable can be put into the data-logger manually.

Drawbacks of Data-Loggers

There are some **drawbacks** to using data-logging in experiments:

- Data-loggers are **not necessarily more precise or accurate** than traditional techniques. It all depends on the accuracy of the calibration of the instruments.
- The sensors can be affected by **noise** (spurious electrical signals) which makes the graphs harder to interpret.
- The equipment can take longer to set up.
- Some data-logging equipment can be difficult to use. This leads to frustration for both the students and the tutor.
- Some data-loggers can only use time as the independent variable.

It is important that **each student should have his/her own copy of the results** from the computer. It is not unknown for students to save their data on the laptop that is then stored away on the laptop trolley, and the students have no idea of which one they used. Another common and depressing scenario is for a student to say to the tutor, "Ollie took the results. He said he would e-mail them, but he never did..."

Examples of Data-Logger Experiments

You will do experiments like these throughout your course. The precise instructions will vary.

The diagram below shows a typical experiment using light gates on a linear air track.

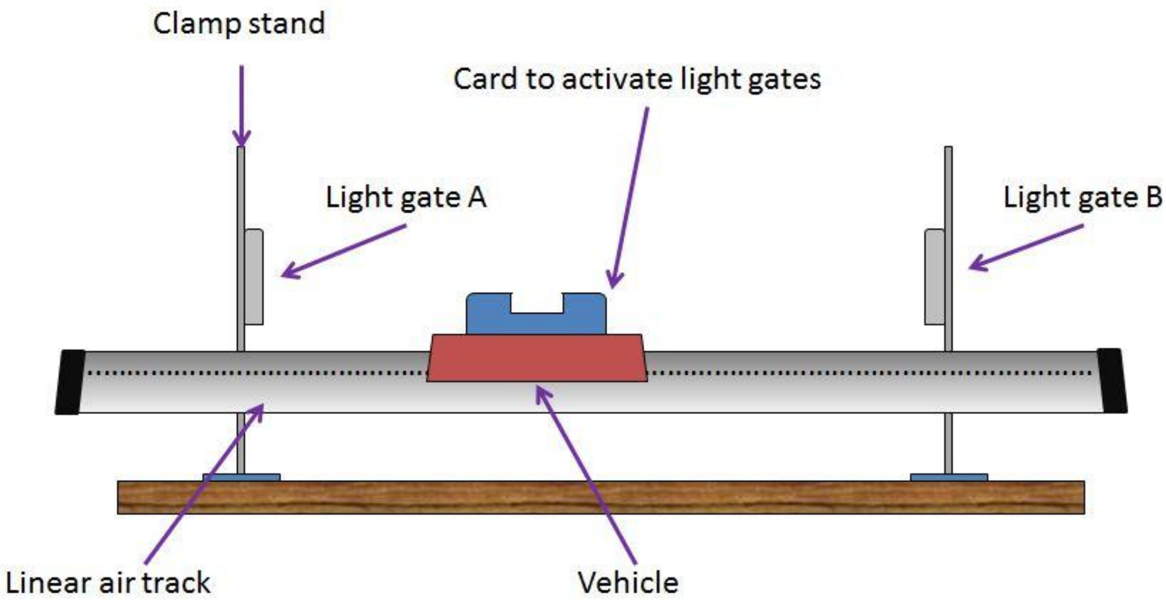


Figure 59 Light gates being used to harvest data on a linear air track

Light gate A is connected to input A on the data logger, and light gate B is connected to input B. Various motion quantities can be measured using the card and the light gates, for example:

- Speed.
- Velocity, where direction is included.
- Acceleration.

You can also use data-logging with light gates to measure the acceleration due to gravity.

This next example shows the circuit diagram to measure the charging up of a capacitor (which you will study in the A-level year).

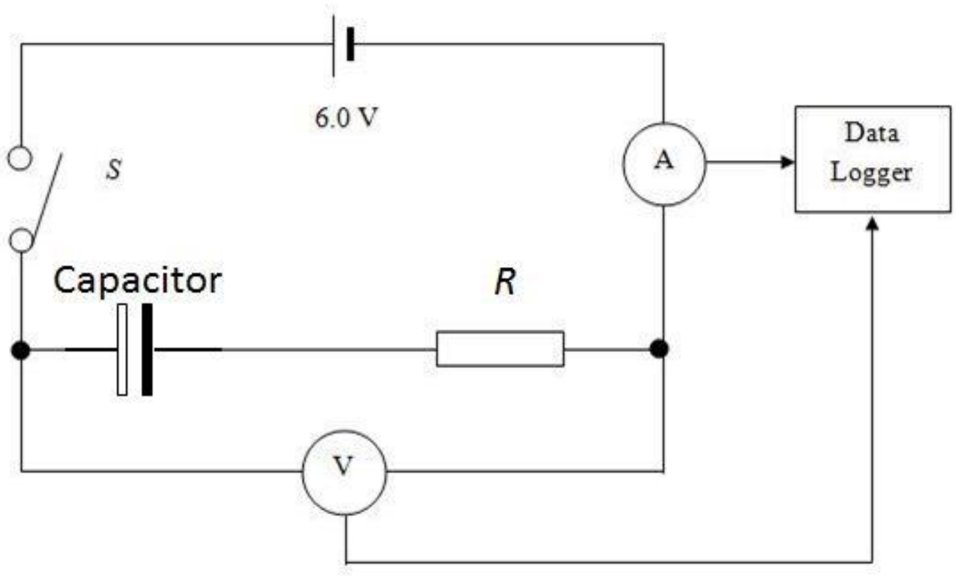


Figure 60 Datalogging used to measure charge and discharge of a capacitor

Notice that the voltmeter and ammeter sensors are represented by their normal symbols, except the connections to the data-logger. The data-logger has to be turned on at the same time as the switch S is closed. Easier said than done.

The data are recorded by the data-logger. They can be transferred to the **computer**, often as a **.CSV** file (Comma Separated Values), which can be read by the Excel spreadsheet program. They can be used to produce a graph. Here is the graph for a data-logging experiment.

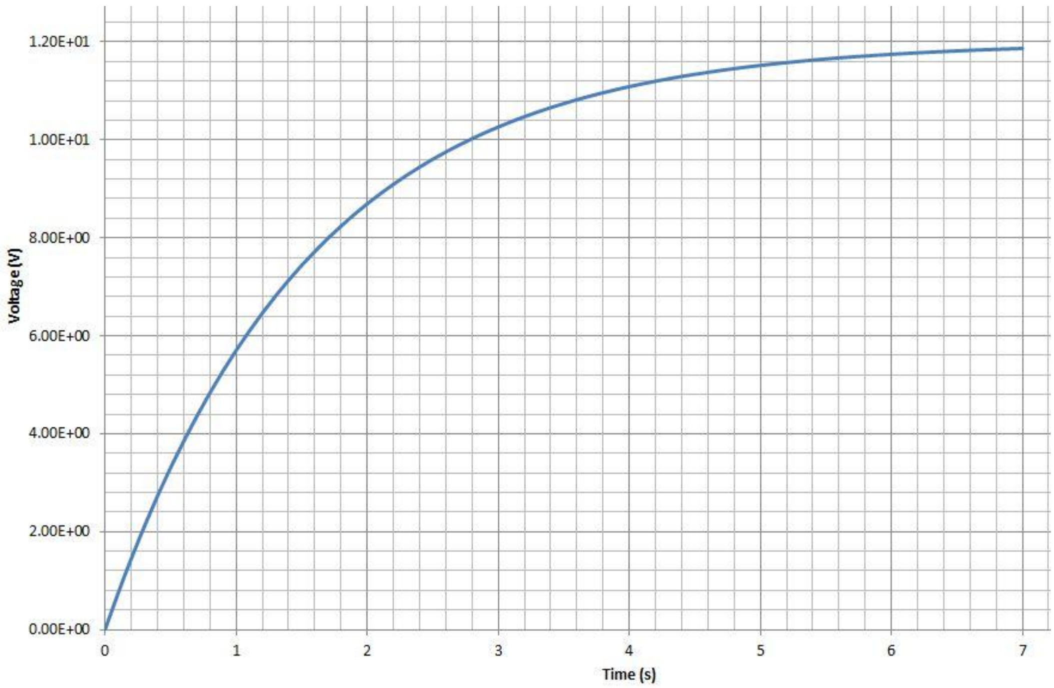
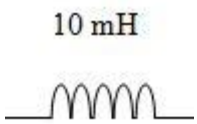


*Figure 61 This graph shows the **charge** of a capacitor recorded by a datalogger*

The experiment below shows an experiment to measure a very brief change in voltage and current in an **inductor**, like an electric motor. The symbol for an inductor is this:



The inductor has a value of 10 millihenries (10 mH).

Don't worry about what an inductive component is or its units. You may meet them in the A-level year, depending on the syllabus you are studying. The way the current and voltage behave is not on the syllabus, but it changes in a very rapid transient, which cannot be studied using a voltmeter and stopwatch. The circuit is like this, as shown in Figure 62:

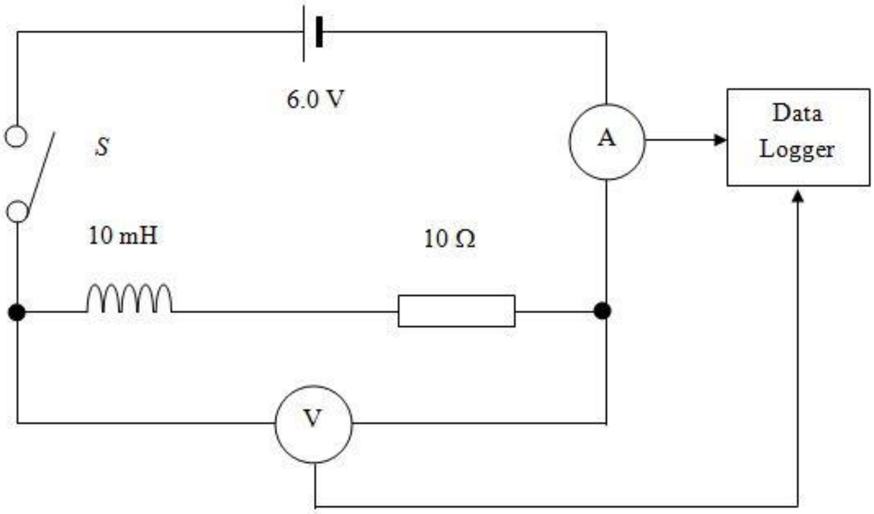


Figure 62 Datalogging the voltage rise in an inductor.

Notice that the voltmeter and ammeter sensors are represented by their normal symbols, except the connections to the data-logger. The data-logger has to be turned on at the same time as the switch S is closed. Easier said than done.

This graph shows the inductive rise in the input voltage of a motor from a data-logging experiment.

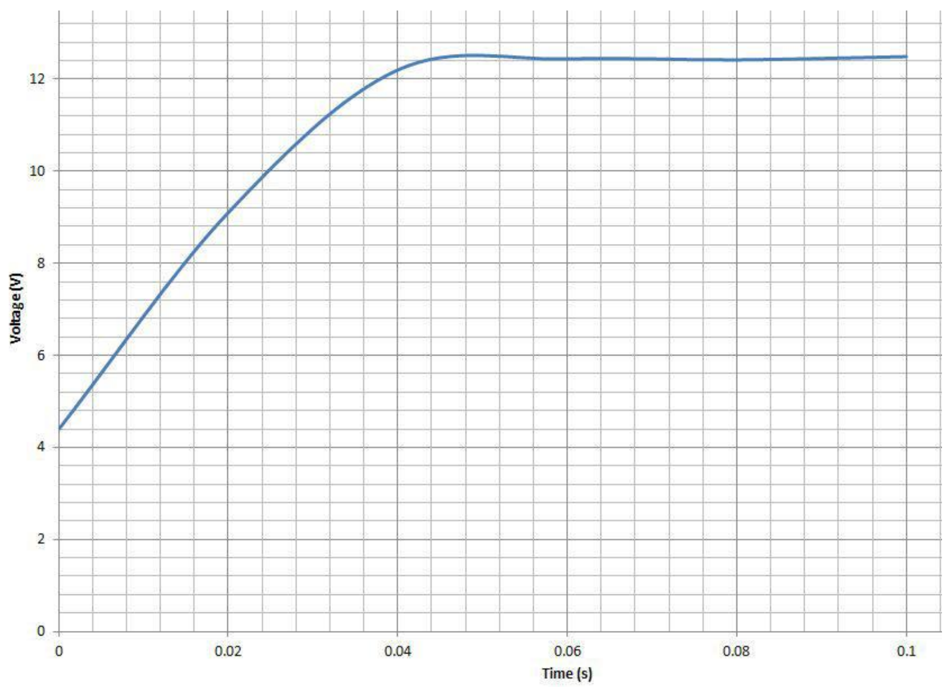


Figure 63 Graph shows inductive rise.

Notice how quickly the voltage rises to its maximum level, 12 V. Also at time = 0, the voltage was at 4.4 V. This is because the data-logger was not switched on at quite the right time.

1.0203 Data-Modelling

On many of the pages of this website, you will see sketch graphs. They give a rough idea of the shape of a relationship. They can be unsatisfactory, as drawing consistent curves freehand is not easy. It's even harder with a mouse! Consistent curves are essential if concepts such as phase are to be illustrated properly. **Excel Spreadsheets** can produce much better graphs, and you will see these on various pages of this site.

Data-modelling is about using a **formula** with known values. A formula is a function machine that processes one number with another to give an answer. You can do it manually, of course, but it is remarkably tedious. A spreadsheet does this in minutes. This is not a tutorial on how to use Excel, which you will have done in ICT lessons. If you are unsure, ask a classmate who is a dab-hand at Excel, or look up an on-line tutorial.

We care going to do a simple piece of **data-modelling** using voltage and current in a resistor. We know that resistance is related to voltage and current by:

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

and that power is related to voltage and current by:

$$P = VI$$

Let's look at the power dissipated by a 15 Ω resistor. So, open an Excel file and call it something meaningful, like *Power*.

In the headings of the table, list voltage, current, and power. In a cell above this, put the value of the resistance.

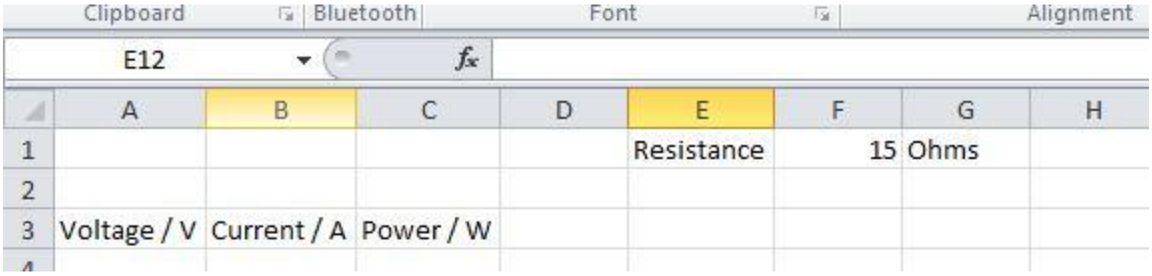


Figure 64 Making a table in MS Excel

You can change the value of the resistance, and the spreadsheet will change everything. So, start at a voltage of 0, and go up in steps of 0.1 V, up to 10 V. We have now defined the step. This is shown below:

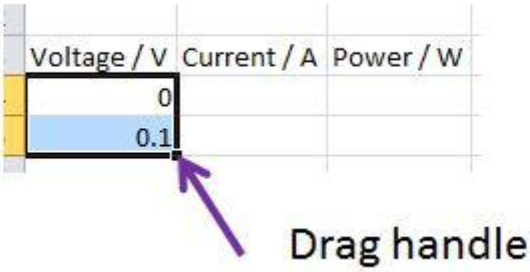


Figure 65 Selecting data in a table.

Pull the drag-handle downwards, and pull it down until you reach 10 V:

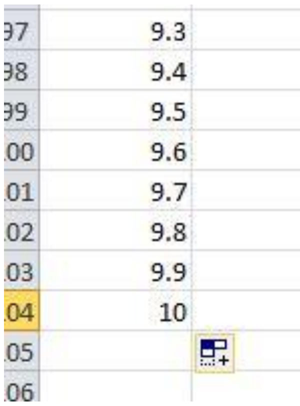


Figure 66 Generating data in a spreadsheet.

Now we make the first formula, as shown here in Figure 66.

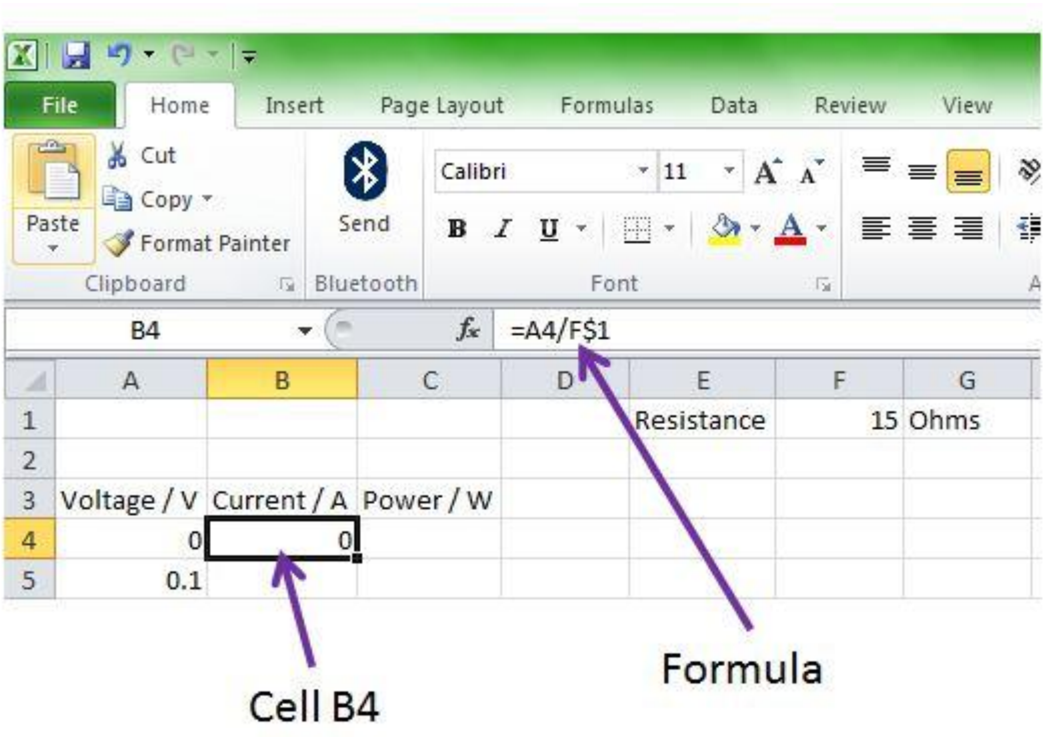


Figure 67 Making a spreadsheet formula.

To start a formula, we type in *Cell 4* an equals sign (=). The formula is *=A4/F$1*. The cell *F1* contains the resistance, 15 ohms. The dollar sign before the number keeps that cell locked. Otherwise, when we pull the drag handle, the formula will pick up *F2* which does not have any contents. The next cell would return the answer to A5 ÷ 0, which would give an error, like this:

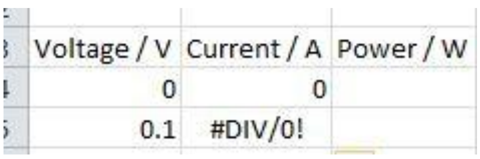


Figure 68 Division-by-zero error

So, pulling the drag handle gives us:

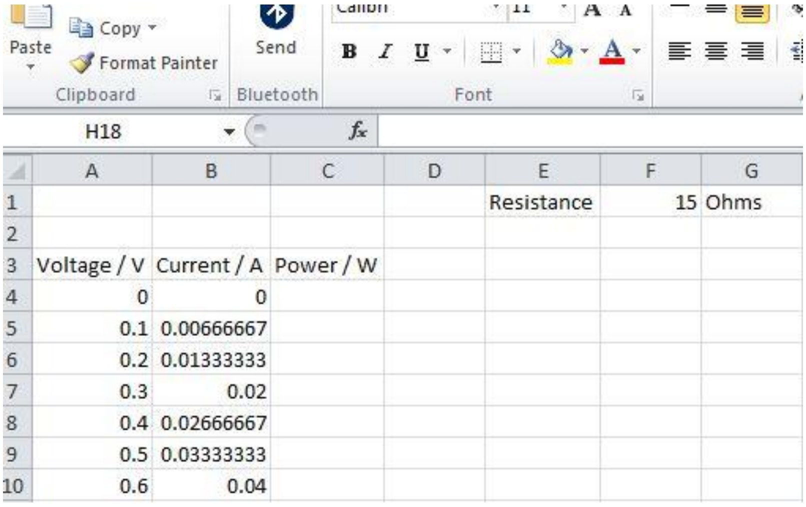


Figure 69 More data generated

The data have all sorts of decimal places, which looks messy. Select *Column B*. We can adjust the number of significant figures displayed by using the *Number* drop-down menu:

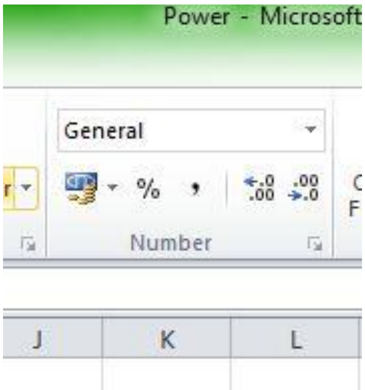


Figure 70 Using the Number menu

Click at the bottom right, and you will see the **dialogue box**.

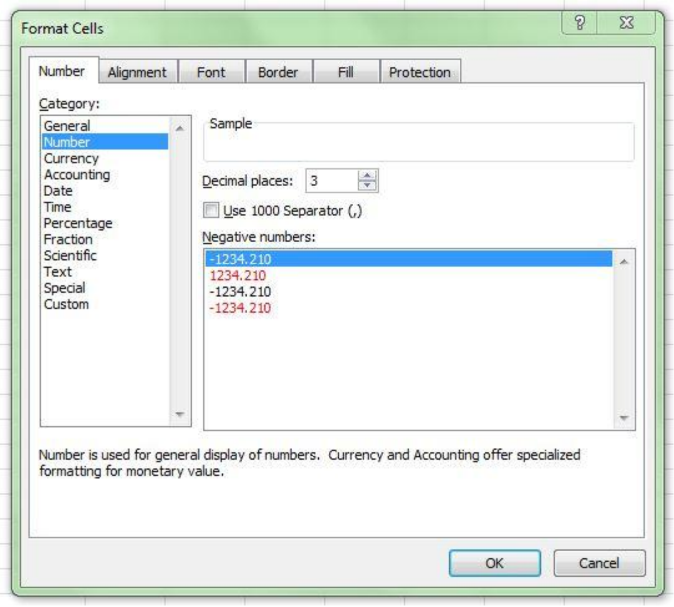
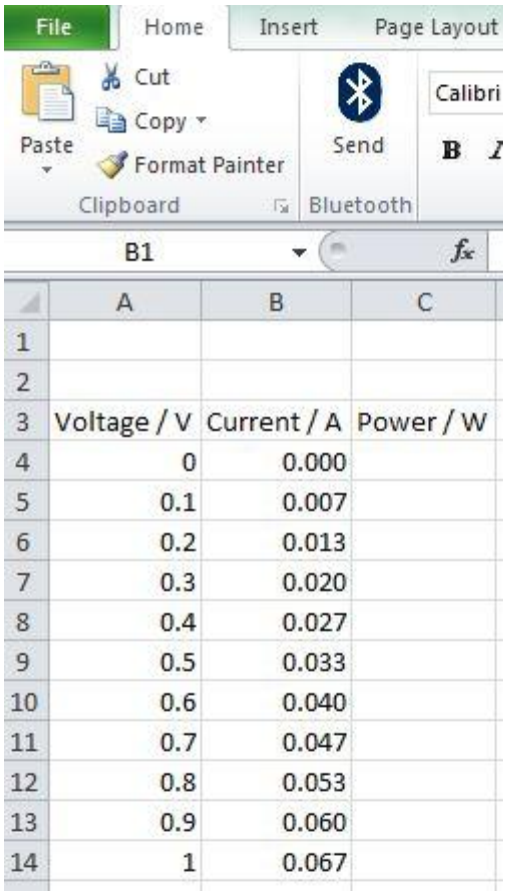


Figure 71 Selecting the number of decimal places

Select the *Number* data type, and select *3* decimal places, before clicking *OK*. Note that whatever the number of decimal places is selected, the underlying data are not affected. The data now look like this:



	A	B	C
1			
2			
3	Voltage / V	Current / A	Power / W
4	0	0.000	
5	0.1	0.007	
6	0.2	0.013	
7	0.3	0.020	
8	0.4	0.027	
9	0.5	0.033	
10	0.6	0.040	
11	0.7	0.047	
12	0.8	0.053	
13	0.9	0.060	
14	1	0.067	

Figure 72 Data to 3 decimal places or 2 significant figures

Now we can apply a formula for *Column C* which gives us the power. Select *C4* and type the = sign. Then select *A4*, then type * (it is the multiplication operator in Excel) then select B4. You should have:

*=A4*B4*

Drag the formula down *Column C*:

Clipboard | Bluetooth | Font

F103 | f_x

	A	B	C	D	E	F	G
1					Resistance	15	Ohms
2							
3	Voltage / V	Current / A	Power / W				
4	0	0.000	0				
5	0.1	0.007	0.0006667				
6	0.2	0.013	0.0026667				
7	0.3	0.020	0.006				
8	0.4	0.027	0.0106667				
9	0.5	0.033	0.0166667				

Figure 73 Generating power data

Format the number to 3 decimal places:

Format Painter

Clipboard | Bluetooth | Font

C1 | f_x

	A	B	C	D	E	F	G
1					Resistance	15	Ohms
2							
3	Voltage / V	Current / A	Power / W				
4	0	0.000	0.000				
5	0.1	0.007	0.001				
6	0.2	0.013	0.003				
7	0.3	0.020	0.006				
8	0.4	0.027	0.011				
9	0.5	0.033	0.017				
10	0.6	0.040	0.024				
11	0.7	0.047	0.033				
12	0.8	0.053	0.043				

Figure 74 These data to 2 s.f.

Now select *Column A* and then *Column B* with the CTRL key pressed. Then go to the *INSERT* menu and select *Scatter Chart*. (Don't select the *Line Chart* which does dot-to-dot.) You will get the graph as an object in your data page:

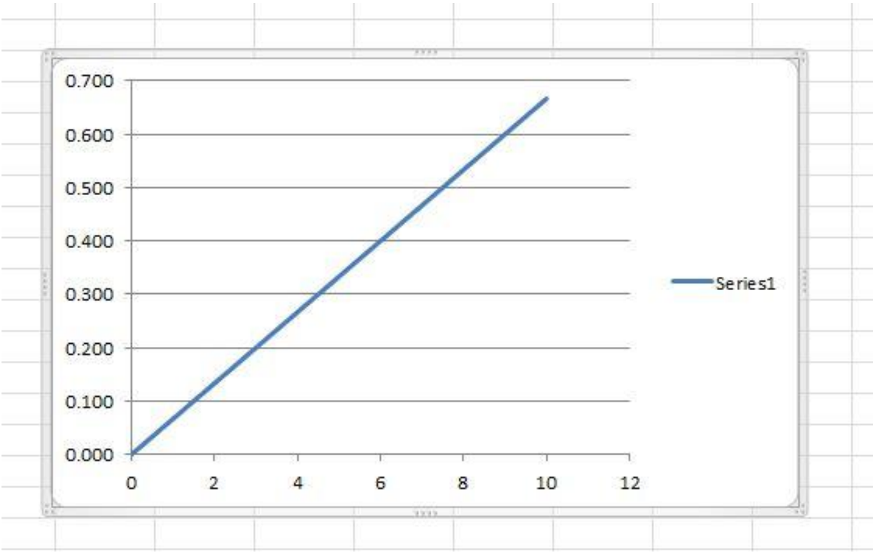


Figure 75 An Excel generated graph

You can move it by pressing the button, *Move Chart Location*. It goes to a separate page. You can then format the graph. The pre-set format given by this button is the most useful:

This gives us:

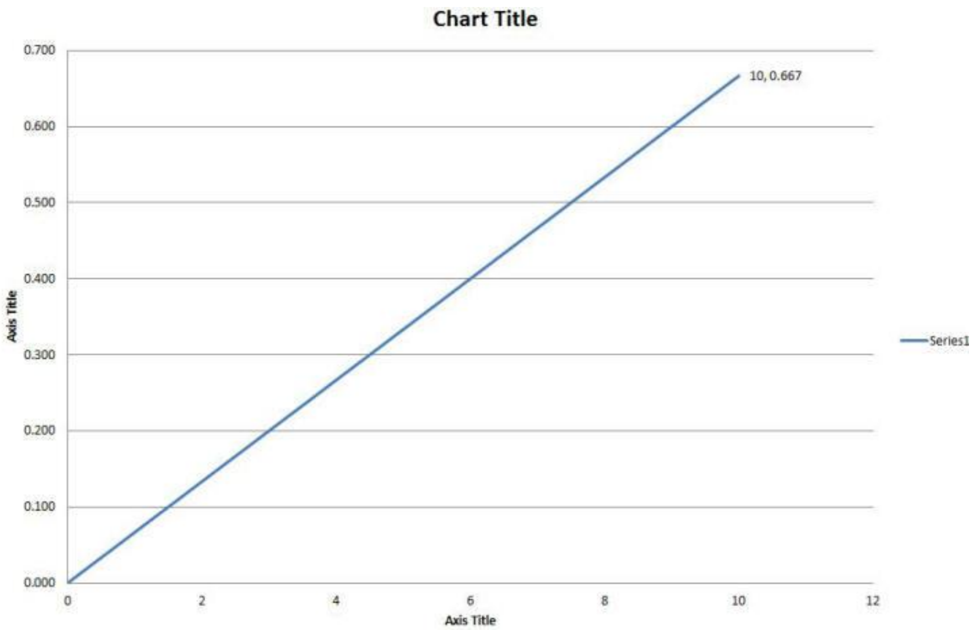


Figure 76 Whole Page version of Figure 75

The box, *Series 1* can be selected and deleted. Put a heading by selecting *Chart Title* and putting in an appropriate heading. Then label the axes. The vertical axis is *Current / A*, and the horizontal axis is *Voltage / V*.

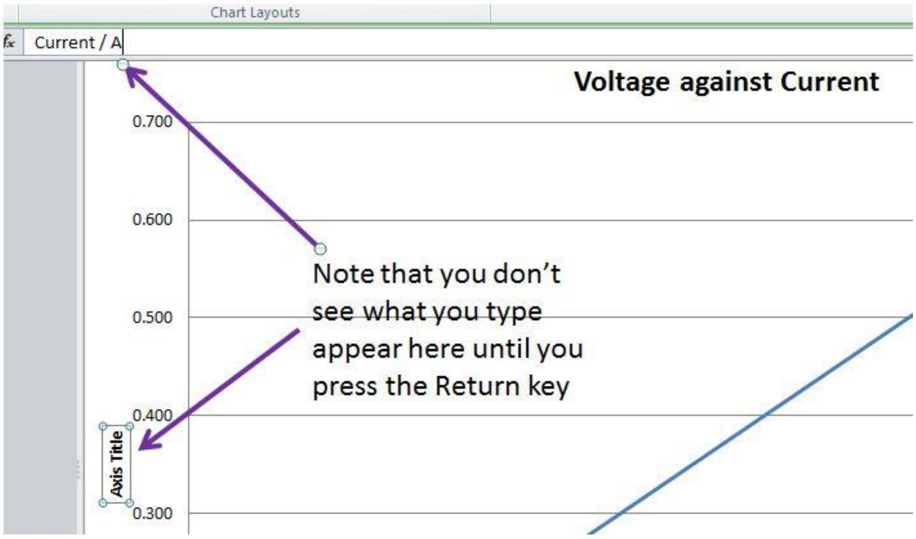


Figure 77 Labelling the axes

We now have our graph:

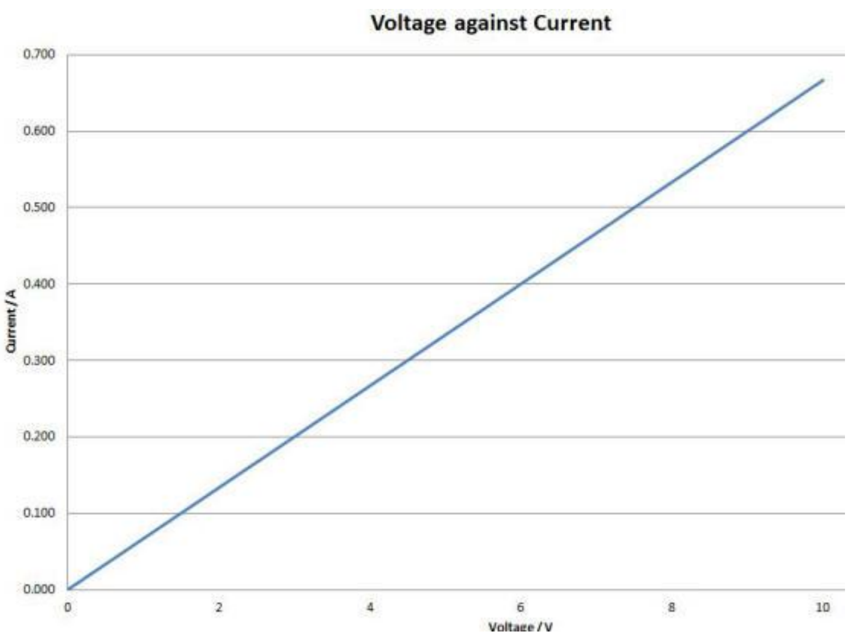


Figure 78 Getting there...

However, it's not quite finished. We want to show the grid lines. We right-click on each axis to format the axis. I cannot show the right-click dialogue box, but select show major grid lines, and then minor gridlines. Do the same for the second axis. This will give us:

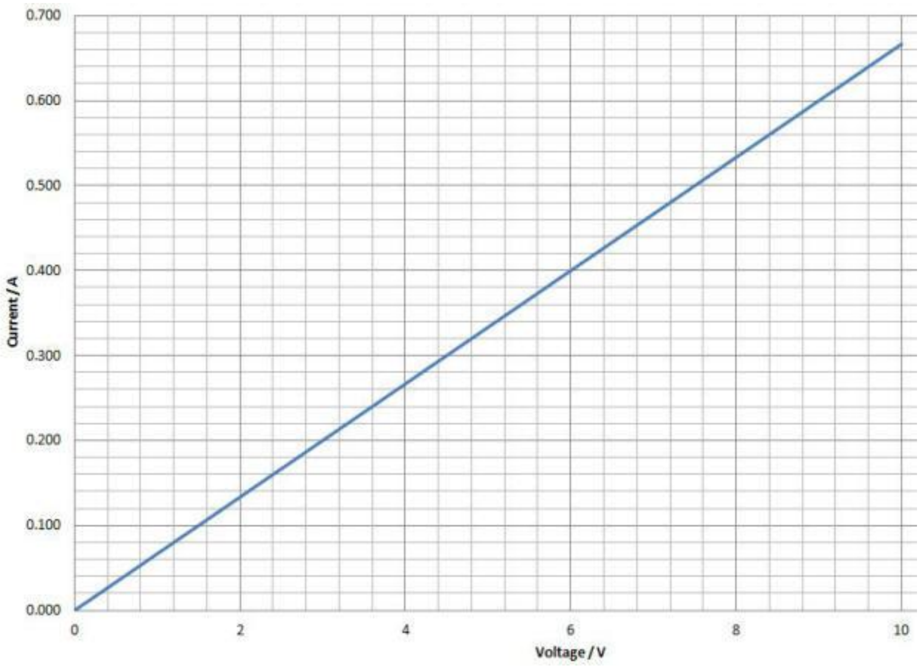


Figure 79 Our completed voltage-current graph

And we can easily draw a graph of **Power against Voltage**:

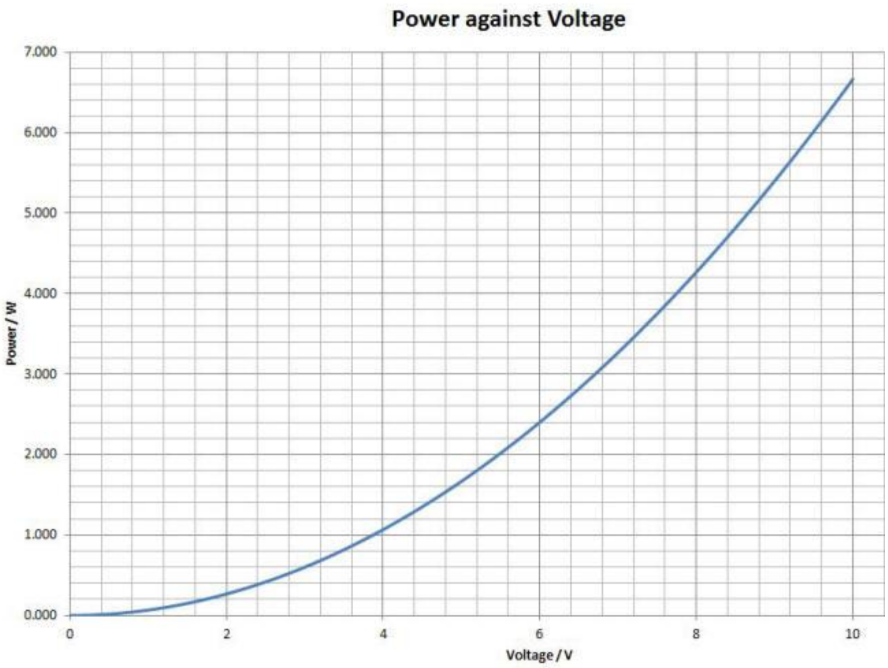
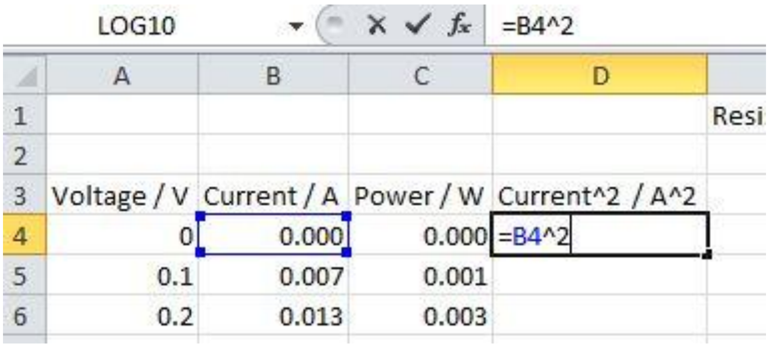


Figure 80 Voltage-power graph

Now let's look at what we can do if we square the current, since:

$$P = I^2R$$

So we can make an extra column, *D*, headed *Current^2 / A^2*. The notation is because Excel does not do superscript text. The formula is *=B4^2*. This will square the number in B4:


LOG10 =B4^2

	A	B	C	D	
1					Resi
2					
3	Voltage / V	Current / A	Power / W	Current^2 / A^2	
4	0	0.000	0.000	=B4^2	
5	0.1	0.007	0.001		
6	0.2	0.013	0.003		

Figure 81 Squaring the current

Excel does not allow us to reverse the axes easily. So, if we want Power against Current^2, we need to copy the contents of column *C* into *Column E*. In *E4* we simply type: *=C4*. Then drag down. This allows us to plot this graph:

Figure 82 Graph of power against square of current

Once you have got the hang of this, the production of spreadsheet data models is not that hard. If you have a complex formula, it is best to break it up into small bits, rather than applying the whole formula, which can easily go wrong. The actual production of this model took me about 10 minutes, a much lower time that it took me to produce the notes. Be aware that later editions of MS office will have slight differences in the design and layout of the pages that you might use.

The data produced by a data model are **idealised**, using a formula. The data from an experiment may well be different, so do not produce neat graphs. This is because of uncertainty in the experimental process.

More advanced software is used by physicists for more complex data-modelling. Very sophisticated programs using complex equations and mathematical techniques can be used to model the behaviour of complex systems like multiple black holes. Engineers use data modelling in the design of new aeroplanes. They can test the model to destruction, without putting a pilot and others at risk.

1.0204 Internet

You are reading these notes because you have downloaded them from the **internet**.

The internet contains a whole library of useful information that you can use help you with your studies. There is also a lot of absolute drivel. Your tutor may recommend sites for you to visit.

If you are using the internet to do a project, you must give the **URL** for where you find material. If you are quoting, it must be obvious that you are, for example the material is in a different font, or in quotation marks. You must reference the extract as instructed by your tutor (I usually insisted on a number in the text, and the link at the end under References).

Plagiarism is where you try to pass off others' work as your own. At its crudest, the introductory paragraph is meaningless and littered with spelling and grammatical mistakes. Then the prose suddenly becomes fluent, sometimes with concepts that are way beyond the level of the writer. The final paragraph reverts to type. You can expect very few marks from something like that. A good number of institutions insist that students submit assignment in electronic form, and they are processed using antiplagiarism software. Institutions take a dim view of plagiarism. If there is plagiarised material, you may well have to account for it with your tutor and/or the Head of Sixth Form. A lenient view may be taken the first time, since you are considered to be doing it out of inexperience. The second time may end up that you have to resubmit the work, and you are warned. Multiple times may lead to a disciplinary.

1.0205 Animations

These can be found on many websites, and there are many programs available with which you can do your own. I am not skilled in the use of **animation software**. I have used *Paintshop Pro 7* which includes *Animationshop*. Both are now quite old programs. My own animations are crude, although illustrate the ideas. Some of my students, who are more skilled than I, have produced some very professional looking animations. Other programs include *Shockwave, Flash* and Photoshop.

The *Shockwave* and *Flash* files need a player. You can use the animated objects in *PowerPoint* as well. Most animations on the internet are either .MPEG or .GIF files.

Production of good animations is a skilful process that takes a long time. However, if you are skilled in ICT, you will find it very satisfying, and your skills would be sought after by many in the industry.

1.0206 Artificial Intelligence (AI)

Open confession is good for the soul. Being something of an old fart, I am of the generation that thinks that a landline telephone is a very smart idea. I have a mobile – a grumpy-old-git phone which can receive text messages as well as making telephone calls. In my lifetime, ICT has made massive advances that are almost impossible for me to keep up with. With these have come some very powerful tools for the professional physicist. Of these, **artificial intelligence** (AI) is the most powerful, even more so than the powerful supercomputers that process thousands of millions of calculations per second.

A common use for AI is often used to enhance pictures. As an example, I drew my bear-trap image using MS Publisher graphics as shown in Figure 83.

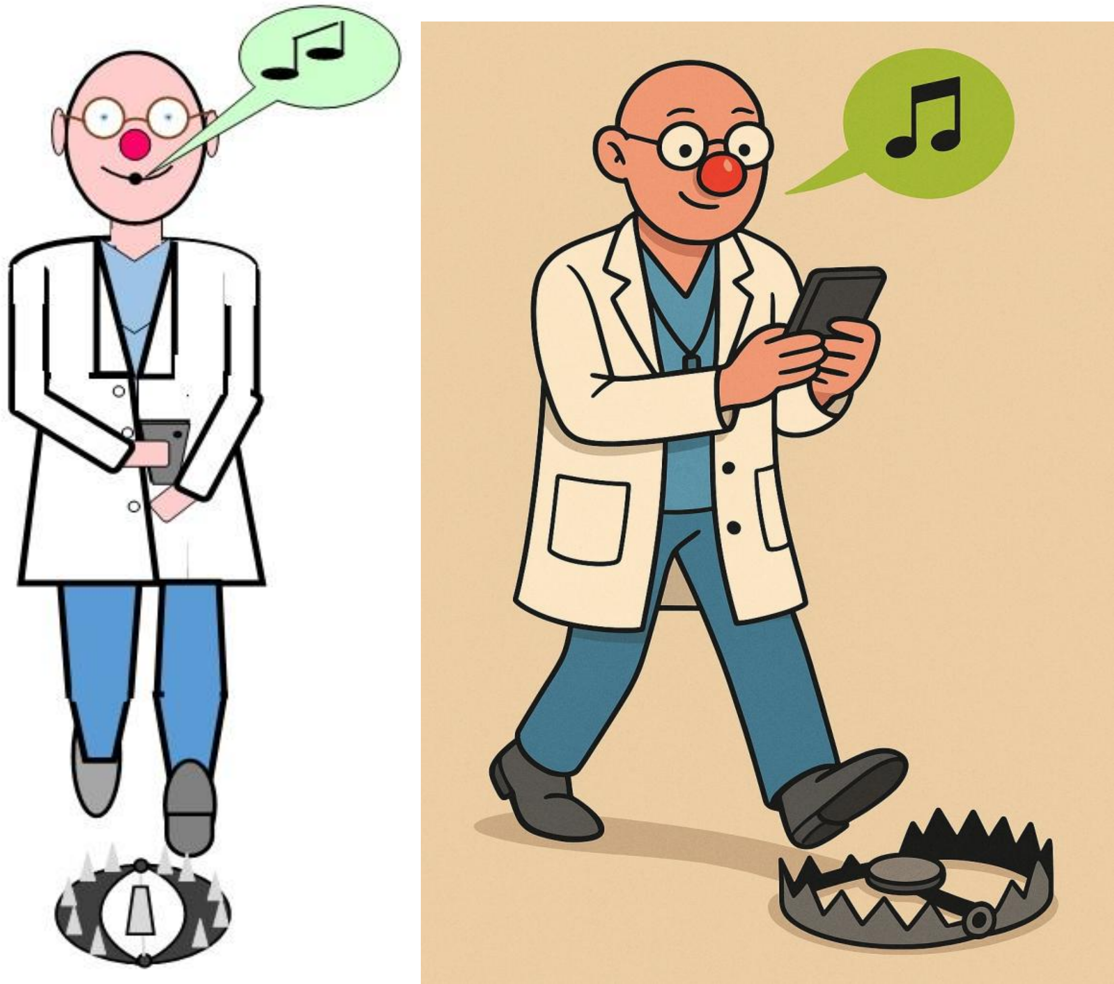


Figure 83 How AI can improve images

My original to the left is not very good. I am not a very good artist. My neighbour uploaded it using his mobile to produce the right-hand image. Rather better, you will agree. There are many ways in which AI can be used, such as in gaming, or to summarise inputs from many a source.

For the physicist, AI can use multiple sources of complex data to model difficult theories and to assess their validity. However, the final assessment has to be made with that superb but underrated device, the human brain. Remember that computers are just adding machines; they cannot subtract, divide, or multiply, let alone find the answer to life, the Universe, or everything else (the answer is 42). But they are very, very fast.

Answers to Questions

Tutorial 1.02

1.02.1

(a) $F = ma$: a – acceleration, F – Force, m – mass.
(b) $E = 1/2mv^2$: E – energy, m – mass, v – speed.
(c) $c = f\lambda$: c – wave speed, f – frequency, λ – wavelength.

1.02.2

(a) 15 cm = 0.15 m

(b) 500 g = 0.500 kg

(c) 3 km = 3000 m

(d) 35 mV = 0.035 V = 3.5×10^{-3} V

(e) 220 nF = 2.2×10^{-7} F = 220×10^{-9} F

1.02.3

(a) 1 m^2 = 1×10^6 mm^2
(b) 0.45 mm^2 = 4.5×10^{-7} m^2
(c) 1 cm^3 = 1×10^{-6} m^3
(d) 22.4 dm^3 = 0.0224 m^3

1.02.4
(a) 1 Coulomb = 1 amp × 1 second = 1 A s
(b) 1 Volt = 1 Joule per Coulomb = 1 kg m^2 s^{-2} ÷ A s = 1 kg m^2 A^{-1} s^{-3}

1.02.5
(a) $P = I^2R$: kg m^2 s^{-3} = A^2 × kg m^2 A^{-2} s^{-3}
The A^2 terms cancel:

$$\text{kg m}^2\text{ s}^{-3} = \text{kg m}^2\text{ s}^{-3}$$

These units are consistent, so this is the correct equation.

(b) $P = I^2 \div R$: kg m^2 s^{-3} = A^2 ÷ kg m^2 A^{-2} s^{-3} = kg m^2 A^4 s^{-3}.

These units are not consistent.

Tutorial 1.03

1.03.1

(a) 3200 – this can be entered.
(b) 5 600 000 – this can be entered.
(c) 2800 000 000 000 - this may overflow in the calculator, depending on how many figures it can handle.
(d) 0.000000000000341 - Many calculators would read this as 0.

1.03.2

(a) 86 = 8.6×10^{1}
(b) 381 = 3.81×10^{2}
(c) 45300 = 4.53×10^{4}
(d) 1 500 000 000 = 1.5×10^{9}
(e) 0.03 = 3.0×10^{-2}
(f) 0.00045 = 4.5×10^{-4}
(g) 0.0000000782 = 7.82×10^{-8}

1.03.3

a) $\dfrac{3.4 \times 10^{-3} \times 6.0 \times 10^{23}}{235} = 8.68 \times 10^{18}$
b) $\dfrac{27.32 - 24.82}{\sqrt{38}} = 21.1$
c) $1.4509^{3} = 3.05$
d) sin 56.4 = 0.833
e) $\cos^{-1} 0.4231 = 65.0°$
f) $\tan^{-1} 2.143 = 65.0°$
g) $\sin^{-1} 1.00052$ - Error; you can't have a sine bigger than 1.
h) Reciprocal of $2.34 \times 10^{5} = 4.27 \times 10^{-6}$
i) $\log_{10} 200 = 2.30$
j) 45 sin 10 = 7.81

1.03.4

Speed = 100 m ÷ 13 s

= 7.6923 m s^{-1}

= 7.7 m s^{-1} to 2 s.f.

Tutorial 1.04

1.04.1

The resistance, R.

1.04.2

The inverse proportionality is written as:

$$E \propto \frac{1}{d}$$

The constant of proportionality is V.

1.04.3

22/7 = 3.142857

π = 3.14159265...

Difference = 1.12644×10^{-3}

Uncertainty = 0.04 %

It's very close.

1.04.4

$$a = \frac{\Delta v}{\Delta t}$$

1.04.5

Equation	***Subject***	***Answer***
$V = IR$	R	$R = V/I$
$p = mv$	v	$v = p/m$
$r = m/V$	m	$m = rV$
$Q = CV$	C	$C = Q/V$

1.04.6

$pV = nRT$	V	$V = \frac{nRT}{p}$
$E_p = mg\Delta h$	Δh (Δh is a single term)	$\Delta h = \frac{E_p}{mg}$
$V = -\frac{GM}{r}$	G	$G = -\frac{rV}{M}$
$\lambda = \frac{ws}{D}$	D	$D = \frac{ws}{\lambda}$

1.04.7

Equation	***Subject***	***Answer***
$v = u + at$	t	$t = \frac{v-u}{a}$
$E = V + Ir$	r	$r = \frac{E-V}{I}$

1.04.8

Equation	***Subject***	***Answer***
$E_k = \frac{1}{2}mv^2$	v	$v = \sqrt{\left(\frac{2E_k}{m}\right)}$
$T = 2\pi\sqrt{\frac{m}{k}}$	k	$k = \frac{4\pi^2 m}{T^2}$
$f = \frac{1}{2\pi\sqrt{(LC)}}$	C	$C = \frac{1}{4\pi^2 Lf^2}$

1.04.9

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

- Rearrange:
  - $\frac{V}{V_0} = e^{\frac{-t}{RC}}$
- Take natural logs:

$$\ln\left(\frac{V}{V_0}\right) = \frac{-t}{RC}$$

- Then:

$$t = -RC \ln\left(\frac{V}{V_0}\right)$$

Tutorial 1.05

1.05.1

12.2.cm; 12.0.cm; 11.7 cm.

1.05.2

Take 0.1 N off each reading (or adjust he knurled knob).

1.05.3

Use a small screwdriver to turn the screw so that it reads zero.

1.05.4

(a) +/- 1 V
(b) 244 V +/- 1 V

1.05.5
(a) 75 g - 73 g = 2.0 g
(b) Balance B is more precise as the readings are more consistent.

1.05.6

Name	Width (cm)	Height (cm)	Depth (cm)	Capacity (cm^3)
Andy	10	9	7	630
Bill	11	8	6.5	572
Cass	10.8	7.9	6.4	547

Cass has the most accurate result, as it's closest to the actual result.

1.05.7

Range = 10.6 – 9.9 s = 0.5 s

1.05.8

(10.1 + 10.2 + 9.9 + 10.0 + 10.3 + 10.6 s) ÷ 6 = 10.18 s = **10.2 s** (3 s.f.)

Data are to 3 significant figures.

1.05.9

Resistances and uncertainties add up. 70 Ω ± 2.0 Ω

1.05.10

(a) 8.5 + 6.3 + 0.86 = 15.66 = 16 % (2 s.f.)

(b) Ω m

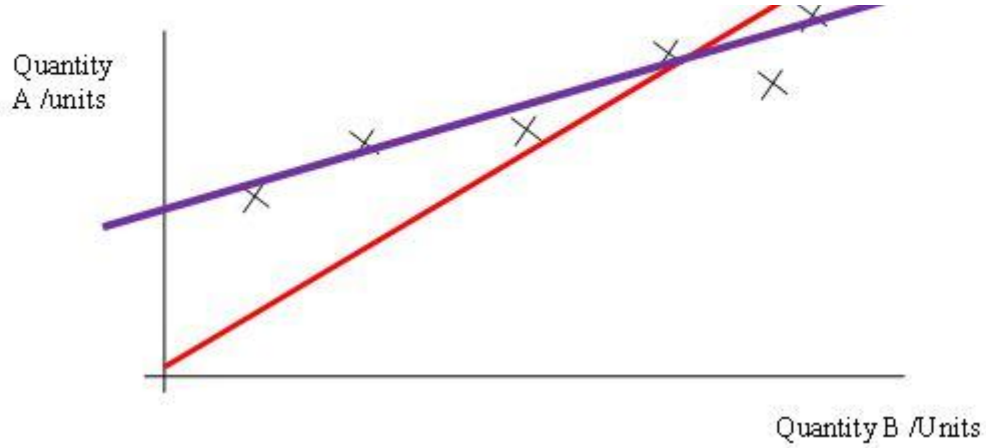
Tutorial 1.06

1.06.1

(a) Quantity A against quantity B.

(b) It misses many of the points.

(c) See diagram (purple line)



(d) It is wrong, as the correct line goes nowhere near the origin. Zero, nul points.

1.06.2

It's a straight line of positive gradient that goes through the origin.

1.06.3

It's a straight line of positive gradient that goes through the origin.

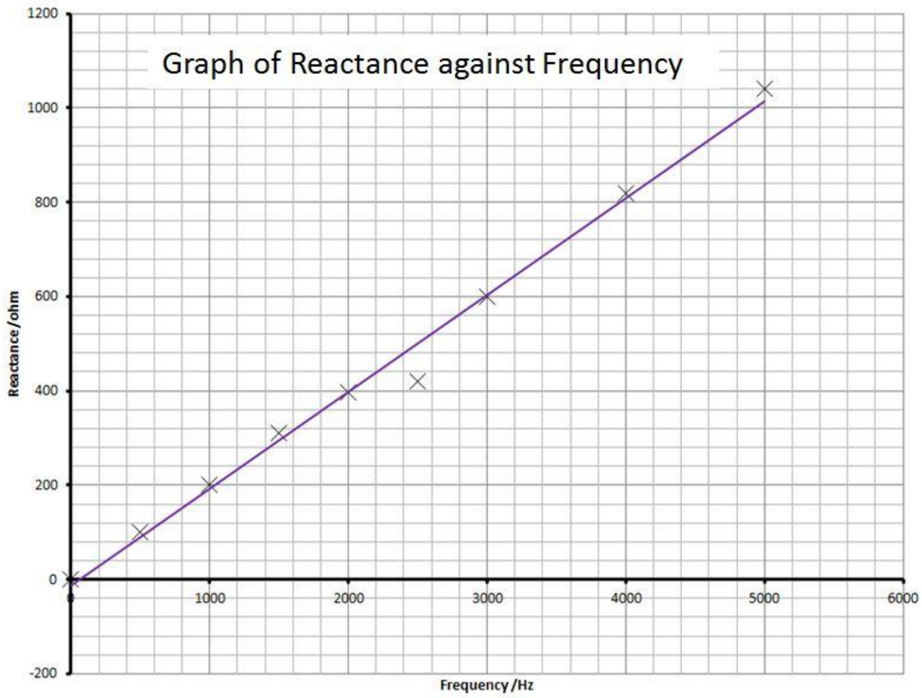
Units for I^2 are A^2.

1.06.4

$$x = \frac{y-c}{m}\,;\ y = 0 \Rightarrow x = \frac{-c}{m}$$

1.06.5

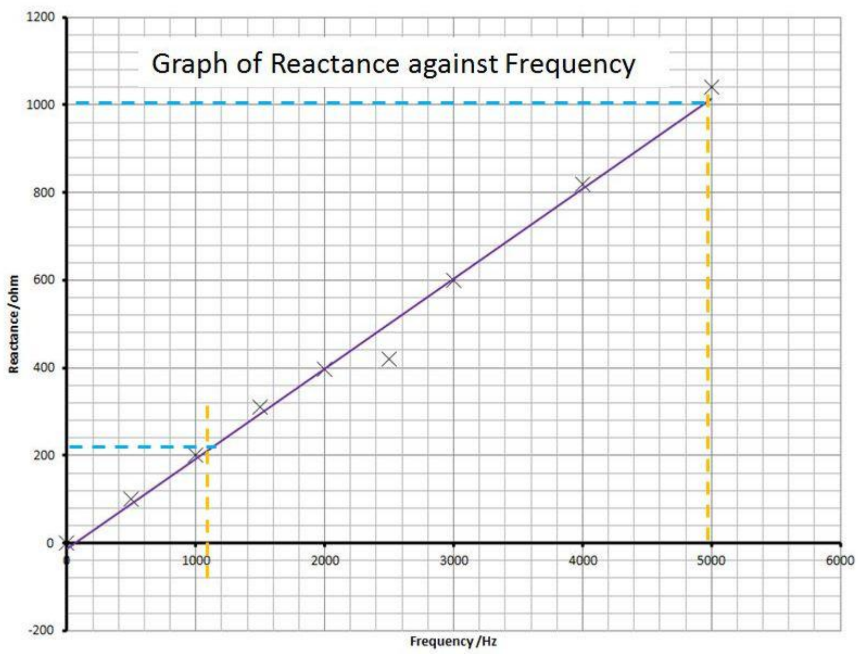
Graph:



(a) 840 Ω
(b) 3500 Hz.

1.06.6

Graph:



Δx = 5000 Hz – 1050 Hz =3950 Hz

Δy = 1000 W – 210 W = 790 Ω

Gradient = 790 Ω ÷ 3950 Hz = 0.2 Ω Hz^{-1}

Units: Ω Hz^{-1} = Ω s

1.06.7

Gradient = $\rho \div A$. Therefore ρ = Gradient × A

1.06.8

(a) Symbols match:

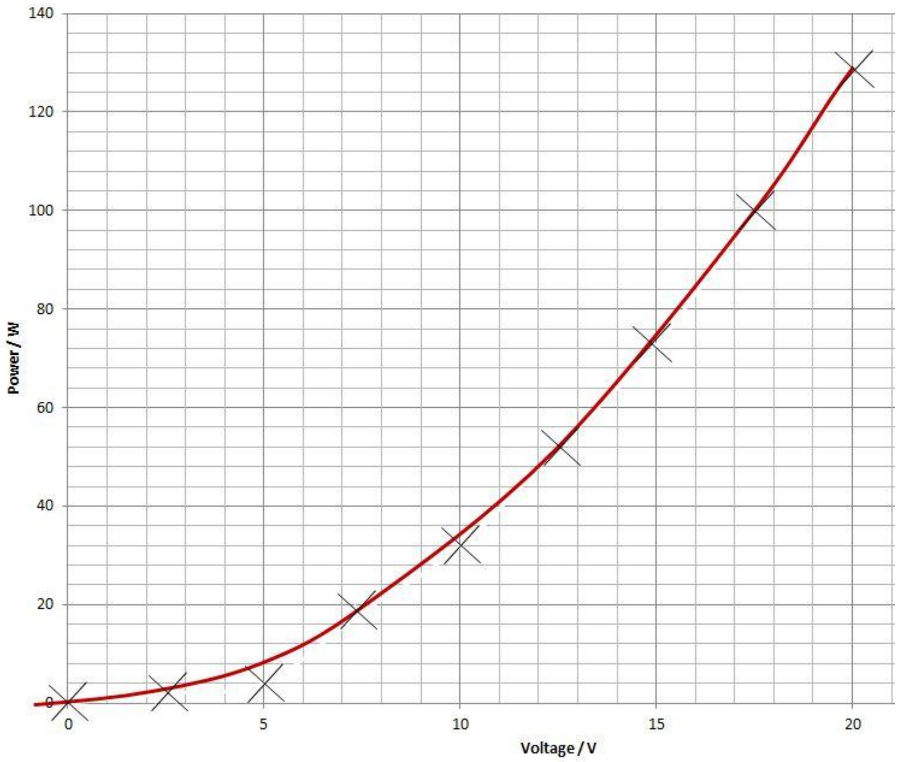
– $y \rightarrow V$
– $m \rightarrow -r$
– $x \rightarrow I$
– $c \rightarrow \varepsilon$

(b) The EMF.
(c) The maximum current.
(d) Find the (negative) gradient of the graph and multiply it by -1 to give a positive r.

Tutorial 1.07

1.07.1

(a)



e

(b) Anomalous result is (5, 4.1).
Repeat readings need to be taken.

1.07.2

At t_1 the acceleration of the car has a higher value than at t_2, shown by the gradient at t_1 being a higher value.

1.07.3

The average accelerations both have a higher value than the accelerations worked out by the tangents. At t_1 there is not much difference, but at t_2, the difference is substantial.

1.07.4

(a) Force /N against Extension /m

(b) N × m = N m (= J)

1.07.5

Voltage:

Uncertainty = (0.10 ÷ 0.5) × 100 = 20 %

Current:

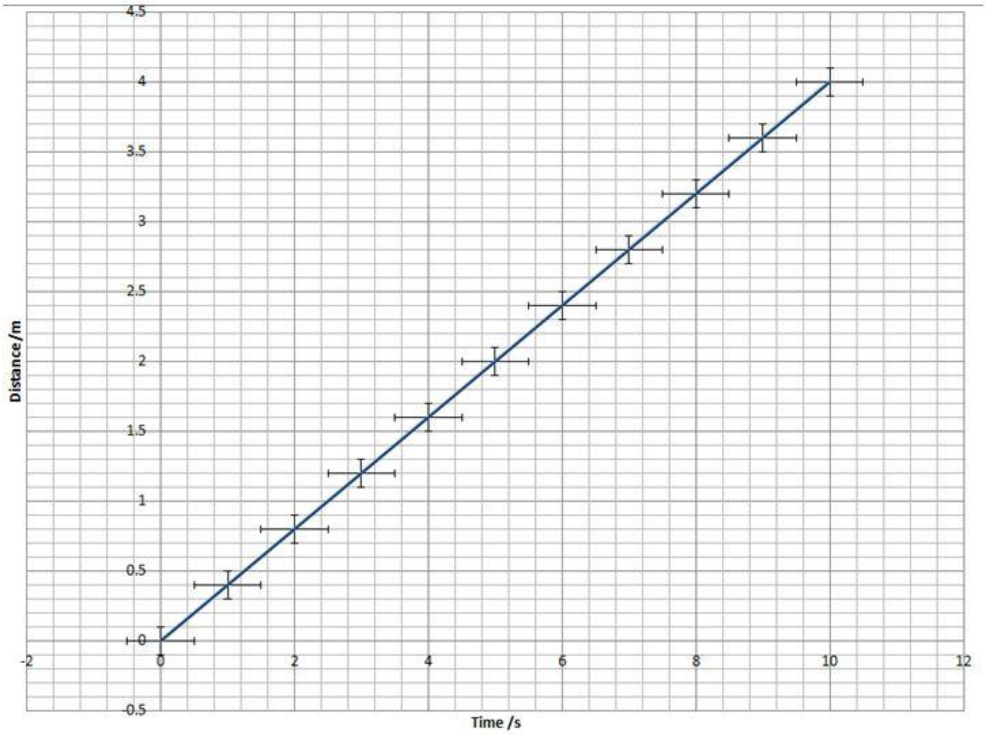
Uncertainty = (0.05 ÷ 0.1) × 100 = 50 %

1.07.6

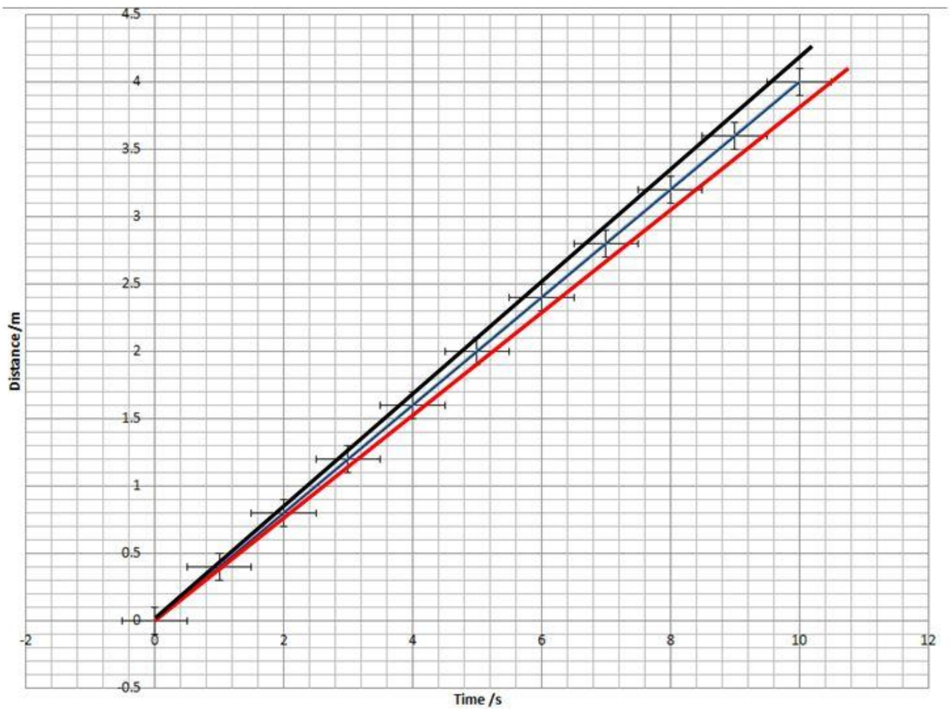
They are not very precise, so are not that good quality.

1.07.7

Graph:



1.07.8



1.07.9

The maximum gradient gives a rise of 4 m in 9.6 s.
This gives a gradient of 4 m ÷ 9.6 = 0.42 m s^{-1}.

Minimum gradient:
  Δy = 4.0 – 0 = 4.0 m
  Δx = 10.4 – 0 = 10.4 s
Gradient = 0.38 m s^{-1}

Tutorial 1.08

1.08.1

When you write something about your A-level Physics, you can be tempted to depend too much on your spell check. It does not pick up every mistake. Many students lose lots of marks because their writing is poor. Sometimes they write rubbish.

Physics has lots of technical terms. It's going to be important to make sure that they're used properly. They will be explained during the course. For example, weight is a force, while current is read from an ammeter. Chemists use density, which is mass divided by volume.

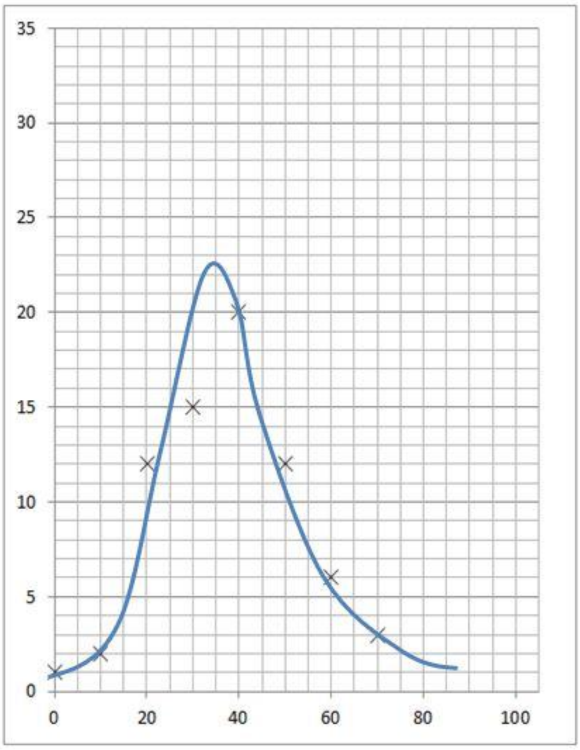
1.08.2

(a) The data that are harvested are x / m and Time for 20 Oscillations (t_1 / s, t_2 / s, t_3 /s)

(b) The processed data are:

- t_{mean} / s.
- Time period T / s.
- log10 (t / s).
- log10 (x / m).

1.08.3



- It is just about OK to cover the paper.
- It is quite small.
- To make it bigger, an awkward scale would be used.

1.08.4

The graph looks OK. It is large and the scales are reasonable.

But the scales are cut off, making it impossible to determine whether the line goes through the origin, or whether there is an intercept, and what value that intercept would have.

Tutorial 1.09

1.09.1

Change in speed = 4 m s^{-2} × 10 s = 40 m s^{-1}.
New speed = 30 m s^{-1} + 40 m s^{-1} = 70 m s^{-1}.
Distance = 70 m s^{-1} × 500 s = 35 000 m.

1.09.2
The answers are not reasonable.
A cheetah can sprint at about 30 m s-1.
It can maintain this speed for about 100 m.

1.09.3
The young man is far too big for the room.

The height of the room is about 80 cm, assuming the young man is about 60 cm in shoulder width.

1.09.4

Width of the car is 65 mm.
Scale is 65 ÷ 1695 = 0.0383 = 1/26th scale.

Note: This answer uses values that were correct for the A4 sized booklet on which it was printed. It may well be different on your display.

1.09.5

6 mm = 200 nm. The shape is 60 mm across, so it's 2000 nm across, i.e. 2 μm.

Note: This answer uses values that were correct for the A4 sized booklet on which it was printed. It may well be different on your display.

1.09.6
A – diameter of a proton;
B – diameter of a nucleus;
C – size of a dust particle;
D – your height;
E – height of Ben Nevis;
F – diameter of the Sun;
G – distance to nearest galaxy.

1.09.7

Current taken by the starter is 500 A;
Power is 500 A × 12 V = 6000 W;
32 amp-hour = 32 A × 3600 s = 115200 C
Energy = 115200 C × 12 V = 1.38×10^{6} J
Time taken = 1.38×10^{6} J ÷ 6000 W = 230 s

Distance travelled = 230 s × 1 m s^{-1} = 230 m;
I would expect the car to move about 200 m.

Tutorial 1.020

There are NO questions.

Now to get on with some Physics!