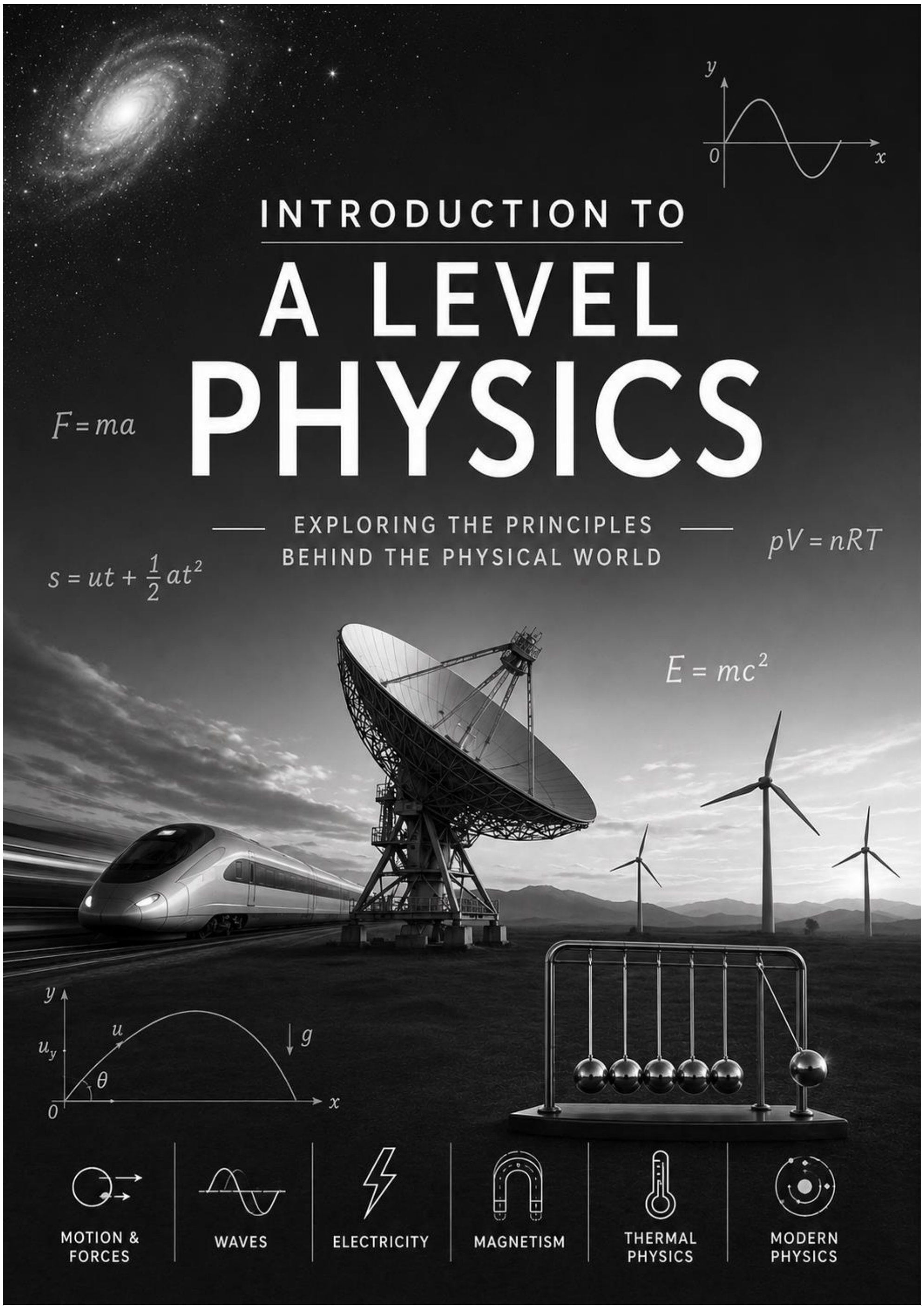
Physics summer work

It's not rocket science… oh wait, it is!



Name: ……………………………………………………………

This booklet covers the essential skills you need to have in order to start, and be successful at, A level Physics. You should have seen the content of most of this booklet before, but we will be using and building upon these heavily.

However, part 6: practical skills will be new. These are skills which you will develop over the two-year course. Give it a go!

Each section has an information section as well as one or two exercise for you to practice. Please complete and mark your work so that you are as prepared as possible to begin the course!

Contents:

Section	**Page**
Part 1: Algebra	3
Part 2: Graphs	6
Part 3: Geometry	11
Part 4: Standard Form	17
Part 5: Physical Quantities and Their Units	24
Part 6: Uncertainty	29
Answers	35

PART 1: Algebra

There are a lot of equations in A level physics… You will need to take a formula and **change its subject.** The subject of a formula is the letter which is on its own, on one side of the equals sign.

Type 1 – Rearranging simple equations

Formula: **F = ma**

At the moment, **F** is the subject of this formula.
I want to make **m** the subject of the formula.

Solution:
In order to get **m** on its own, I have to move the **a** to the left-hand side.
Notice what the **a** is doing to the **m**: it is MULTIPLYING.
When I move the **a** to the left-hand side, I must do the opposite: DIVIDE by **a.**

Answer: $\frac{F}{a} = m$

So the formula has now got **m** as its subject.

Exercise 1: Rearranging simple equations

1. Rearrange each of these Physics formulae, to make the letter given in brackets the subject:

i) W = mg (m)

ii) W = Fd (F)

iii) $P = \frac{F}{A}$ (F)

iv) $E = mc^2$ (m)

v) E = mgh (h)

vi) $s = \frac{d}{t}$ (t) – Be careful: you need to do 2 rearrangements here.

Type 2 – rearranging more complex equations

Take this slightly more complicated formula: **$E = \frac{1}{2} mv^2$**

At the moment, **E** is the subject of this formula.
I would like to make **v** the subject.

Solution:
In order to leave v on its own, I need to do 3 jobs:

First: move the ½ to the left-hand side.
At the moment, we are MULTIPLYING the right-hand side by **½,** so – in order to reverse this – I will DIVIDE the left-hand side by **½.**
But – dividing by **½** is the same as multiplying by **2**, so the formula becomes:

$2E = mv^2$

Second: move the m to the left-hand side.
At the moment, we are MULTIPLYING by **m**, so – in order to reverse this – I will DIVIDE the left-hand side by **m**.
So the formula becomes:

$$\frac{2E}{m} = v^2$$

Third: we need to leave **v** on its own.
At the moment, we are SQUARING the **v**, so – in order to reverse this – I will SQUARE ROOT both sides of the formula. So the formula becomes:

$$\sqrt{\frac{2E}{m}} = v$$

Exercise 2: Rearranging more complex equations
1. Rearrange these (fictitious!) formulae to make the given letter the subject:

i) $P = 3kr^2$ (r)

ii) $Q = \frac{1}{2} nt^2$ (t)

iii) $R = \frac{mp^2}{2}$ (p)

iv) $M = \frac{st^3}{5}$ (t)

(Be careful – in this one, you will not take the SQUARE ROOT, but rather the CUBE ROOT)

Type 3 – Rearranging even more complex equations!

Take this more complicated formula: $\mathbf{s = ut + \frac{1}{2} at^2}$

At the moment, **s** is the subject. I would like to make **a** the subject. This will require 3 jobs.

I would like to leave **a** on its own on the right-hand side. Notice what is happening to the **a**:
Firstly – it is being MULTIPLIED by **½** .
Secondly – it is being MULTIPLIED by $\mathbf{t^2}$.
Thirdly – the expression **ut** is being ADDED to this quantity.

In order to rearrange the formula, I must reverse each of these operations. I must do each of these jobs in REVERSE order, as follows:

First – I will move the expression **ut** by SUBTRACTING it from the left-hand side. The formula becomes:

$$\mathbf{s - ut = \frac{1}{2} at^2}$$

Second – I will move the $\mathbf{t^2}$ by DIVIDING the left hand side by $\mathbf{t^2}$. The formula becomes:

$$\mathbf{\frac{s - ut}{t^2} = \frac{1}{2} a}$$

Third – I will move the **½** by DIVIDING the left-hand side by **½**. Remember: this is the same as MULTIPLYING the left-hand side by **2**. The formula becomes:

$$\mathbf{\frac{2(s - ut)}{t^2} = a}$$

a is now the subject of the formula.

Exercise 3: Rearranging even more complex equations!

1. Rearrange these (fictitious!) formulae to make the given letter the subject:

i) $t = ab + 3pq^2$ (p)

ii) $m = \frac{1}{2} tv - 2ac$ (a)

iii) $s = 3pq + \frac{1}{2} pm^2$ (q)

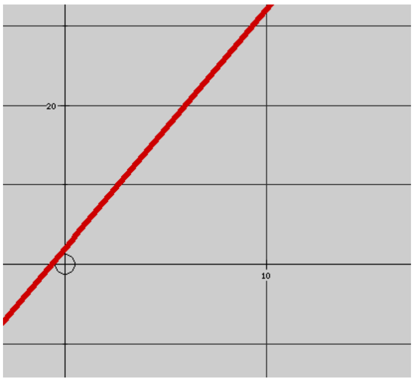
iv) $W = \frac{1}{2} mk^2 - 7m$ (k)

v) $E = \frac{sba}{3} + 4t$ (t)

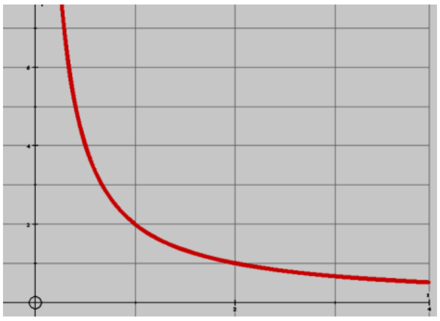
Part 2: Understanding Graphs

Graphs are a very important tool in Science. They are used to display the relationship between two sets of data (two variables). Two important types of relationship are:

i) Direct Proportionality

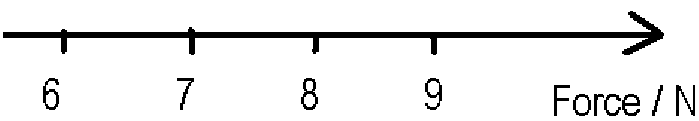


ii) Indirect Proportionality



It is important to realise that – in order to plot a graph – you are only interested in the numerical values of your data (i.e. you are dividing the physical quantity by its unit). You should label this on your axes as follows:

E.g.: If you are plotting Force data on the x-axis, the label would look like this:

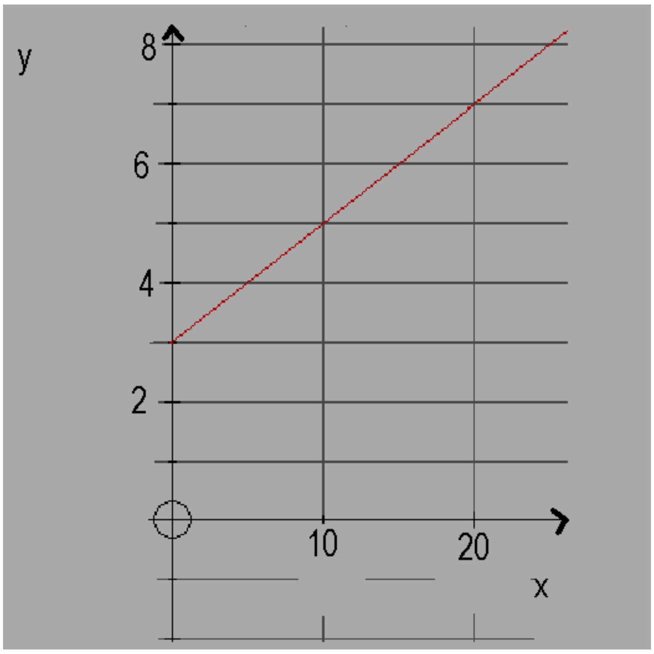


Straight-Line Graphs

Straight line graphs are particularly useful in physics, since they can be used to work out the equation that connects the two variables. All straight line graphs follow the pattern:

$$y = mx + c$$

where:
y represents the variable which is plotted on the vertical (y)-axis
x represents the variable which is plotted on the horizontal (x)-axis
m represents the gradient of the line
c represents the y-intercept of the line: this is where the line cuts the y-axis.
Example: Interpreting a Straight-Line Graph



Find the gradient.

Find the intercept.

Hence, write down the equation connecting y and x.

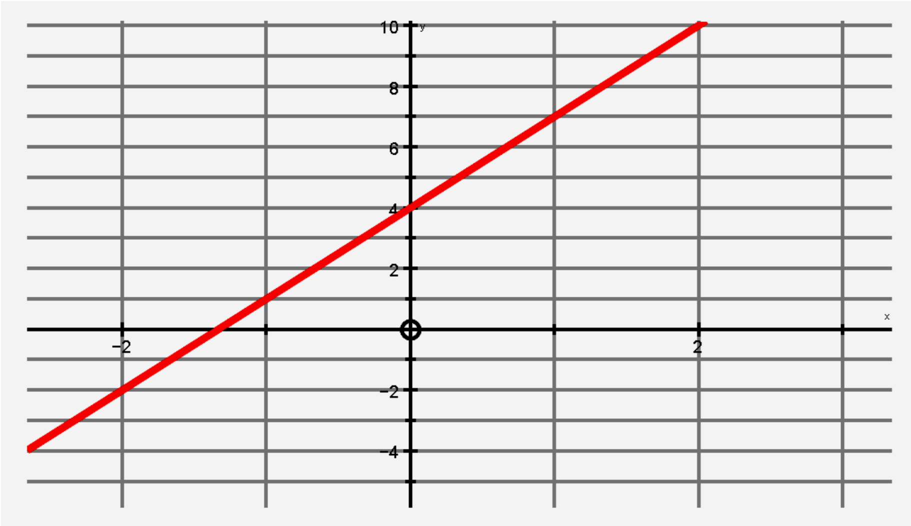
In Physics, we sometimes need to find the area underneath a graph, as this value can tell us something we need for our problem.
Calculate the area under the graph, between x = 0 and x = 20.

Exercise 4: Working with Straight-Line Graphs

For the following straight-line graphs, find:

i) the gradient
ii) the intercept
iii) the equation which connects the variables
iv) the area under the graph, between the x-values indicated.

Graph 1 – find the area under the graph, between the values x = 0 and x = 2



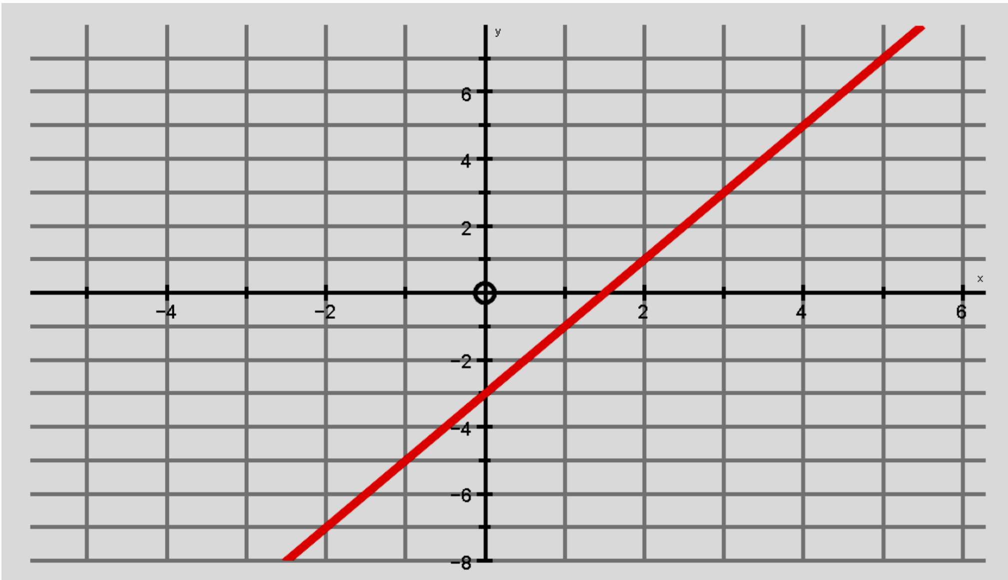
Gradient:

Intercept:

Equation:

Area:

Graph 2 - find the area under the graph, between the values x = 2 and x = 4



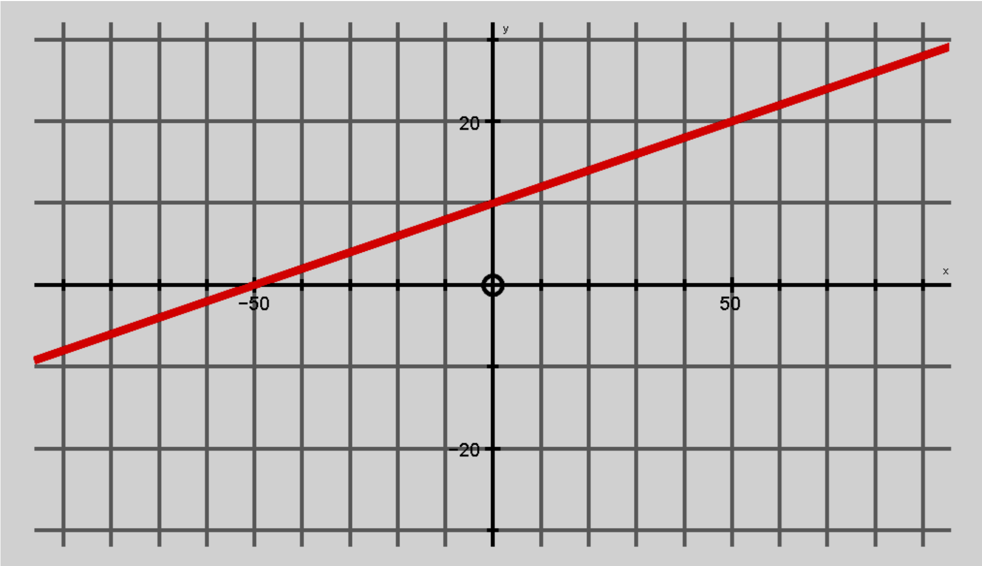
Gradient:

Intercept:

Equation:

Area:

Graph 3 - find the area under the graph, between the values x = 0 and x = 50



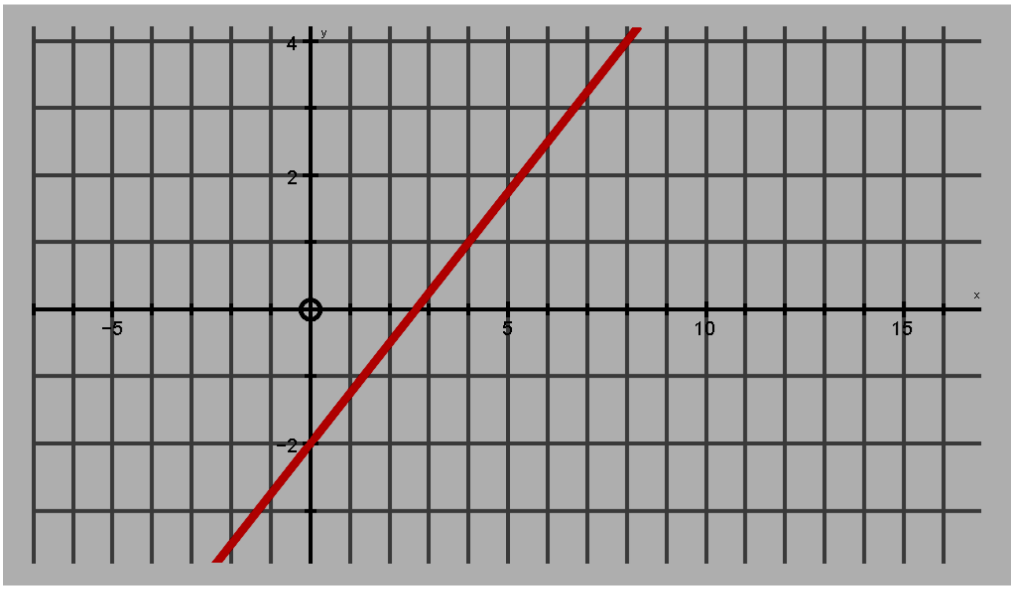
Gradient:

Intercept:

Equation:

Area:

Graph 4 - find the area under the graph, between the values x = 4 and x = 8



Gradient:

Intercept:

Equation:

Area:

Exercise 5: Graph Plotting

A student performs an experiment involving stretching a metal spring, by applying a force and measuring the length of the spring. She collects the following data:

Force / N	3.4	7.3	8.4	10.6	15.7	6.9
Length / m	0.13	0.81	0.20	0.22	0.29	0.17

The Force is called the **Independent Variable**, since this is the factor that she is controlling: it should be plotted on the x-axis.

The Length is called the **Dependent Variable**, since this depends on the Force that the student applies: it should be plotted on the y-axis.

i) Plot the graph of Force against Length.

ii) Explain the second data point in the table. Why do you think she took the final measurement in the table?

iii) Draw the line of best fit through the data.

iv) Find the gradient, intercept and equation of the graph.

v) Explain what is meant by the value of the intercept.

vi) Use your graph to estimate the force required to stretch the spring to a length of 25cm.

vii) The student knows that the area under the graph represents the amount of Energy stored in the stretched spring. Use your graph to estimate the Energy stored in the spring when it is stretched to a length of 25cm.

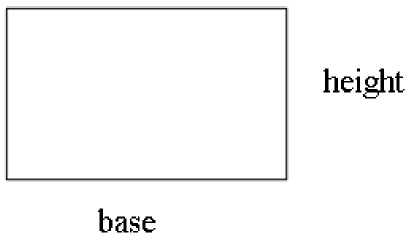
Part 3: Geometry

There are two mechanics modules in A level physics so understanding trigonometry and vectors is essential. However, the skills outlined in this unit come up again and again all over the course. Even more reason to master them!

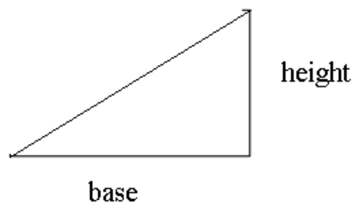
Calculating Areas and Volumes

Basic formulae:

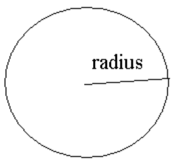
Area of a rectangle = base x height



Area of a triangle = $\frac{\text{base x height}}{2}$

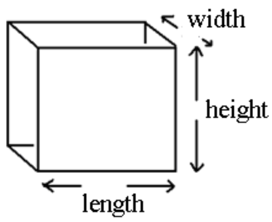


Circles:
Diameter = 2 x radius
Circumference = π x diameter
Area = πr^2

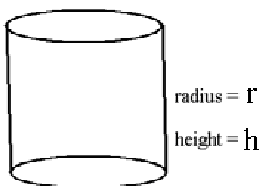


r = radius
π is approximately 3.14

Volume of a cuboid = length x width x height

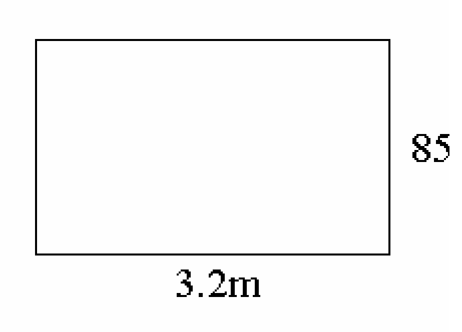


Volume of cylinder = area of circular end x height
= πr^2 x h



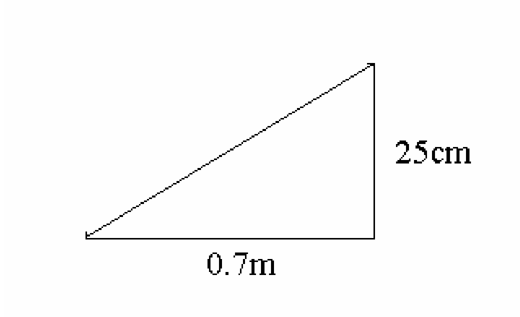
Exercise 6: areas and volumes

1. Find the area of the rectangle below:

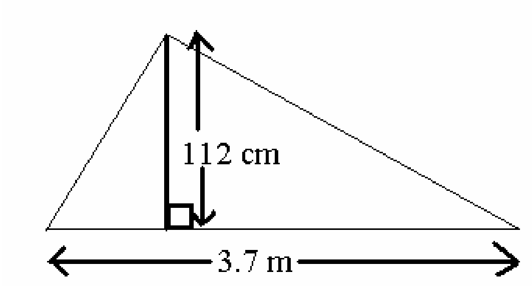


2. Find the area of the triangles below:

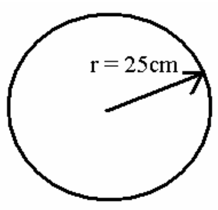
a)



b)



3. Circles:



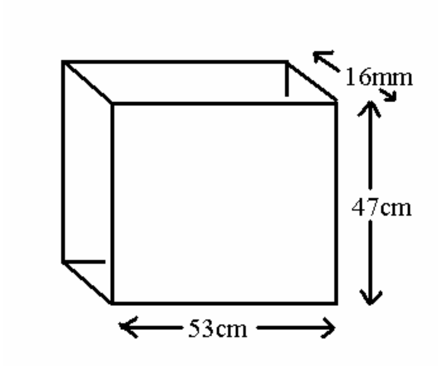
   a) State the diameter of the circle:

   b) Find the Circumference of the circle:

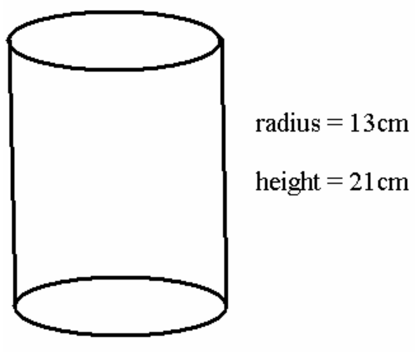
   c) Find the area of the circle:

4. Another circle has area $189cm^2$. Find its circumference.

5. Find the volume of this cuboid:



6. Find the volume of this cylinder:



In that last section, you should have noticed that some of the units needed converting. Before we go any further, let's practice this

Exercise 7: Converting Units with multiples and sub-multiples.

Distance:

i) 6.4km = _______m

ii) 3.68m = _______mm

iii) 56,900mm = _______m

iv) 906,893cm = ________km

v) An ant is 1.3mm long. How many ants would there be in a line 4.9km long?

vi) A pile of 45000 sheets of paper is 57cm high. What is the thickness of a sheet of paper?

vii) The distance between the Earth and the Moon is around 400,000km. Estimate how many people would need to stand one on top of the other in order to reach the Moon.

Area:

i) $16cm^2$ = ______mm^2

ii) $158mm^2$ = ______cm^2

iii) $169000cm^2$ = _________m^2

iv) $1.73m^2$ = __________cm^2

v) $6.034m^2$ = _____________mm^2

Hint!!!:

12cm x 15cm = $180cm^2$

$180cm^2 \neq 1.8m^2$

Instead, 0.12m x 0.15m = $0.018m^2$

To convert from cm^2 to m^2

You need to x 10^{-2} x 10^{-2} or the equivalent of x 10^{-4}

Volume:

i) $9m^3$ = ___________cm^3

ii) $489mm^3$ = _________cm^3

iii) $8526km^3$ = ____________m^3

iv) $42,600,000,000mm^3$ = _________m^3

Time:

iii) How many seconds are there in September?

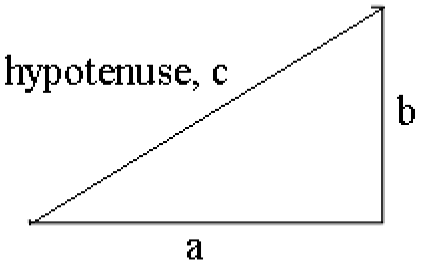
iv) How many seconds in a year?

v) Light travels 300,000km every second. How far would it travel in a year?

vi) A drum-skin vibrates once every 3ms (millisecond). How many times would it vibrate in 1 second?

Right-Angled Triangles: Pythagoras' Theorem and Trigonometry

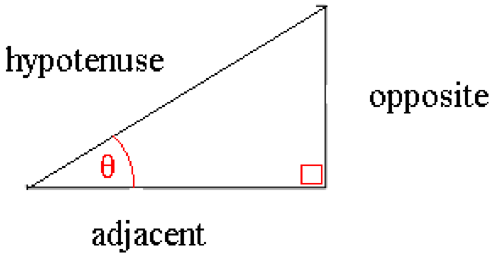
Pythagoras' Theorem: To be used when we are dealing with the lengths of sides, but not angles.



In any right-angled triangle, the longest side is called the hypotenuse, and is labelled c.
The other two sides are labelled a and b (it doesn't matter which way round).
The lengths of the three sides are connected by the formula:

$c^2 = a^2 + b^2$

Trigonometry with Right-angled triangles: To be used when we are dealing with angles as well.



The longest side is called the hypotenuse (**hyp**).
The side opposite the angle we are dealing with is called **opp**
The side adjacent to (next to) the angle is called **adj**

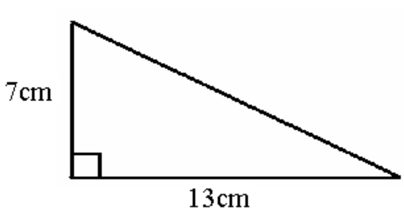
3 rules:

$$tan\theta = \frac{opp}{adj} \qquad sin\theta = \frac{opp}{hyp} \qquad cos\theta = \frac{adj}{hyp}$$

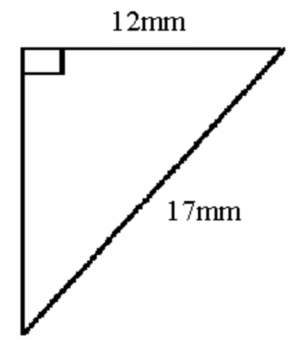
Exercise 8: Right-Angled Triangles

1. Use Pythagoras' Theorem to calculate all the missing sides.

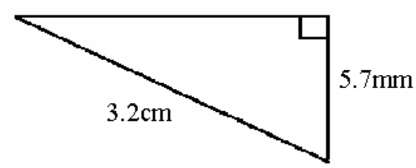
a)



b)

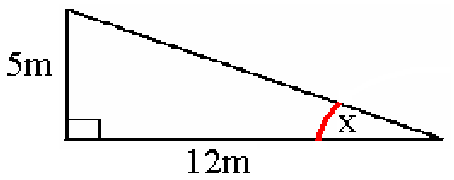


c)

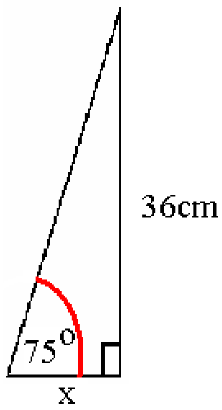


2. Use Trigonometry rules for Right-angled Triangles to calculate the missing sides or angles.

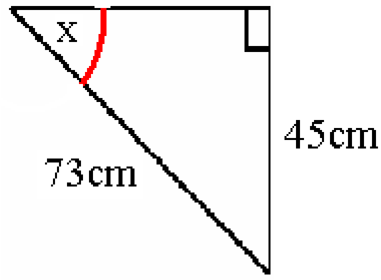
a)



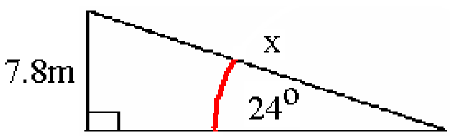
b)



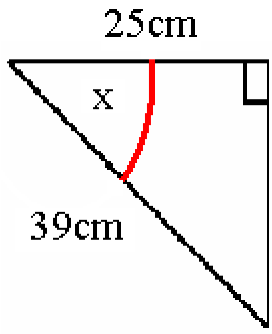
c)



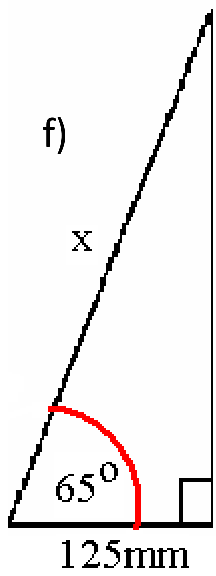
d)



e)



f)



Part 4: Standard Form

Standard Form is a useful way of writing numbers which are either very large or very small. You will be using it throughout your work in Physics. It is based on powers of 10, as shown in the following table:

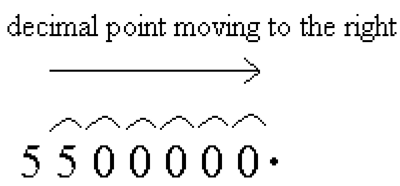
10^6	= 10 x 10 x 10 x 10 x 10 x 10	1,000,000
10^5	= 10 x 10 x 10 x 10 x 10	100,000
10^4	= 10 x 10 x 10 x 10	10,000
10^3	= 10 x 10 x 10	1,000
10^2	= 10 x 10	100
10^1	= 10	10
10^0	Notice: any number to the power of 0 equals 1.	1

So, for example, we can express a very large number, such as 5,500,000 in the following way:

5,500,000 = 5.5 x 1,000,000 = 5.5 x 10^6

Notice, we can convert backwards into "ordinary" form:

5.5 x 10^6: This tells us that we need to move the decimal point 6 places to the right, putting zeroes into all the new columns that we create:



Exercise 9: Dealing with large numbers

1. Express these large numbers in standard form:

a) 3,800,000 =

b) 734,000 =

c) 12,600,000 =

d) 1,893 =

2. Express these large numbers in “ordinary” form:

a) 2.7×10^4 =

b) 3.15×10^5 =

c) 9.11×10^8 =

d) 1.003×10^3 =

Standard form can also be used to express very small numbers. To do this, you need to remember the meaning of a negative power:

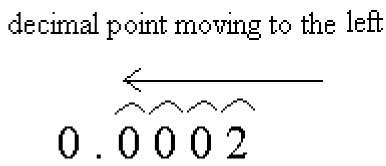
Eg: $10^{-2} = \frac{1}{10^2} = \frac{1}{100} = 0.01$ and $10^{-3} = \frac{1}{10^3} = \frac{1}{1,000} = 0.001$

Example:

$0.0002 = 2 \times 0.0001 = 2 \times \frac{1}{10,000} = 2 \times 10^{-4}$

Again, we can work backwards:

2×10^{-4}: The decimal point is currently after the figure 2. We need to move it to the LEFT, 4 places:



Exercise 10: Dealing with small numbers

1. Express these small numbers in standard form:

a) 0.003 =

b) 0.00025 =

c) 0.0000017 =

d) 0.0134 =

2. Express these small numbers in "ordinary" form:

a) 1.2×10^{-4}

b) 3.645×10^{-7}

c) 2.41×10^{-9}

d) 6.79×10^{-5}

<u>Using standard form on a Scientific Calculator:</u>

It is important that you get used to using your Scientific Calculator when dealing with numbers in standard form. If you don't have a calculator capable of doing this next exercise, then you must get one. You don't even need to buy the graphical calculator which the maths department flogs, my decent calculator has been doing me fine for the last twenty years thank you very much!

When you are confident using this facility of your calculator, it makes calculations with numbers in standard form very easy.

<u>Exercise 11: Using your calculator</u>

1. Find the answers to the following using your calculator:

a) $6.3 \times 10^4 + 2.15 \times 10^5 =$

b) $3.178 \times 10^8 - 8.64 \times 10^7 =$

c) $1.57 \times 10^7 \times 2.89 \times 10^3 =$

d) $5.39 \times 10^{-4} \times 2.14 \times 10^{-2} =$

e) $\dfrac{6.99 \times 10^{11}}{1.03 \times 10^8} =$

Now try these Physics problems:

2. A beam of light travels 3×10^8m every second. How far will it travel in:

a) 1 minute?

b) 1 hour?

c) 1 day?

d) 1 year?

3. The Andromeda galaxy is approximately 2×10^6 light-years away. How far is this in metres? (Hint: 1 light-year is defined as the distance travelled by a ray of light in 1 year).

4. The diameter of an atom is approximately 1×10^{-10}m. How many atoms would you need to place side-by-side in order to stretch across a distance of 6m?

5. The mass of an electron is 9.11×10^{-31}kg. What is the mass of 100 billion electrons? (Hint: 1 billion = 1×10^9)

Making Estimates of Physical Quantities

Sometimes, it is important to estimate quantities to get an understanding of their impact. For example, why does the gravitational attraction between two protons not matter when they repel each other? Using some calculations, we can estimate that the electrostatic repulsion between protons is around 10,000x larger than their gravitational attraction when they are 1 μm apart. Hence, we can completely ignore the force of gravity when dealing with protons.

	Mass / kg		Distance/ m		Time /s		Power/ W
Galaxy	10^{41}						
Sun	6×10^{26}					**Sun**	10^{26}
Earth	6×10^{24}						
Moon	2×10^{24}	**Universe** **Earth to Sun**	10^{24} 1.5×10^{11}	**Since the Big Bang** **Age of Earth**	5×10^{17} 2×10^{17}	**Power of sunlight reaching the Earth**	10^{17}
Supertanker	5×10^{8}	**Sun's radius** **Earth to Moon** **Earth's radius**	7×10^{8} 4×10^{8} 6.4×10^{6}	**Lifetime of human** **Year**	2.5×10^{9} 3.2×10^{7}	**Power station** **Locomotive**	10^{9} 5×10^{6}
Train	6×10^{5}					**Family Car**	10^{6}
Jumbo Jet	1.6×10^{5}	**London to Paris** **Marathon race**	3.4×10^{5} 4.2×10^{4}	**Day**	86400		
Lorry	40000	**Radio wavelength**	1500	**Hour** **10000 m race**	3600 2000		
Car	1000	**Race track** **Pyramids**	400 150	**Time to boil an egg**	300	**I horse power** **Human power**	746 100
Person	80	**Height of a house**	10	**Minute**	60	**Light bulb**	30
New Baby	3	**Height of a person**	2				
Mouse	0.1	**Eye radius**	0.02	**Heart beat**	1	**Clock**	10^{-3}

Human egg	2 x 10^{-6}	**Light wavelength** **X-ray wavelength** **Hydrogen atom diameter**	5 x 10^{-7} 10^{-10} 5 x 10^{-11}				
Blood corpuscle	1 x 10^{-12}	**Proton diameter**	1 x 10^{-15}	**Period of a light wave**	2 x 10^{-15}		
DNA molecule	3 x 10^{-18}						
Uranium-238 atom	4 x 10^{-25}						
Proton	1.6 x 10^{-27}						
Electron	9 x 10^{-31}						

<u>Exercise 12: Estimations</u>

Use the table of data on the previous page to help you to estimate the following quantities. Give your estimates in standard form.

1. How many cars would you need to put together to have the same mass as a supertanker?

2. Estimate the number of cells in the human body.

3. Estimate the number of protons in a mouse's body.

4. Estimate how long it would take you to walk non-stop around the world.

5. How many light bulbs would you need to put together to give the same power output as the Sun?

6. How old is the Universe, in years?

7. Cosmologists estimate that the observable Universe contains around 10^{11} galaxies. Astrophysicists estimate that the vast majority of the matter in the Universe is in the form of Hydrogen. A Hydrogen atom is composed of a single proton and a single electron. Estimate the number of atoms in the Universe.

8. If you were to take your body apart, atom by atom, and lay them all in a line, how far would they stretch?

Part 5: Physical Quantities and their Units

Symbols and Units:

At A level, units like metres per second (m/s) are written in index notation: ms^{-1}. When a symbol is given a power of -1, it means that you are DIVIDING by that symbol.

Similarly, you will be working with the units of ACCELERATION in this module: this quantity has the units metres per second-squared (m/s^2). In index notation, this is written ms^{-2}.

Prefixes for Multiples and Sub-Multiples of Units.

In Physics, you will be dealing with both the LARGEST and the SMALLEST things in the Universe, and you will soon encounter situations where the scale of the standard units is completely inappropriate. So, we use different prefixes (symbols in front of the unit) to represent different amounts of that unit. You should learn the following symbols:

Prefix	Symbol	Apply prefix to amperes				
		Words	**Symbol**	**Conversion factor (decimal)**	**Conversion factor (power of 10)**	**Example**
Tera	T	tera-amperes	TA	×1 000 000 000 000	$\times 10^{12}$	3.6 TA = 3.6×10^{12}A or 3 600 000 000 000 A
Giga	G	giga-amperes	GA	× 1 000 000 000	$\times 10^{9}$	72 GA = 72×10^{9}A or 72 000 000 000 A
Mega	M	mega-amperes	MA	× 1 000 000	$\times 10^{6}$	0.55 MA = 0.55×10^{6}A or 550 000 A
kilo	k	kiloampere	kA	× 1000	$\times 10^{3}$	7.8 kA = 7.8×10^{3}A or 7 800 A
centi	c	centiampere	cA	÷ 100	$\times 10^{-2}$	7.4 cA = 7.4×10^{-2} or 0.074 A
milli	m	milliampere	mA	÷ 1 000	$\times 10^{-3}$	3.6 mA = 3.6×10^{-3}A or 0.0036 A
micro	μ (Greek letter 'mu')	microampere	μA	÷ 1 000 000	$\times 10^{-6}$	5.7 μA = 5.7×10^{-6}A or 0. 000 005 7 A
nano	n	nanoampere	nA	÷ 1 000 000 000	$\times 10^{-9}$	6.2 μA = 6.2×10^{-9}A or 0. 000 000 006 2 A

Exercise 13: Problems with Units

1. Convert the following distances into metres (m).
a) 6km
b) 149km
c) 12cm
d) 7mm
e) 17Gm
f) 13nm
g) 15000pm

2. A current of 3.5 micro-amps (µA) flows through a circuit. What is this current in Amps?

3. A star has a mass of 100 million tera-grams (Tg). What is its mass in kilograms? (Answer in Standard Form)

4. An atom has a diameter 1.5×10^{-10} m. Express its diameter in nanometres (nm) and picometres (pm).

5. The Sun has a mass of approximately 10^{30} kg. It is estimated that there are approximately 100 billion stars in our Galaxy. It is estimated that there are approximately 100 billion galaxies in the observable Universe. It is also estimated that stars make up approximately 10% of all the matter in the Universe. Calculate an estimate of the mass of the observable Universe.

Science involves making measurements of certain physical quantities, or using formulae to calculate their values. Physical quantities include things like: distance, time, force, mass, temperature, energy etc.

In Physics, you must always quote the unit of the physical quantity that you have calculated or measured…
E.g.: “7 kilometres”.

Base units: All units in science are derived from seven base units:

Mass	kilogram	kg
Distance	metres	m
Time	seconds	s
Current	amp	A
Amount	mole	mol
Temperature	kelvin	K
Light intensity	candela	cd

Derived units: There are many other units that we use, but all of these are derived by multiplication or division of some combinations of the base units.

Quantity	**Unit**	**Symbol**	**Base unit equivalent**
Velocity	metres per second	ms^{-1}	ms^{-1}
Acceleration	metres per second squared	ms^{-2}	ms^{-2}
Force	newtons	N	$kg\ ms^{-2}$
Work or Energy	joules	J	$kg\ m^2s^{-2}$
Power	watts	W	$kg\ m^2s^{-3}$
Pressure	pascal	Pa	$kg\ m^{-1}s^{-2}$
Frequency	hertz	Hz	s^{-1}
Charge	coulomb	C	A s

Exercise 14: Base SI units

The history of these 7 base units is really interesting. For example, the kilogram started out as a random lump of (special) metal which was held in France. Countries would travel to France to create and calibrate their own version of the kilogram which would then standardise all of the masses back home. Nowadays, we need a bit more of a scientific definition…

Research each of the seven base units. Briefly write down a bit about their history and their modern definition.

Mass – kg

Length – m

Time – s

Current – A

Amount – mol

Temperature – K

Light intensity – cd

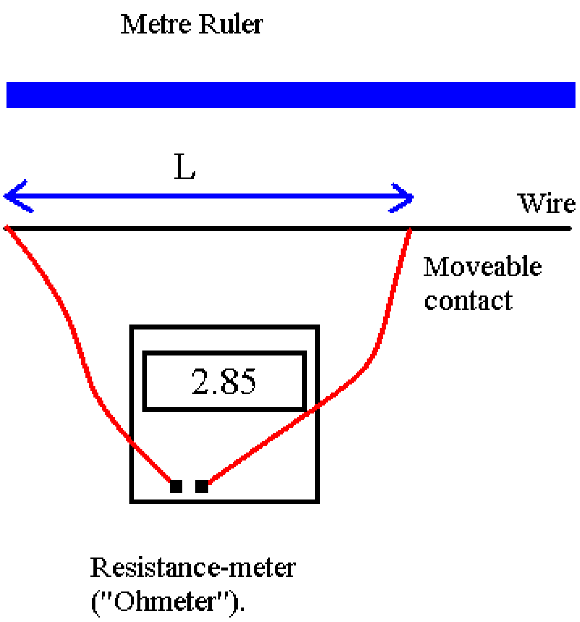
PART 6: Uncertainty

Part of your physics course involves carrying out 12 required practicals which are marked against set criteria. You will practice skills and techniques which will be asked about in the third of your A level exams.

Physics relies on performing accurate experiments, which all involve taking careful measurements of physical quantities: such as length, time, mass, force, temperature and so on. Taking such measurements depends on the use of measuring instruments: such as rulers, clocks, weighing scales, Newton-meters, thermometers and so on. However, there is always a limit to the precision that can be achieved with any measuring instrument. Therefore, whenever we conduct an experiment, we have to consider the following issues: Accuracy, Uncertainty and Reliability.

Accuracy

Imagine you are conducting an experiment with a piece of wire, to determine how its electrical **Resistance** varies with its **length.** You would probably decide to set up your experiment like so:

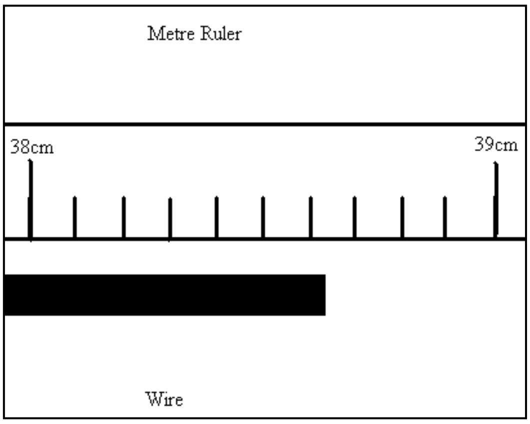


Proceedure:

- Attach the moveable contact to the wire at a certain point.
- Measure the length, L, by lining the wire up with the metre ruler.
- Measure the Resistance, R, by reading from the Ohmeter.
- Change the length, L, by moving the moveable contact.
- Measure the new value of L, using the metre ruler, and the new value of R, using the Ohmeter
- Repeat the procedure, until you have at least 7 readings.
- Plot a graph of L (x-axis) against R (y-axis).

However, this procedure will NOT be 100% accurate.....

Consider the measurement of LENGTH:



The smallest markings on a metre ruler are the millimetre divisions, so you will only ever be able to measure the length of the wire **to the nearest millimetre**. The picture shows a “zoomed-in” view of the end of the wire.

You would quote the length of the wire as 38cm and 6mm, or 38.6cm, or 386mm.

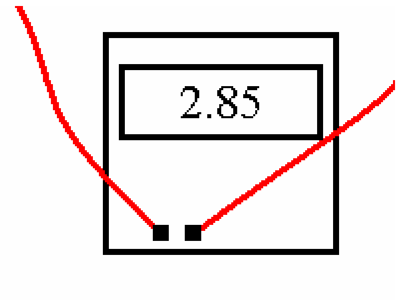
In reality, the length of the wire is somewhere between 386mm and 387mm.

It is good technique to quote the length of the wire with a statement of the accuracy in that measurement:

L = 386 mm ± 1mm

Your choice of this value will depend on the size of the smallest division on your

- Consider the measurement of RESISTANCE:



Resistance-meter ("Ohmeter").

The Ohmeter in the picture shows a Resistance of 2.85 Ohms (Ω). However, this is not 100% accurate, because the screen only shows figures up to the 2nd decimal place.

In reality, the Resistance could be anything in the range:

2.845 Ω to 2.855 Ω

Again, it is good practice to quote the measurement together with a statement of its accuracy:

R = 2.85 Ω ± 0.01 Ω

Your choice of this value will depend on the size of the smallest division on your measuring

Uncertainty

The two measurements given above each have their own Uncertainty value:

Eg: With the length measurement, **L = 386mm ± 1mm**

This means that the ABSOLUTE UNCERTAINTY in this measurement of length is 1mm.

Uncertainty can also be expressed as PERCENTAGE UNCERTAINTY as follows:

$$\text{Percentage Uncertainty} = \frac{\text{Absolute Uncertainty}}{\text{Measured Value}} \times 100\%$$

$$\text{Percentage Uncertainty} = \frac{1\text{mm}}{386\text{mm}} \times 100\% = 0.259067......\%$$

It is sufficient to round this value to 1 significant figure, therefore **0.3%**

Exercise 15: Uncertainty

_You are given the following data, from the wire experiment shown above:

Length / mm	Absolute Uncertainty / mm	Percentage Uncertainty / %	Resistance / Ώ	Absolute Uncertainty / Ώ	Percentage Uncertainty / %
157			0.76		
194			1.32		
216			1.98		
386			2.85		
495			3.15		
617			5.02		
958			8.19		

1. Complete the table, by finding the absolute uncertainty and percentage uncertainty values in both length and Resistance.

2. Plot a graph of Length (the INDEPENDENT variable on the x-axis) against Resistance (the DEPENDENT variable, on the y-axis).

3. Draw a line of best-fit through the data.

4. Find:

a) the gradient of your line of best-fit

b) the intercept of your line of best-fit.

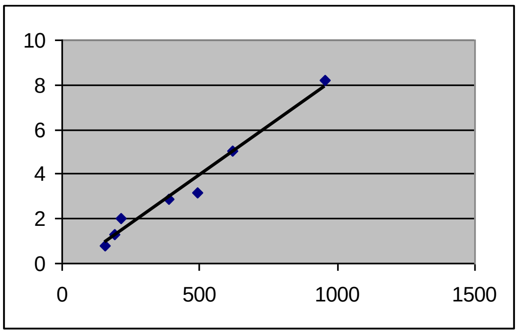
When considering the ACCURACY of this experiment, you would need to talk about the Uncertainty values for each of your measurements.

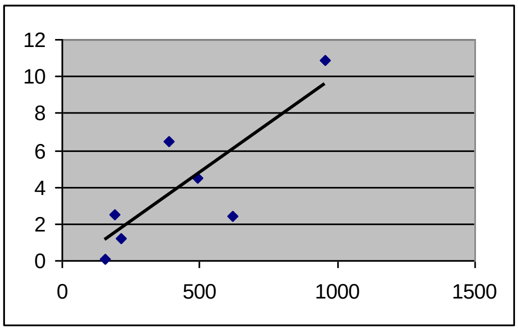
You should notice that the Percentage Uncertainty is less for the larger measurements.

You should also notice that the points on your graph do not lie on a perfectly straight line: there is some SCATTERING of the points around your line of best-fit. This is linked to idea of **RELIABILITY**.

An experiment is MORE RELIABLE if the points on the graph lie very close to a perfect straight line: i.e. there is LITTLE SCATTERING.

An experiment is LESS RELIABLE if the points on the graph lie relatively far away from a perfect straight line: i.e. there is A LOT OF SCATTERING

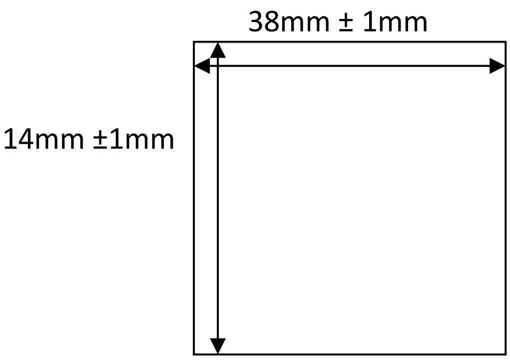




Combining uncertainty

There are many occasions in Physics where you will be conducting an experiment to find the value of a particular quantity. In order to find this value, you may need to measure several other quantities, which will each have their own uncertainty. How do we know the uncertainty of the final value?

EXAMPLE:



You have measured the LENGTH of this rectangle to be 38mm, and the WIDTH to be 14mm. Your measurements were taken with a 30cm ruler, which has 1mm markings as its smallest division. Therefore, both of your measurements have an ABSOLUTE uncertainty of ±1mm.

Evaluating the PERIMETER of the Rectangle

To find the PERIMETER, we need to add all four sides together. However, each measurement carries its percentage uncertainty value with it, as follows:

PERIMETER = LENGTH + WIDTH + LENGTH + WIDTH
= (38mm ± 1mm) + (14mm ± 1mm) + (38mm ± 1mm) + (14mm ± 1mm)

= 104mm ± 4mm

*When physical quantities are ADDED or SUBTRACTED, we take ADD the **absolute** uncertainties together*

Evaluating the AREA of the Rectangle

To find the AREA, we need to multiply the two measured quantities together, each carrying its own percentage uncertainty value, as follows:

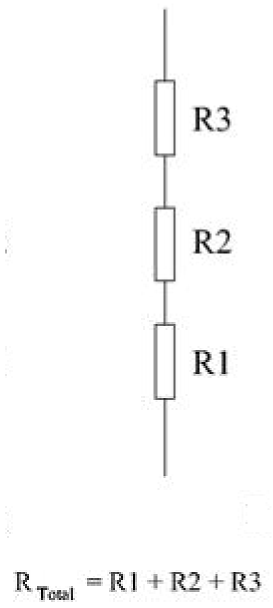
AREA = LENGTH x WIDTH
= (38mm ± 3%) x (14mm ± 7%)

= $532mm^2$ ± 10%

*When physical quantities are MULTIPLIED or DIVIDED, we need to ADD the **percentage** uncertainty values for our final answer.*

Exercise 16: Combining uncertainties

1. Context: Electric circuits



When 3 resistors are connected in series (i.e. end-to-end, as shown in the diagram) the total resistance, R_{total} can be calculated with the following formula:

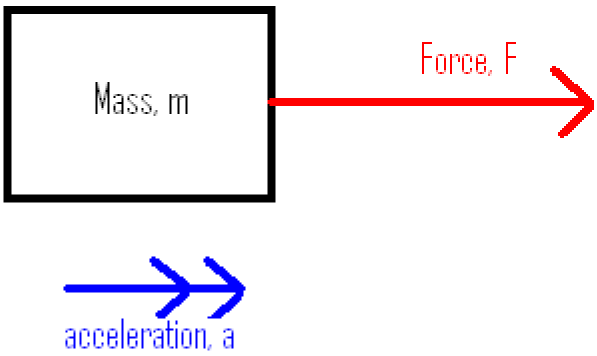
$R_{total} = R_1 + R_2 + R_3$

The 3 resistors have the following measured values of resistance:

	Measured value of Resistance	Absolute Uncertainty
R_1	165 Ohms	± 1 Ohm
R_2	132 Ohms	± 0.5 Ohms
R_3	450 Ohms	± 10 Ohms

Find the value of R_{total}, together with its value of absolute uncertainty:

2. Context: Forces and Motion



When a force, F is applied to an object of mass m, the object accelerates (speeds up). These three quantities are connected by Newton's Second Law:

$F = ma$

The following values are measured:

	Measured value of Force	Absolute Uncertainty	Percentage Uncertainty
F	190 Newtons	± 10 Newtons	
a	1.6 metres per second squared (ms^{-2})	± 0.05 ms^{-2}	

Find the value of m (in kilograms), together with its value of percentage uncertainty.

ANSWERS

Exercise 1: Rearranging simple equations

1. i) $m = \frac{W}{g}$ ii) $F = \frac{W}{d}$ iii) $F = PA$ iv) $m = \frac{E}{c^2}$

v) $h = \frac{E}{mg}$ vi) $t = \frac{d}{s}$

Exercise 2: Rearranging more complex equations

1. i) $r = \sqrt{\frac{P}{3k}}$ ii) $t = \sqrt{\frac{2Q}{n}}$ iii) $p = \sqrt{\frac{2R}{m}}$ iv) $t = \sqrt[3]{\frac{5M}{s}}$

Exercise 3: Rearranging even more complex equations!

1. i) $p = \frac{t - ab}{3q^2}$ ii) $a = \frac{½ tv - m}{2c}$ iii) $q = \frac{s - ½ pm^2}{3p}$

iv) $k = \sqrt{\frac{W + 7m}{\frac{1}{2}m}}$ v) $t = \frac{E - \frac{sba}{3}}{4}$

Exercise 4: Working with Straight-Line Graphs

Graph 1:
Gradient = 3, Intercept = 4, Equation: $y = 3x + 4$, Area = 14

Graph 2:
Gradient = 2, Intercept = -3, Equation: $y = 2x – 3$, Area = 6

Graph 3:
Gradient = 0.2, Intercept = 10, Equation: $y = 0.2x + 10$, Area = 750

Graph 4:
Gradient = 0.75, Intercept = -2, Equation: $y = 0.75x – 2$, Area = 10

Exercise 5: Graph Plotting

The graph should be plotted on graph paper.

The equation from this graph is y = 0.017x + 0.084
Since y represents length, and x represents force, we may write:

L = 0.017F + 0.084

v) The value of the y-intercept represents the original length of the spring (i.e. its length when no force is applied). Its original length = 0.084m = 8.4cm

vi) Reading from the graph, the length 25cm (0.25m) occurs when the force is 12.3N

vii) To find the area under the graph from x = 0 to x = 12.3:

Area of rectangle = 12.3 x 0.084 = 1.0332
Area of triangle = $\frac{0.166 \times 12.3}{2}$ = 1.0209
Total area = 2.0541.
Therefore, Energy stored is approximately 2.05 Joules (2.05J)

Exercise 6: areas and volumes

1 a) Area of triangle = $\frac{0.7 \times 0.25}{2}$ = $0.0875m^2$

b) Area of triangle = $\frac{1.12 \times 3.7}{2}$ = $2.072m^2$

1. Area of rectangle = 0.85 x 3.2 = $2.72m^2$
2. a) Diameter = 50cm = 0.5m
   b) Circumference = π x diameter = 3.14 x 0.5 = 1.57m
   c) Area = πr^2 = 3.14 x 0.25^2 = $0.19625m^2$

3. Area = $189cm^2 = \pi r^2$.
Therefore, r = 7.76cm. Diameter = 15.52cm. Circumference = 48.73cm.

4. Volume of cuboid = 1.6 x 47 x 53 = $3985.6cm^3$
5. Volume of cylinder = πr^2 x h = 3.14 x 13^2 x 21 = $11143.86cm^3$

Exercise 7: Converting Units with multiples and sub-multiples.

Distance:
i) 6400 ii) 3680 iii) 56.9 iv) 9.06893
v) 3,769,231 vi) 0.0127mm vii) Estimate: height = 2m. 200,000,000 people.

Area:
i) 1600 ii)1.58 iii) 16.9 iv) 17300 v) 6,034,000

Volume:
i) 9,000,000 ii) 0.489 iii) 8,526,000,000,000 iv) 42.6

Time:
i) 2,592,000 ii) 31,536,000 iii) 9,460,800,000,000km iv) 333.3 times

Exercise 8: Right-Angled Triangles

1. a) 14.76cm b) 12.04cm c) 3.15cm
2. a) 22.6° b) 9.65cm c) 38.1° d) 19.18cm e) 50.1° f) 295.78mm

Exercise 9: Dealing with large numbers

1. a) 3.8×10^{6} b) 7.34×10^{5} c) 1.26×10^{7} d) 1.893×10^{3}
2. a) 27,000 b) 315,000 c) 911,000,000 d)1003

Exercise 10: Dealing with small numbers

1. a) 3×10^{-3} b) 2.5×10^{-4} c) 1.7×10^{-6} d) 1.34×10^{-2}
2. a) 0.00012 b) 0.0000003645 c) 0.00000000241 d) 0.0000679

Exercise 11: Using your calculator

1 a) 278000 = 2.78×10^{5} b) 231,400,000 = 2.314×10^{8} c) 4.5373×10^{10}
d) 1.15346×10^{-5} e) 6786.407767 = 6.79×10^{3} (to 3 significant figures).

2. a) 1.8×10^{10} m b) 1.08×10^{12} m c) 2.592×10^{13} d) 9.4608×10^{15} m.

3. 1.89216×10^{22} m 4. 6×10^{10} atoms 5. 9.11×10^{-20} kg.

Exercise 12: Estimations

Answers are approximate:

1. 500,000 cars 2. 8×10^{10} cells. 3. 3×10^{25} protons
4. 20 million seconds = 233 days. 5. 3.3×10^{24} light bulbs.
6. 16 billion years 7. 6×10^{78} atoms

Exercise 13: Problems with Units

1.
a) 6000m b)149000m c)0.12m d)0.007m
e)17,000,000,000m
f) 0.000000013m g)0.000000015m

2. 0.0000035 A

3. 1 x 10^{17} kg.

4. 0.15nm. 0.00015pm.

5. 1 x 10^{53} kg

Exercise 14: Base SI units

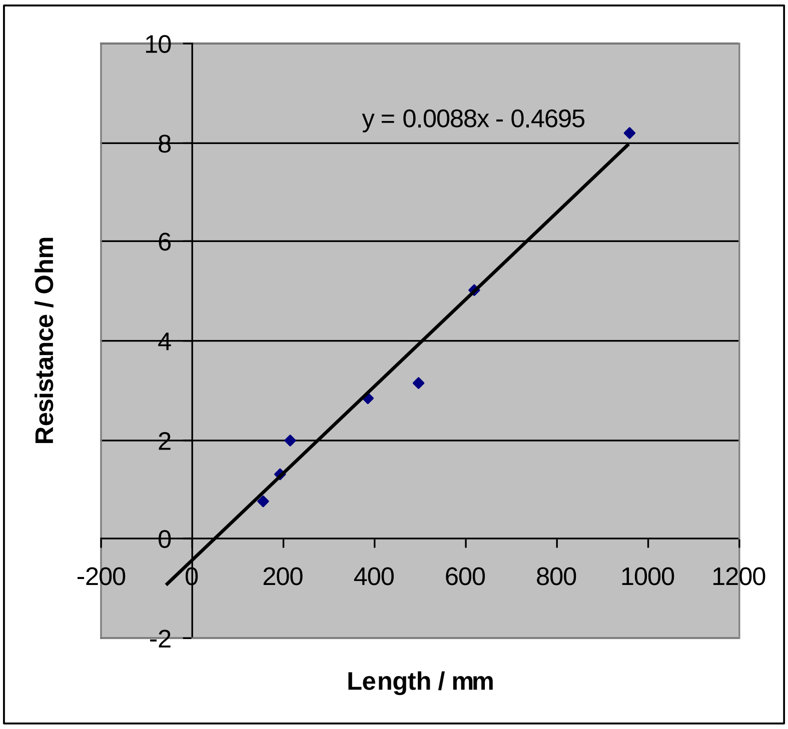
Use google!

Exercise 15: Uncertainty

1.

Length / mm	Absolute Uncertainty / mm	Percentage Uncertainty / %	Resistance / Ώ	Absolute Uncertainty / Ώ	Percentage Uncertainty / %
157	1	0.64	0.76	0.01	1.3
194	1	0.52	1.32	0.01	0.76
216	1	0.46	1.98	0.01	0.51
386	1	0.26	2.85	0.01	0.35
495	1	0.20	3.15	0.01	0.32
617	1	0.16	5.02	0.01	0.20
958	1	0.10	8.19	0.01	0.12

2.



4. Gradient = 0.0088   Intercept = - 0.4695

Exercise 16: Combining uncertainties

1. R_{Total} = 727 Ω± 11.5 Ω
2.

	Measured value of Force	Absolute Uncertainty	Percentage Uncertainty
F	190 Newtons	± 10 Newtons	5.3%
a	1.6 metres per second squared (ms^{-2})	± 0.05 ms^{-2}	3.1%

m = 119kg ± 8.4%