Braintree Sixth Form

Preparatory material for A level physics

Summer Task 2018

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Chapter 1: Introduction

One of things that many people find disconcerting when studying Physics is the idea of having to deal with lots of complicated equations. On first sight, it can be very daunting to see a page full of funny looking letters and symbols but with practice you will see that this really is just to save us having to write words out over and over again (physicists like to work efficiently).

The purpose of this introductory unit is to help you develop the core skills needed to solve numerical problems which will make your Year 12 Physics studies much more enjoyable and successful than they otherwise would be. Without these core skills solving problems becomes much more difficult if not impossible, a bit like trying to build a house with no wood or bricks. A bit of work before the course starts will pay huge dividends later and allow you to work and learn much more efficiently.

The key to success is to break numerical problems, where calculations are necessary, into smaller, simpler steps which can be followed every time.

The steps can be summarised as follows:-

Step 1: *Write down the values of everything you are given and put a question mark next to what you are asked to work out.*

Step 2: *Convert all the values into SI units i.e. time in seconds, distances in metres and so on.*

Step 3: *Pick an equation that contains the values we know and the quantity we are trying to work out.*

Step 4: *Re-arrange the equation so what we are trying to work out is the subject.*

Step 5: *Insert the values into the equation including the units.*

Step 6: *Type it into our calculator to get the answer and quote the answer to a reasonable number of significant figures and with units.*

Step 7: *Pause for one moment and think about if our answer is sensible.*

Chapters 2 and 3 will help you with Step 1

Chapters 4 and 5 will help you with Step 2

Chapter 6 will help with Steps 3 and 4

Chapters 7 and 8 will help with Step 6.

Chapter 9 will show a couple of examples to demonstrate how this all fits together.

With experience some of these steps can be done more quickly or in your head but you should always show your working. This is for several reasons:-

1. If you don't show your working, you will needlessly lose many marks in the exam (probably enough to drop your score by one whole grade, i.e. from B → C).

2. It will help make the steps outlined above more apparent and easy to follow when tackling numerical problems.
3. It makes it easier for the teacher to see where you have gone wrong and therefore help you learn more quickly and effectively.

Chapter 2: Physical Quantities/Units

When we first look at numerical problem in Physics then we need to be able to recognise what quantities we are given in the question. This can be made a lot easier if we know what quantity corresponds to the units given in the question. For example, if a question says someone's speed changes at a rate of 5 ms^{-2}, you need to be able to recognise that ms^{-2} is the unit of acceleration and so we know that we have been given an acceleration (even though the word acceleration wasn't used in the question).

We can classify physical quantities as either

(a) Basic: These are **fundamental** which are **defined** as being independent

There are seven basic quantities defined by the Systeme International d'Unites (SI Units). They have been defined for convenience not through necessity (force could have been chosen instead of mass). Once defined we can make measurements using the correct unit and measure with direct comparison to that unit.

Basic quantity	Unit	
	Name	Symbol
Mass	Kilogram	kg
Length	Metre	m
Time	Second	s
Electric current	Ampere	A
Temperature	Kelvin	K
Amount of a substance	Mole	mol
Luminous intensity	Candela	cd

NOTE: Base units are also referred to as dimensions.

(b) <u>Derived</u>: These are obtained by multiplication or division of the basic units **<u>without</u>** numerical factors. For example:

Derived quantity	Unit	
	Name	Symbols used
Volume	Cubic metre	m^3
Velocity	Metre per second	ms^{-1}
Density	Kilogram per cubic metre	kgm^{-3}

Some derived SI units are complicated and are given a simpler name with a unit defined in terms of the base units.

Farad (F) is given as $m^{-2}kg^{-1}s^4A^2$ **Watt** (W) is given as m^2kgs^{-3}

A table of quantities with their units is shown on the next page along with the most commonly used symbols for both the quantities and units.

Note that in GCSE we wrote units like metres per second in the format of m/s but in A-level it is written as ms^{-1}, and this is the standard way units are written at university level Physics.

Quantity	Quantity	SI Unit	Unit Symbol
Length	L or l	Metre	m
Distance	s	Metre	m
Height	h	Metre	m
Thickness (of a Wire)	d	Metre	m
Wavelength	λ	Metre	m
Mass	m or M	kilogram	kg
Time	t	second	s
Period	T	second	s
Temperature	T	Kelvin	K
Current	I	Ampere	A
Potential Difference	V	Volt	V
Area	A	Metres squared	m^2
Volume	V	Metres cubed	m^3
Density	ρ	Kilograms per metre cubed	$kg\ m^{-3}$
Force	F	Newton	N
Initial Velocity	u	Metres per second	ms^{-1}
Final Velocity	v	Metres per second	ms^{-1}
Energy	E	Joule	J
Kinetic Energy	E_K	Joule	J
Work Done	W	Joule	J
Power	P	Watt	W
Luminosity	L	Watt	W

Frequency	f	Hertz	Hz
Charge	Q	Coulomb	C
Resistance	R	Ohm	Ω
Electromotive Force	ε	Volt	V
Resistivity	ρ	Ohm Metre	Ωm
Work Function	ϕ	Joule	J
Momentum	p	kilogram metres per second	kg ms^{-1}
Specific Charge		Coulombs per kilogram	C kg^{-1}
Planck's Constant	h	Joule seconds	Js
Gravitational Field Strength	g	Newtons per kilogram	N kg^{-1}

This table needs to be memorised – once you know this it will significantly improve your ability to answer numerical questions. It is so important that we will test you on this very early on in Year 12.

Exercise

For each of the following questions write down the quantities you are trying to work out and write a question mark next to the quantity you are asked to find out with SI units shown. Note that you don't have to know any equations or any of the underlying physics to do this, it is a simply an exercise in recognising what you are being given in the question and what you are being asked to find out.

Example
Find the momentum of a 70 kg ball rolling at 2 ms^{-1}.
m=70 kg
v= 2 ms^{-1}
p= ? kg ms^{-1}

1. The resultant force on a body of mass 4.0 kg is 20 N. What is the acceleration of the body?
2. A particle which is moving in a straight line with a velocity of 15 ms^{-1} accelerates uniformly for 3.0s, increasing its velocity to 45 ms^{-1}. What distance does it travel whilst accelerating?
3. A car moving at 30 ms^{-1} is brought to rest with a constant retardation of 3.6 ms^{-2}. How far does it travel whilst coming to rest?
4. A man of mass 75 kg climbs 300 m in 30 minutes. At what rate is he working?
5. What is the maximum speed at which a car can travel along a level road when its engine is developing 24kW and there is a resistance to motion of 800 N?
6. Find the current in a circuit when a charge of 40 C passes in 5.0s.
7. What is the resistance of a copper cylinder of length 12 cm and cross-sectional area 0.40 cm^2 (Resistivity of copper = 1.7×10^{-8} Ωm)?
8. When a 12 V battery (i.e. a battery of EMF 12 V) is connected across a lamp with a resistance of 6.8 ohms, the potential difference across the lamp is 10.2 V. Find the current through the lamp.

9. Calculate the energy of a photon of wavelength 3.0×10^{-7} m.
10. Calculate the de Broglie wavelength of an electron moving at 3.0×10^{6} ms^{-1} (Planck's constant = 6.63×10^{-34} Js, mass of electron = 9.1×10^{-31} kg).

Chapter 3: Standard Form

You may well already be familiar with Standard Form from GCSE Maths, but just in case you aren't or could do with refreshing your memory then this chapter will explain what it is and why we use it.

Why use standard form? Standard form is used to make very large or very small numbers easier to read. Standard form also makes it easier to put large or small numbers in order of size.

In Physics, we often deal with quantities that are either really large, such as a parsec

1 pc = 30,900,000,000,000,000 m

Or really small like Planck's Constant:-

h= 0.000000000000000000000000000000000663 Js

Now, it would be tiresome to write out numbers like this over and over again and so we use a different notation known as standard form. Standard form shows the magnitude (size) of the number as powers of ten. We write a number between 1 and 10 and then show it multiplied by a power of 10.

For example

	1.234×10^{4}	1.234×10^{-4}
This means	1.234 x (10 x 10 x 10 x 10)	1.234 x(1 ÷ 10 ÷ 10 ÷ 10 ÷ 10)
Which is	12340	0.0001234

Let's see some more examples.

$0.523 = 5.23 \times 10^{-1}$ (note that $\times 10^{-1}$ means divide 5.23 by 10)

$52.3 = 5.23 \times 10^{1}$ (note that $\times 10^{1}$ means multiply 5.23 by 10)

$523 = 5.23 \times 10^{2}$ (note that $\times 10^{2}$ means multiply 5.23 by 100)

$5230 = 5.23 \times 10^{3}$ (note that $\times 10^{3}$ means multiply 5.23 by 1000)

$0.00523 = 5.23 \times 10^{-3}$ (note that $\times 10^{-3}$ means divide 5.23 by 1000)

Note that the sign (positive or negative) in the index tells you whether you are dividing or multiplying; a positive number means you are multiplying and a negative number means you are dividing. The number tells you how many times you are either dividing or multiplying by 10. So 1.60×10^{-19} means take the number 1.60 and divide it by 10 nineteen times (divide by 10^{19}) i.e. move the decimal point 19 places to the left.

And to go back to our examples from above:-

1 pc = 3.09×10^{16} m

h= 6.63×10^{-34} Js

So this is a much shorter way of writing these numbers!

To put a list of large numbers in order is difficult because it takes time to count the number of digits and hence determine the magnitude of the number.

1. Put these numbers in order of size,

5239824 , 25634897 , 5682147 , 86351473 , 1258964755
142586479, 648523154

But it is easier to order large numbers when they are written in standard form.

2. Put these numbers in order of size,

5.239×10^{6} , 2.563×10^{7} , 5.682×10^{6} , 8.635×10^{7} , 1.258×10^{9}
1.425×10^{8} , 6.485×10^{8}

You can see that it is easier to work with large numbers written in standard form. To do this we must be able to convert from one form into the other.

3. Convert these numbers into normal form.

a) 5.239×10^{3}
b) 4.543×10^{4} c) 9.382×10^{2} d) 6.665×10^{6}
e) 1.951×10^{2} f) 1.905×10^{5} g) 6.005×10^{3}

4. Convert these numbers into standard form.

a) 65345 (how many times do you multiply 6.5345 by 10 to get 65345 ?)

b) 28748 c) 548454 d) 486856
e) 70241 f) 65865758 g) 765

Standard form can also be used to write small numbers

e.g. 0.00056 = 5.6×10^{-4}

5. Convert these numbers into normal form.

a) 8.34×10^{-3} b) 2.541×10^{-8} c) 1.01×10^{-5}
d) 8.88×10^{-1} e) 9×10^{-2} f) 5.05×10^{-9}

6. Convert these numbers to standard form.

a) 0.000567 b) 0.987 c) 0.0052
d) 0.0000605 e) 0.008 f) 0.0040302

7. Calculate, giving answers in standard form,

a) $(3.45 \times 10^{-5} + 9.5 \times 10^{-6}) \div 0.0024$
b) $2.31 \times 10^{5} \times 3.98 \times 10^{-3} + 0.0013$

Chapter 4: Converting Units to SI Units

Some common non-SI units that you will encounter during Year 12 Physics:-

Quantity	Quantity	Alternative Unit	Unit Symbol	Value in SI Units
Energy	E	electron volt	eV	1.6×10^{-19} J
Charge	Q	charge on electron	e	1.6×10^{-19} C
Mass	m	atomic mass unit	u	1.67×10^{-27} J
Mass	m	tonne	t	10^{3} kg
Time	t	hour	hr	3,600 s
Time	t	year	yr	3.16×10^{7} s
Distance	d	miles	miles	1,609 m
Distance	d	astronomical unit	AU	3.09×10^{11} m
Distance	d	light year	ly	9.46×10^{15} m
Distance	d	parsec	pc	3.09×10^{16} m

It is essential that you recognise these units and also know how to change them to SI units and back again. A lot of marks can be lost if you are not absolutely competent doing this.

When you are converting from these units to SI units you need to multiply by the value in the right hand column. When you convert back the other way you need to divide.

Example

The nearest star (other than the Sun) to Earth is Proxima Centauri at a distance of 4.24 light years.

What is this distance expressed in metres?

4.24 light years = $4.24 \times 9.46 \times 10^{15}$ m = 4.01×10^{16} m

What is this distance expressed in parsecs?

4.01×10^{16} m = $4.01 \times 10^{16} / 3.09 \times 10^{16}$ m = 1.30 pc

Exercise

Convert the following quantities:-

1. What is 13.6 eV expressed in joules?
2. What is a charge of 6e expressed in coulombs?
3. An atom of Lead-208 has a mass of 207.9766521 u, convert this mass into kg.
4. What is 2.39 × 108 kg in tonnes?
5. It has been 44 years since England won the World Cup, how long is this in seconds?
6. An TV program lasts 2,560s, how many hours is this?
7. The semi-major axis of Pluto's orbit around the Sun is 5.91 × 1012 m, what is this distance in AU?

Converting Speeds

Things get a little more complicated when you have to convert speeds. For example, if Usain Bolt runs at an average speed of 10.4 ms^{-1}, what is this speed in miles per hour?

First, we will change from ms^{-1} to miles s^{-1}:-

10.4 ms^{-1} = 10.4 /1609 miles s^{-1} = 6.46×10^{-3} miles s^{-1}

Now we have to change from miles s^{-1} to miles hr^{-1}

6.46×10^{-3} miles s^{-1} = $6.46 \times 10^{-3} \times 3{,}600$ miles hr^{-1} = 23.3 miles hr^{-1}

Notice that in last line we had to multiply by the number of seconds in an hour. This is because you would go further in an hour than you would in a second. If you find this hard to understand sometimes you can multiply by the conversion factor and divide by it and see which value is sensible. Let's see what would have happened if we had divided by 3,600:-

6.46×10^{-3} miles s^{-1} = 6.46×10^{-3} / 3,600 miles hr^{-1} = 1.80×10^{-6} miles hr^{-1}

Do you think Usain Bolt was running at a speed of about 2 millionths of a mile an hour? This is clearly wrong so we would have realised that we needed to multiply by 3,600.

Exercise

1. Convert 0.023 kms^{-1} into ms^{-1}.
2. Express 3456 m hr^{-1} into km hr^{-1}
3. What is 30 miles hr^{-1} in ms^{-1}?
4. What is 50 ms-1 in miles hr-1?
5. Convert 33 km hr-1 into ms-1.
6. Express 234 miles hr^{-1} in km hr^{-1}.

Chapter 5: Prefixes & Converting Unit Magnitudes

How to use and convert prefixes

Often in Physics, quantities are written using prefixes which is an even shorter way of writing numbers than standard form. For example instead of writing 2.95×10^{-9} m we can write 2.95 nm where n means nano and is a short way of writing $\times 10^{-9}$. Here is a table that shows all the prefixes you need to know in Year 12 Physics.

Prefix	Symbol	Name	Multiplier
femto	f	quadrillionth	10^{-15}
pico	p	trillionth	10^{-12}
nano	n	billionth	10^{-9}
micro	μ	millionth	10^{-6}
milli	m	thousandth	10^{-3}
centi	c	hundredth	10^{-2}
deci	d	tenth	10^{-1}
deka	da	ten	10^{1}
hecto	h	hundred	10^{2}
kilo	k	thousand	10^{3}
mega	M	million	10^{6}
giga	G	billion†	10^{9}
tera	T	trillion†	10^{12}
peta	P	quadrillion	10^{15}

Again, it is essential you know all of these to ensure that you don't lose easy marks when answering numerical problems.

When you are given a variable with a prefix you must convert it into its numerical equivalent in standard form before you use it in an equation.

FOLLOW THIS! Always start by replacing the prefix symbol with its equivalent multiplier.

For example: $0.16\ \mu A = 0.16 \times 10^{-6}\ A = 0.00000016 A$

$3\ km = 3000 m = 3 \times 10^{3}\ m$

$10\ ns = 10 \times 10^{-9}\ s = 0.00000001\ s$

DO NOT get tempted to follow this further (for example: $0.16 \times 10^{-6}\ A = 1.6 \times 10^{-7}\ A$ and also $10 \times 10^{-9}\ s = 10^{-8}\ s$) unless you are absolutely confident that you will do it correctly. It is always safer to stop at the first step (10×10^{-9} s) and type it like this into your calculator.

NOW TRY THIS!

1.4 kW =

24 cm =

46 pF =

52 Gbytes =

10 μC =

340 MW =

0.03 mA =

43 kΩ =

Converting between unit magnitudes for distances.

Convert the following: (Remember that milli = 10^{-3} and centi = 10^{-2})

1. 5.46m to cm
2. 65mm to m
3. 3cm to m
4. 0.98m to mm
5. 34cm to mm
6. 76mm to cm

Converting between unit magnitudes for areas and volumes

It's really important that when we convert areas and volumes that we don't forget to square or cube the unit.

Example

Let's take the example of converting a sugar cube of volume 1 cm^3 into m^3.

If we just use the normal conversion, then 1 cm^3 = 1 x 10^{-2} m^3 ← **Wrong Answer!**

STOP! Let's think about this one second:

Imagine in your head a box 1m by 1m by 1m, how many sugar cubes could you fit in there? A **lot** more than 100! That would only fill up one line along one of the bottom edges of the box! **So our answer must be wrong.**

What we have to do is do the conversion and then cube it, like this:-

$1\ cm^3 = 1\ (\times 10^{-2}\ m)^3 = 1 \times 10^{-6}\ m^3$.

So this means we could fit a million sugar cubes in the box, which is right.

Exercise

1. What is 5.2 mm^3 in m^3?
2. What is 24cm^2 in m^2?
3. What is 34 m^3 in μm^3?
4. What is 0.96 x 10^6 m^2 in km^2?
5. Convert 34 Mm^3 into pm^3.

Chapter 6: Re-arranging Equations

The first step in learning to manipulate an equation is your ability to see how it is done once and then repeat the process again and again until it becomes second nature to you.

In order to show the process once I will be using letters rather than physical concepts.

You can rearrange an equation $a = b \times c$ with

b as the subject $\qquad b = \dfrac{a}{c}$

or c as the subject $\qquad c = \dfrac{a}{b}$

Any of these three symbols a, b, c can be itself a summation, a subtraction, a multiplication, a division, or a combination of all. So, when you see a more complicated equation, try to identify its three individual parts a, b, c before you start rearranging it.

Worked examples

Equation	First Rearrangement	Second Rearrangement
$v = f \times \lambda$	$f = \dfrac{v}{\lambda}$	$\lambda = \dfrac{v}{f}$
$T = \dfrac{1}{f}$	$1 = T \times f$	$f = \dfrac{1}{T}$
$\dfrac{1}{v} = \dfrac{1}{u} + \dfrac{1}{f}$	$1 = v \times \left(\dfrac{1}{u} + \dfrac{1}{f}\right)$	$v = \dfrac{1}{\dfrac{1}{u} + \dfrac{1}{f}}$

THINK! As you can see from the third worked example, not all rearrangements are useful. In fact, for the lens equation only the second rearrangement can be useful in problems. So, in order to improve your critical thinking and know which rearrangement is the most useful in every situation, you must practise with as many equations as you can.

NOW TRY THIS!

From now on the multiplication sign will not be shown, so $a = b \times c$ will be simply written as $a = bc$

Equation	First Rearrangement	Second Rearrangement
(Power of lens) $P = \frac{1}{f}$	$1 =$	$f =$
(Magnification of lens) $m = \frac{v}{u}$	$v =$	$u =$
(refractive index) $n = \frac{c}{v}$	$c =$	$v =$
(current) $I = \frac{\Delta Q}{\Delta t}$		
(electric potential) $V = \frac{\Delta E}{\Delta Q}$		
(power) $P = \frac{\Delta E}{\Delta t}$		
(power) $P = VI$		
(conductance) $G = \frac{I}{V}$		
(resistance) $R = \frac{V}{I}$		
(resistance) $R = \frac{1}{G}$		
(power) $P = I^2 R$		
(power) $P = \frac{V^2}{R}$		
(stress) $\sigma = \frac{F}{A}$	$F =$	$A =$
(strain) $\varepsilon = \frac{x}{l}$	$x =$	$l =$

Further Rearranging Practice

1. a = bc , b=?
2. a = b/c, b=?,c=?
3. a = b – c, c=?
4. a = b + c , b=?
5. a = bc + d, c=?
6. a = b/c – d, c=?
7. a = bc/d, d=?, b=?
8. a = (b + c)/d, c=?
9. a = b/c + d/e, e=?

Chapter 7: Using Your Calculator

Quick Exercise

- Evaluate:-

$$\frac{30}{5\times3}=?$$

Using your calculator.

What answer did you get? 18? If you did it may surprise you to know that you are wrong. Nope – there's nothing wrong with your calculator we just need to establish exactly how it works.

Order of Operations

Your calculator has a rule to decide which operation to do first which is summarised by the word BODMAS, which stands for the order in which operations are done:-

1. B - Brackets first
2. O - Orders (i.e. Powers and Square Roots, etc.)
3. DM - Division and Multiplication (left-to-right)
4. AS - Addition and Subtraction (left-to-right)

So if we type in the numbers like this:-

$30 \div 5 \times 3 = 6 \times 3 = 18$ ← Left to Right is the conventional order and is what your calculator does.

But if we use brackets we can get the right answer:-

$30 \div (5 \times 3) = 30 \div 15 = 2$

Note that the fact that the 5 and 3 are put on the bottom implies they should be multiplied first.

You will need to be able to use your calculator correctly and be familiar with scientific notation, such as standard form, brackets etc.

e.g. $3\ 670\ 000 = 3.67 \times 10^6$

$0.0\ 000\ 367 = 3.67 \times 10^{-4}$

To enter 3.67×10^6 into your calculator press:

3.67 exp 6

Note that 10^8 means 1×10^8 and so must be keyed in as 1 exp 8 not 10 exp 8!

As a result when I write out what I know I write out 1×10^8 to remind myself to do this.

Exercise A Always give your answer in standard form,
e.g. 7.0×10^{-3} and not as 7.0^{-3}, which is how it is displayed on the calculator.

Your answer should have the same amount of significant figures as the question.

1. $(7.5 \times 10^3) \times (24) =$
2. $(6.2 \times 10^{-5}) \times (5.0 \times 10^{-3}) =$
3. $(1.4 \times 10^5) \times (2.0 \times 10^4) =$
4. $4.5 \times 10^3 / 7.0 \times 10^4 =$
5. $4.3 \times 10^{-6} / 6.0 \times 10^3 =$

Exercise B In each case, find the value of "y".

1. $y = (7.5 \times 10^3)^2$

2. $y = \dfrac{(1.3 \times 10^{3}) \times (1.6 \times 10^{-4})}{(6.6 \times 10^{6}) + (3.27 \times 10^{-3})}$

3. $y = \dfrac{(5.6 \times 10^{-4})^{2} \times (7.8 \times 10^{8})}{(6.6 \times 10^{-11}) \times (9.1 \times 10^{-2})^{2}}$

4. $y = \sqrt{\dfrac{(4.12 \times 10^{3}) + (6.5 \times 10^{2})}{(2.3 \times 10^{4}) \times (8.1 \times 10^{2})}}$

Chapter 8: Significant Figures

You can lose a mark if you quote too many significant figures in an answer. It is not as bad a leaving off a unit when answering a question – but why lose marks needlessly when you don't have to?

The Rules

1. All non-zero digits are significant.

2. In a number without a decimal point, only zeros BETWEEN non-zero digits are significant. E.g. significant in 12001 but not in 12100

3. In a number with a decimal point, all zeros to the right of the right-most non-zero digit are significant. 12.100 → 5 s.f.

Examples

39.389 → 5 s.f.

120000000000000→ 2 s.f

3400.000 → 7 s.f.

34224000 → 5 s.f.

200000.0004 → 10 s.f.

Exercise:-

How many significant figures are the following numbers quoted to?

1. 224.4343
2. 0.00000000003244654
3. 3442.34
4. 200000
5. 43.0002
6. 24540000
7. 543325
8. 23.5454353
9. 4.0000000000
10. 4456001

Exercise II – For the numbers above that are quoted to more than 3 s.f., convert the number to standard form and quote to 3 s.f.

Using a Reasonable Number of S.F.

Try to use the same s.f. as those provided in the question or just one more.

Example:

Let's say we were faced with this question:

A man runs 110 metres in 13 seconds, calculate his average speed.

Distance = 110 m

Time = 13 s

Speed = Distance/Time = 110 metres / 13 seconds

=8.461538461538461538461538461538 m/s

This is a ridiculous number of significant figures!

=8.46 m/s seems acceptable (3 s.f.) because the figures we were given in the question we given to 2 s.f, so we've used just one more than that in our answer.

If in doubt quote answers to 3 s.f. in the exam – this is normally close enough to what they are looking for.

Chapter 9: Example Numerical Problems

A Step by Step Guide on Tackling a Numerical Problem

This example may look lengthy, but that's because I am describing every step that I do in my head.
Only the yellow shaded bits will end up written down on my paper.

Let's try Q2(a) from the worksheet given out in class:-

The question says:-

Speed of electromagnetic radiation in free space (c) = 3.00 x 10^{8} m s^{-1}
Planck's constant (h) = 6.63 x 10^{-34} J s

2. Calculate the energies of a quantum of electromagnetic radiation of the following wavelengths:

(a) gamma rays wavelength 10^{-3} nm

Step 1: *Write down the values of everything you are given and put a question mark next to what you are asked to work out:-*

$c = 3.00 \times 10^{8}$ ms^{-1}
$h = 6.63 \times 10^{-34}$ Js
$\lambda = 10^{-3}$ nm
$E = ?$

Step 2: *Convert all the values into SI units i.e. time in seconds, distances in metres and so on:-*

$c = 3.00 \times 10^{8}$ ms^{-1}
$h = 6.63 \times 10^{-34}$ Js
$\lambda = 10^{-3}$ nm
$E = ?$

From the table I handed out in class:-

nm = 10^{-9} m

So now replace nm with 10^{-9} m:-
λ = 10^{-3} nm
= $10^{-3} \times 10^{-9}$ m
= 10^{-12} m
= 1×10^{-12} m

So our list of known values becomes:-

c = 3.00×10^{8} ms^{-1}
h = 6.63×10^{-34} Js
λ = 10^{-3} nm = 1×10^{-12} m
E = ?

Step 3: *Pick an equation that contains the values we know and the quantity we are trying to work out:-*

So we want an equation with c, h, λ and E in it. This looks like a job for the photon energy equation:

$$E = \frac{hc}{\lambda}$$

Step 4: *Re-arrange the equation so what we are trying to work out is the subject.*

We got lucky this time, the thing we are trying work out is the Energy, E, and that is already the subject, so no re-arranging to do!

Step 5: *Insert the values into the equation including the units:-*

$$E = \frac{hc}{\lambda} = \frac{6.63 \times 10^{-34} Js \times 3.00 \times 10^{8} ms^{-1}}{1 \times 10^{-12} m}$$

Step 6: *Type it into our calculator to get the answer and quote the answer to a reasonable number of significant figures:-*

Answer in the calculator:

$$E = 1.989 \times 10^{-13} J$$

The values for h and c were quoted to 3 significant figures, the value for λ was only quoted to 1 s.f. but it's not clear whether this actually was an exact value or rounded to 1 s.f.. Quoting our answer to 3 significant figures seems reasonable. (If in doubt, quote to 3 significant figures, you won't be too far wrong.)

$$E = 1.99 \times 10^{-13} J \ \ (3.s.f.)$$

Step 7: *Pause for one moment and think about if our answer is sensible.*

This comes with practice and experience. The first time I tried this calculation out I got an answer of 1.989×10^{-37} J. Photon energies for the visible part of the electromagnetic spectrum are about 1 eV = 1.60×10^{-19} J and gamma rays are more energetic so I knew I must have made a mistake somewhere to get such a small energy.

Looking back over my working, I could see that I had accidentally used a value of 1×10^{12} m for the wavelength, λ, instead of the correct value of 1×10^{-12} m.

After a few practice questions, you can do the same and in the exam it is reassuring when you calculate an answer and know that it looks about right.

Worked Solution to a Two Step Problem

This example may look lengthy, but that's because I am describing every step that I do in my head.
Only the yellow shaded bits will end up written down on my paper.

Example question:

A metal surface is illuminated with monochromatic light of frequency 8.57×10^{14} Hz. The maximum kinetic energy of the emitted photoelectrons is 0.55 eV. Calculate, for this metal, the threshold frequency, in Hz.

Step 1: *Write down the values of everything you are given and put a question mark next to what you are asked to work out:-*

$c = 3.00 \times 10^{8}$ ms^{-1}
$h = 6.63 \times 10^{-34}$ Js
$f = 8.57 \times 10^{14}$ Hz
$E_{K(max)} = 0.55$ eV
$f_0 = ?$

Step 2: *Convert all the values into SI units i.e. time in seconds, distances in metres and so on:-*

$c = 3.00 \times 10^{8}\ ms^{-1}$
$h = 6.63 \times 10^{-34}\ Js$
$f = 8.57 \times 10^{14}\ Hz$
$E_{K(max)} = 0.55\ eV$
$f_0 = ?$

So we need to convert $E_{K(max)}$ into Joules…

Recall from the second lesson that:-

1 eV = 1.60×10^{-19} J

So now replace eV with 1.60×10^{-19} J:-
$E_{K(max)} = 0.55$ eV
$= 0.55 \times 1.60 \times 10^{-19}$ J
$= 8.8 \times 10^{-20}$ J

So our list of values becomes:-
$c = 3.00 \times 10^{8}\ ms^{-1}$
$h = 6.63 \times 10^{-34}\ Js$
$f = 8.57 \times 10^{14}\ Hz$
$E_{K(max)} = 0.55\ eV = 8.8 \times 10^{-20}\ J$
$f_0 = ?$

Step 3: *Pick an equation that contains the values we know and the quantity we are trying to work out:-*

So we want an equation with f_0 in it and where all the other values are known. Hmm, well the only equation we have with f_0 in it is:

$$\phi = hf_0$$

But there's a problem! Our equation can only have one unknown value in it, i.e. the quantity we are working out. In this equation we know the value of Planck's constant, h, but we don't know the value of the work function, φ, so let's find an equation that will help us work that out (this is why I call this a two step problem).

So now we want an equation with φ in it and where we know all the other values, Einstein's Photoelectric Equation looks useful:

$$hf = \phi + E_{K(\max)}$$

We know h, f and $E_{K(max)}$ so this equation will allow us to work out φ and then we can work out f_0 using that value of φ.

Step 4: *Re-arrange the equation so what we are trying to work out is the subject.*

Part A:

Subtracting both sides of Einstein's Photoelectric Equation by $E_{K(max)}$ and writing the equation the other way round we get:-

$$\phi = hf - E_{K(\max)}$$

Part B: Starting with φ=hf_0 dividing both sides by h and writing the equation the other way round we get:

$$f_0 = \frac{\phi}{h}$$

Now we have our equations re-arranged and can now proceed to inserting values into the equations.

Step 5: *Insert the values into the equation including the units:-*

$$\phi = hf - E_{K(\max)} = 6.63\times10^{-34}\,Js\times8.57\times10^{14}\,Hz - 8.8\times10^{-20}\ \mathrm{J}$$

Step 6: *Type it into our calculator to get the answer and quote the answer to a reasonable number of significant figures:-*

Appears in the calculator as:

$$\phi = 4.80191\times10^{-19}\,J$$

Store this number in our calculator.

Can write down a rounded value as part of our working:-

$$\phi = 4.80\times10^{-19}\,J\ \ (3\ s.f.)$$

Use the stored number in our threshold frequency equation:-

$$f_0 = \frac{\phi}{h} = \frac{4.80191 \times 10^{-19} J}{6.63 \times 10^{-34} Js}$$

Answer in the calculator:

$$f_0 = 7.242699849 \times 10^{14} Hz$$

The values for h, c and f were quoted to 3 significant figures and $E_{K(max)}$ to 2 significant figures so quoting our answer to 3 significant figures seems reasonable. (remember if in doubt, quote to 3 significant figures, you won't be too far wrong).

$$f_0 = 7.24 \times 10^{14} Hz \ (3 \ s.f.)$$

Step 7: *Pause for one moment and think about if our answer is sensible.*

I can't recall typical threshold frequencies off the top of my head but I do know that the wavelength of visible light is about 500 nm. Using c=fλ, the corresponding threshold wavelength is λ = c/f ~ 400 nm, so that is at the blue end of the visible spectrum getting towards UV light. We needed UV light to release photoelectrons from the zinc plate, so our answer looks sensible enough.

Chapter 10: Checking Equations using Dimensions

You can check an equation you have written by examining the base units on both sides of that equation. If you have an extra base unit on one side then your equation is wrong!

Now define the derived unit for force in terms of its base units. Hint: Use an equation for Force and replace the symbols with base units.

Now try these

1\. a. In the equation below, c represents the speed of water waves in a shallow tank of depth d and g is the acceleration due to gravity.

$$c = (g.d)^{1/2}$$

Show from an analysis of the units that the equation is dimensionally consistent.

b. Assuming $g = 9.8\ ms^{-2}$, calculate the speed of the waves if the depth of the water is 1 cm.

c. What depth of water would be required to double the speed of the waves from the value calculated in part a?

d. Would the speeds be any different if the experiment was carried out on the surface of the moon?

2\. a. The pressure (P), volume (V) and temperature (T) of an ideal gas are related by the following equation:

$$P.V = n.R.T$$

where n is the number of moles of the gas. Analyse the equation to find the units of R.

b. Show that P.V has the units of joules.

3\. a. Use the two equations below to find the base units of the constants ε_0 and μ_0.

$$F = \frac{1}{4\pi\varepsilon_0} \cdot \frac{Q_1.Q_2}{r^2}$$

$$F = \frac{\mu_0}{2\pi} \cdot \frac{I_1.\ I_2.a}{b}$$

F = force; Q = charge; a, b and r are lengths; I = current.

b. Hence show that $(\varepsilon_0.\ \mu_0)^{-1/2}$ has the same units as velocity.

Transition from GCSE to A Level

Moving from GCSE Science to A Level can be a daunting leap. You'll be expected to remember a lot more facts, equations, and definitions, and you will need to learn new maths skills and develop confidence in applying what you already know to unfamiliar situations.

This worksheet aims to give you a head start by helping you:

- to pre-learn some useful knowledge from the first chapters of your A Level course
- understand and practise of some of the maths skills you'll need.

Learning objectives

After completing the worksheet you should be able to:

- define practical science key terms
- recall the answers to the retrieval questions
- perform maths skills including:
  - unit conversions
  - uncertainties
  - using standard form and significant figures
  - resolving vectors
  - rearranging equations
  - equations of work, power, and efficiency.

Retrieval questions

You need to be confident about the definitions of terms that describe measurements and results in A Level Physics.

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

Practical science key terms

When is a measurement valid?	when it measures what it is supposed to be measuring
When is a result accurate?	when it is close to the true value
What are precise results?	when repeat measurements are consistent/agree closely with each other
What is repeatability?	how precise repeated measurements are when they are taken by the *same* person, using the *same* equipment, under the *same* conditions
What is reproducibility?	how precise repeated measurements are when they are taken by *different* people, using *different* equipment
What is the uncertainty of a measurement?	the interval within which the true value is expected to lie
Define measurement error	the difference between a measured value and the true value
What type of error is caused by results varying around the true value in an unpredictable way?	random error
What is a systematic error?	a consistent difference between the measured values and true values
What does zero error mean?	a measuring instrument gives a false reading when the true value should be zero
Which variable is changed or selected by the investigator?	independent variable
What is a dependent variable?	a variable that is measured every time the independent variable is changed
Define a fair test	a test in which only the independent variable is allowed to affect the dependent variable
What are control variables?	variables that should be kept constant to avoid them affecting the dependent variable

Foundations of Physics

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

What is a physical quantity?	a property of an object or of a phenomenon that can be measured
What are the S.I. units of mass, length, and time?	kilogram (kg), metre (m), second (s)
What base quantities do the S.I. units A, K, and mol represent?	current, temperature, amount of substance
List the prefixes, their symbols and their multiplication factors from pico to tera (in order of increasing magnitude)	pico (p) 10^{-12}, nano (n) 10^{-9}, micro (μ) 10^{-6}, milli (m) 10^{-3}, centi (c) 10^{-2}, deci (d) 10^{-1}, kilo (k) 10^{3}, mega (M) 10^{6}, giga (G) 10^{9}, tera (T) 10^{12}
What is a scalar quantity?	a quantity that has magnitude (size) but *no* direction
What is a vector quantity?	a quantity that has magnitude (size) *and* direction
What are the equations to resolve a force, F, into two perpendicular components, F_x and F_y?	$F_x = F\cos\theta$ $F_y = F\sin\theta$
What is the difference between distance and displacement?	distance is a scalar quantity displacement is a vector quantity
What does the Greek capital letter Δ (delta) mean?	'change in'
What is the equation for average speed in algebraic form?	$v = \frac{\Delta x}{\Delta t}$
What is instantaneous speed?	the speed of an object over a very short period of time
What does the gradient of a displacement–time graph tell you?	velocity
How can you calculate acceleration and displacement from a velocity–time graph?	acceleration is the gradient displacement is the area under the graph
Write the equation for acceleration in algebraic form	$a = \frac{\Delta v}{\Delta t}$
What do the letters *suvat* stand for in the equations of motion?	s = displacement, u = initial velocity, v = final velocity, a = acceleration, t = time taken
Write the four *suvat* equations.	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $s = \frac{1}{2}(u+v)t$ $v^2 = u^2 + 2as$
Define *stopping distance*	the total distance travelled from when the driver first sees a reason to stop, to when the vehicle stops
Define *thinking distance*	the distance travelled between the moment when you first see a reason to stop to the moment when you use the brake
Define *braking distance*	the distance travelled from the time the brake is applied until the vehicle stops
What does *free fall* mean?	when an object is accelerating under gravity with no other force acting on it

Matter and radiation

Learn the answers to the questions below then cover the answers column with a piece of paper and write as many answers as you can. Check and repeat.

What is an atom made up of?	a positively charged nucleus containing protons and neutrons, surrounded by electrons
Define a *nucleon*	a proton or a neutron in the nucleus
What are the absolute charges of protons, neutrons, and electrons?	$+1.60\times10^{-19}$, 0, and -1.60×10^{-19} coulombs (C) respectively
What are the relative charges of protons, neutrons, and electrons?	1, 0, and – 1 respectively (charge relative to proton)
What is the mass, in kilograms, of a proton, a neutron, and an electron?	1.67×10^{-27}, 1.67×10^{-27}, and 9.11×10^{-31} kg respectively
What are the relative masses of protons, neutrons, and electrons?	1, 1, and 0.0005 respectively (mass relative to proton)
What is the atomic number of an element?	the number of protons
Define an isotope	isotopes are atoms with the same number of protons and different numbers of neutrons
Write what *A*, *Z* and X stand for in isotope notation (${}^{A}_{Z}\mathrm{X}$)?	*A*: the number of nucleons (protons + neutrons) *Z*: the number of protons X: the chemical symbol
Which term is used for each type of nucleus?	nuclide
How do you calculate specific charge?	charge divided by mass (for a charged particle)
What is the specific charge of a proton and an electron?	9.58×10^{7} and 1.76×10^{11} C kg^{-1} respectively
Name the force that holds nuclei together	strong nuclear force
What is the range of the strong nuclear force?	from 0.5 to 3–4 femtometres (fm)
Name the three kinds of radiation	alpha, beta, and gamma
What particle is released in alpha radiation?	an alpha particle, which comprises two protons and two neutrons
Write the symbol of an alpha particle	${}^{4}_{2}\alpha$
What particle is released in beta radiation?	a fast-moving electron (a beta particle)
Write the symbol for a beta particle	${}^{0}_{-1}\beta$
Define *gamma radiation*	electromagnetic radiation emitted by an unstable nucleus
What particles make up everything in the universe?	matter and antimatter
Name the antimatter particles for electrons, protons, neutrons, and neutrinos	positron, antiproton, antineutron, and antineutrino respectively
What happens when corresponding matter and antimatter particles meet?	they annihilate (destroy each other)
List the seven main parts of the electromagnetic spectrum from longest wavelength to shortest	radio waves, microwaves, infrared, visible, ultraviolet, X-rays, gamma rays
Write the equation for calculating the wavelength of electromagnetic radiation	$\text{wavelength } (\lambda) = \dfrac{\text{speed of light } (c)}{\text{frequency } (f)}$
Define a *photon*	a packet of electromagnetic waves
What is the speed of light?	3.00×10^{8} m s^{-1}
Write the equation for calculating photon energy	photon energy (*E*) = Planck constant (*h*) × frequency (*f*)
Name the four fundamental interactions	gravity, electromagnetic, weak nuclear, strong nuclear

Maths skills

1 Measurements

1.1 Base and derived SI units

Units are defined so that, for example, every scientist who measures a mass in kilograms uses the same size for the kilogram and gets the same value for the mass. Scientific measurement depends on standard units – most are *Système International* (SI) units. Every measurement must give the unit to have any meaning. You should know the correct unit for physical quantities.

Base units

Physical quantity	Unit	Symbol
length	metre	m
mass	kilogram	kg
time	second	s

Physical quantity	Unit	Symbol
electric current	ampere	A
temperature difference	Kelvin	K
amount of substance	mole	mol

Derived units

Example:

$$\text{speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

If a car travels 2 metres in 2 seconds:

$$\text{speed} = \frac{2\,\text{metres}}{2\,\text{seconds}} = 1\frac{\text{m}}{\text{s}} = 1\,\text{m/s}$$

This defines the SI unit of speed to be 1 metre per second (m/s), or 1 m s^{-1} ($s^{-1} = \frac{1}{s}$).

Practice questions

1 Complete this table by filling in the missing units and symbols.

Physical quantity	Equation used to derive unit	Unit	Symbol and name (if there is one)
frequency	period^{-1}	s^{-1}	Hz, hertz
volume	length^3		–
density	mass ÷ volume		–
acceleration	velocity ÷ time		–
force	mass × acceleration		
work and energy	force × distance		

1.2 Significant figures

When you use a calculator to work out a numerical answer, you know that this often results in a large number of decimal places and, in most cases, the final few digits are 'not significant'. It is important to record your data and your answers to calculations to a reasonable number of significant figures. Too many and your answer is claiming an accuracy that it does not have, too few and you are not showing the precision and care required in scientific analysis.

Numbers to 3 significant figures (3 s.f.):

<u>3.62</u> <u>25.4</u> <u>271</u> 0.0<u>147</u> 0.<u>245</u> <u>39 4</u>00

(notice that the zeros before the figures and after the figures are *not* significant – they just show you how large the number is by the position of the decimal point).

Numbers to 3 significant figures where the zeros *are* significant:

<u>207</u> <u>405</u>0 <u>1.01</u> (any zeros between the other significant figures *are* significant).

Standard form numbers with 3 significant figures:

9.42×10^{-5} 1.56×10^{8}

If the value you wanted to write to 3.s.f. was 590, then to show the zero was significant you would have to write:

590 (to 3.s.f.) or 5.90×10^2

Practice questions

2 Give these measurements to 2 significant figures:

a 19.47 m **b** 21.0 s **c** 1.673×10^{-27} kg **d** 5 s

3 Use the equation:

$$\text{resistance} = \frac{\text{potential difference}}{\text{current}}$$

to calculate the resistance of a circuit when the potential difference is 12 V and the current is 1.8 mA. Write your answer in kΩ to 3 s.f.

1.3 Uncertainties

When a physical quantity is measured there will always be a small difference between the measured value and the true value. How important the difference is depends on the size of the measurement and the size of the uncertainty, so it is important to know this information when using data.

There are several possible reasons for uncertainty in measurements, including the difficulty of taking the measurement and the resolution of the measuring instrument (i.e. the size of the scale divisions).

For example, a length of 6.5 m measured with great care using a 10 m tape measure marked in mm would have an uncertainty of 2 mm and would be recorded as 6.500 ± 0.002 m.

It is useful to quote these uncertainties as percentages.

For the above length, for example,

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{measurement}} \times 100$$

$$\text{percentage uncertainty} = \frac{0.002}{6.500} \times 100\% = 0.03\%.$$ The measurement is 6.500 m ± 0.03%.

Values may also be quoted with absolute error rather than percentage uncertainty, for example, if the 6.5 m length is measured with a 5% error,

the absolute error = 5/100 × 6.5 m = ±0.325 m.

Practice questions

4 Give these measurements with the uncertainty shown as a percentage (to 1 significant figure):

a 5.7 ± 0.1 cm **b** 450 ± 2 kg **c** 10.60 ± 0.05 s **d** 366 000 ± 1000 J

5 Give these measurements with the error shown as an absolute value:

a 1200 W ± 10% **b** 330 000 Ω ± 0.5%

6 Identify the measurement with the smallest percentage error. Show your working.

A 9 ± 5 mm **B** 26 ± 5 mm **C** 516 ± 5 mm **D** 1400 ± 5 mm

2 Standard form and prefixes

When describing the structure of the Universe you have to use very large numbers. There are billions of galaxies and their average separation is about a million light years (ly). The Big Bang theory says that the Universe began expanding about 14 billion years ago. The Sun formed about 5 billion years ago. These numbers and larger numbers can be expressed in standard form and by using prefixes.

2.1 Standard form for large numbers

In standard form, the number is written with one digit in front of the decimal point and multiplied by the appropriate power of 10. For example:

- The diameter of the Earth, for example, is 13 000 km.
  13 000 km = 1.3 × 10 000 km = 1.3×10^4 km.
- The distance to the Andromeda galaxy is 2 200 000 light years = 2.2 × 1 000 000 ly = 2.2×10^6 ly.

2.2 Prefixes for large numbers

Prefixes are used with SI units (see Topic 1.1) when the value is very large or very small. They can be used instead of writing the number in standard form. For example:

- A kilowatt (1 kW) is a thousand watts, that is 1000 W or 10^3 W.
- A megawatt (1 MW) is a million watts, that is 1 000 000 W or 10^6 W.
- A gigawatt (1 GW) is a billion watts, that is 1 000 000 000 W or 10^9 W.

Prefix	Symbol	Value
kilo	k	10^3
mega	M	10^6

Prefix	Symbol	Value
giga	G	10^9
tera	T	10^{12}

For example, Gansu Wind Farm in China has an output of 6.8×10^9 W. This can be written as 6800 MW or 6.8 GW.

Practice questions

1 Give these measurements in standard form:

a 1350 W **b** 130 000 Pa **c** 696×10^6 s **d** 0.176×10^{12} C kg^{-1}

2 The latent heat of vaporisation of water is 2 260 000 J/kg. Write this in:

a J/g **b** kJ/kg **c** MJ/kg

2.3 Standard form and prefixes for small numbers

At the other end of the scale, the diameter of an atom is about a tenth of a billionth of a metre. The particles that make up an atomic nucleus are much smaller. These measurements are represented using negative powers of ten and more prefixes. For example:

- The charge on an electron = 1.6×10^{-19} C.
- The mass of a neutron = $0.016\,75 \times 10^{-25}$ kg = 1.675×10^{-27} kg (the decimal point has moved 2 places to the right).
- There are a billion nanometres in a metre, that is 1 000 000 000 nm = 1 m.
- There are a million micrometres in a metre, that is 1 000 000 μm = 1 m.

Prefix	Symbol	Value
centi	c	10^{-2}
milli	m	10^{-3}
micro	μ	10^{-6}

Prefix	Symbol	Value
nano	n	10^{-9}
pico	p	10^{-12}
femto	f	10^{-15}

Practice questions

3 Give these measurements in standard form:

a 0.0025 m **b** 160×10^{-17} m **c** 0.01×10^{-6} J **d** 0.005×10^6 m **e** 0.00062×10^3 N

4 Write the measurements for question 3a, c, and d above using suitable prefixes.

5 Write the following measurements using suitable prefixes.

a a microwave wavelength = 0.009 m

b a wavelength of infrared = 1×10^{-5} m

c a wavelength of blue light = 4.7×10^{-7} m

2.4 Powers of ten

When multiplying powers of ten, you must *add* the indices.

So 100 × 1000 = 100 000 is the same as $10^2 \times 10^3 = 10^{2+3} = 10^5$

When dividing powers of ten, you must *subtract* the indices.

So $\frac{100}{1000} = \frac{1}{10} = 10^{-1}$ is the same as $\frac{10^2}{10^3} = 10^{2-3} = 10^{-1}$

But you can only do this when the numbers with the indices are the same.

So $10^2 \times 2^3 = 100 \times 8 = 800$

And you can't do this when adding or subtracting.

$10^2 + 10^3 = 100 + 1000 = 1100$

$10^2 - 10^3 = 100 - 1000 = -900$

Remember: You can only add and subtract the indices when you are multiplying or dividing the numbers, not adding or subtracting them.

Practice questions

6 Calculate the following values – read the questions very carefully!

a $20^6 + 10^{-3}$

b $10^2 - 10^{-2}$

c $2^3 \times 10^2$

d $10^5 \div 10^2$

7 The speed of light is 3.0×10^8 m s^{-1}. Use the equation $v = f\lambda$ (where λ is wavelength) to calculate the frequency of:

a ultraviolet, wavelength 3.0×10^{-7} m

b radio waves, wavelength 1000 m

c X-rays, wavelength 1.0×10^{-10} m.

3 Resolving vectors

3.1 Vectors and scalars

Vectors have a magnitude (size) and a direction. Directions can be given as points of the compass, angles or words such as forwards, left or right. For example, 30 mph east and 50 km/h north-west are velocities.

Scalars have a magnitude, but no direction. For example, 10 m/s is a speed.

Practice questions

1 State whether each of these terms is a vector quantity or a scalar quantity: density, temperature, electrical resistance, energy, field strength, force, friction, frequency, mass, momentum, power, voltage, volume, weight, work done.

2 For the following data, state whether each is a vector or a scalar: 3 ms^{-1}, +20 ms^{-1}, 100 m NE, 50 km, −5 cm, 10 km S 30° W, 3×10^8 ms^{-1} upwards, 273 °C, 50 kg, 3 A.

3.2 Drawing vectors

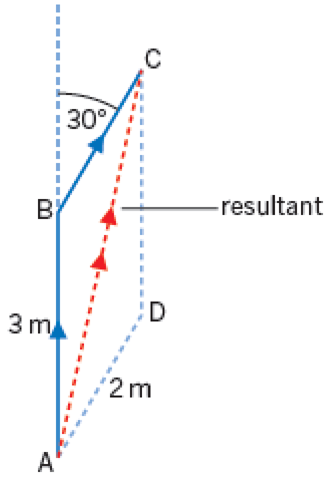
Vectors are shown on drawings by a straight arrow. The arrow starts from the point where the vector is acting and shows its direction. The length of the vector represents the magnitude.

When you add vectors, for example two velocities or three forces, you must take the direction into account.

The combined effect of the vectors is called the resultant.

This diagram shows that walking 3 m from A to B and then turning through 30° and walking 2 m to C has the same effect as walking directly from A to C. AC is the resultant vector, denoted by the double arrowhead.

A careful drawing of a scale diagram allows us to measure these. Notice that if the vectors are combined by drawing them in the opposite order, AD and DC, these are the other two sides of the parallelogram and give the same resultant.



Practice questions

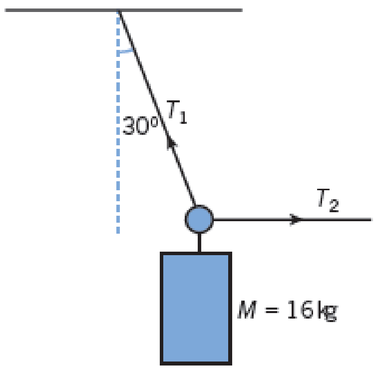
3 Two tractors are pulling a log across a field. Tractor 1 is pulling north with force 1 = 5 kN and tractor 2 is pulling east with force 2 = 12 kN. By scale drawing, determine the resultant force.

3.3 Free body force diagrams

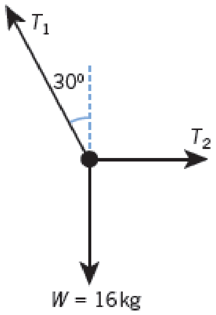
To combine forces, you can draw a similar diagram to the one above, where the lengths of the sides represent the magnitude of the force (e.g., 30 N and 20 N). The third side of the triangle shows us the magnitude and direction of the resultant force.

When solving problems, start by drawing a free body force diagram. The object is a small dot and the forces are shown as arrows that start on the dot and are drawn in the direction of the force. They don't have to be to scale, but it helps if the larger forces are shown to be larger. Look at this example.

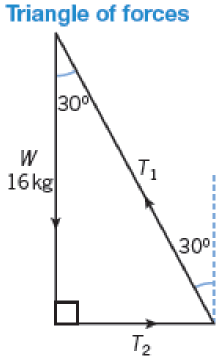
A 16 kg mass is suspended from a hook in the ceiling and pulled to one side with a rope, as shown on the right. Sketch a free body force diagram for the mass and draw a triangle of forces.



Free body force diagram



Triangle of forces



Notice that each force starts from where the previous one ended and they join up to form a triangle with no resultant because the mass is in equilibrium (balanced).

Practice questions

4 Sketch a free body force diagram for the lamp (**Figure 1**, below) and draw a triangle of forces.

5 There are three forces on the jib of a tower crane (**Figure 2**, below). The tension in the cable *T*, the weight *W*, and a third force *P* acting at X.

The crane is in equilibrium. Sketch the triangle of forces.

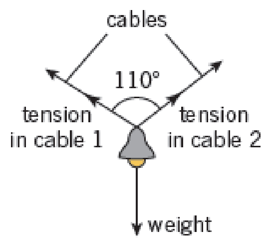


Figure 1

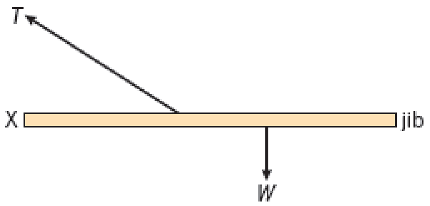


Figure 2

3.4 Calculating resultants

When two forces are acting at right angles, the resultant can be calculated using Pythagoras's theorem and the trig functions: sine, cosine, and tangent.

For a right-angled triangle as shown:

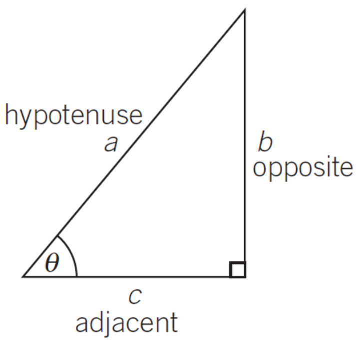
$h^2 = o^2 + a^2$

$\sin\theta = \frac{o}{h}$

$\cos\theta = \frac{a}{h}$

$\tan\theta = \frac{o}{a}$

(soh-cah-toa).



Practice questions

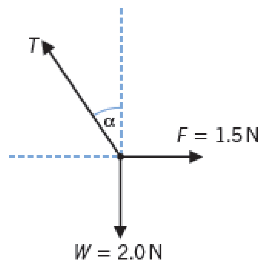


Figure 3

6 **Figure 3** shows three forces in equilibrium.
Draw a triangle of forces to find T and α.

7 Find the resultant force for the following pairs of forces at right angles to each other:

a 3.0 N and 4.0 N **b** 5.0 N and 12.0 N

4 Rearranging equations

Sometimes you will need to rearrange an equation to calculate the answer to a question. For example, if you want to calculate the resistance R, the equation:

potential difference (V) = current (A) × resistance (Ω) or $V = I R$

must be rearranged to make R the subject of the equation:

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

When you are solving a problem:

- Write down the values you know and the ones you want to calculate.
- you can rearrange the equation first, and then substitute the values

  or
- substitute the values and then rearrange the equation

4.1 Substitute and rearrange

A student throws a ball vertically upwards at 5 m s^{-1}. When it comes down, she catches it at the same point. Calculate how high it goes.

Step 1: Known values are:

- initial velocity u = 5.0 m s^{-1}
- final velocity v = 0 (you know this because as it rises it will slow down, until it comes to a stop, and then it will start falling downwards)
- acceleration $a = g = -9.81$ m s^{-2}
- distance s = ?

Step 2: Equation:

(final velocity)^2 − (initial velocity)^2 = 2 × acceleration × distance

or $v^2 - u^2 = 2 \times g \times s$

Substituting: $(0)^2 - (5.0 \text{ m s}^{-1})^2 = 2 \times -9.81 \text{ m s}^{-2} \times s$

$0 - 25 = 2 \times -9.81 \times s$

Step 3: Rearranging:

$-19.62\, s = -25$

$s = \frac{-25}{-19.62} = 1.27 \text{ m} = 1.3 \text{ m (2 s.f.)}$

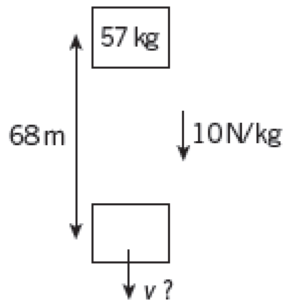
Practice questions

1. The potential difference across a resistor is 12 V and the current through it is 0.25 A. Calculate its resistance.
2. Red light has a wavelength of 650 nm. Calculate its frequency. Write your answer in standard form.
   (Speed of light = 3.0×10^8 m s^{-1})

4.2 Rearrange and substitute

A 57 kg block falls from a height of 68 m. By considering the energy transferred, calculate its speed when it reaches the ground.

(Gravitational field strength = 10 N kg^{-1})



Step 1: m = 57 kg h = 68 m g = 10 N kg^{-1} v = ?

Step 2: There are three equations:

PE = $m\,g\,h$ KE gained = PE lost   KE = 0.5 $m\,v^2$

Step 3: Rearrange the equations before substituting into it.

As KE gained = PE lost, $m\,g\,h = 0.5\,m\,v^2$

You want to find v. Divide both sides of the equation by 0.5 m:

$$\frac{mgh}{0.5m} = \frac{0.5mv^2}{0.5m}$$

$2\,g\,h = v^2$

To get v, take the square root of both sides: $v = \sqrt{2gh}$

Step 4: Substitute into the equation:

$v = \sqrt{2 \times 10 \times 68}$

$v = \sqrt{1360} = 37\ \text{m s}^{-1}$

Practice questions

3 Calculate the specific latent heat of fusion for water from this data:
4.03×10^4 J of energy melted 120 g of ice.
Use the equation:
thermal energy for a change in state (J) = mass (kg) × specific latent heat (J kg^{-1})
Give your answer in J kg^{-1} in standard form.

5 Work done, power, and efficiency

5.1 Work done

Work is done when energy is transferred. Work is done when a force makes something move. If work is done *by* an object its energy decreases and if work is done *on* an object its energy increases.

work done = energy transferred = force × distance

Work and energy are measured in joules (J) and are scalar quantities (see Topic 3.1).

Practice questions

1 Calculate the work done when the resultant force on a car is 22 kN and it travels 2.0 km.

2 Calculate the distance travelled when 62.5 kJ of work is done applying a force of 500 N to an object.

5.2 Power

Power is the rate of work done.

It is measured in watts (W) where 1 watt = 1 joule per second.

$$\text{power} = \frac{\text{energy transferred}}{\text{time taken}} \quad \textit{or} \quad \text{power} = \frac{\text{work done}}{\text{time taken}}$$

$P = \Delta W / \Delta t$ *Δ is the symbol 'delta' and is used to mean a 'change in'*

Look at this worked example, which uses the equation for potential energy gained.

A motor lifts a mass m of 12 kg through a height Δh of 25 m in 6.0 s.

Gravitational potential energy gained:

$\Delta PE = mg\Delta h = (12\ \text{kg}) \times (9.81\ \text{m s}^{-2}) \times (25\ \text{m}) = 2943\ \text{J}$

$$\text{Power} = \frac{2943\ \text{J}}{6.0\ \text{s}} = 490\ \text{W (2 s.f.)}$$

Practice questions

3 Calculate the power of a crane motor that lifts a weight of 260 000 N through 25 m in 48 s.

4 A motor rated at 8.0 kW lifts a 2500 N load 15 m in 5.0 s. Calculate the output power.

5.3 Efficiency

Whenever work is done, energy is transferred and some energy is transferred to other forms, for example, heat or sound. The efficiency is a measure of how much of the energy is transferred usefully.

Efficiency is a ratio and is given as a decimal fraction between 0 (all the energy is wasted) and 1 (all the energy is usefully transferred) or as a percentage between 0 and 100%. It is not possible for anything to be 100% efficient: some energy is always lost to the surroundings.

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}} \text{ or Efficiency} = \frac{\text{useful power output}}{\text{total power input}}$$

(multiply by 100% for a percentage)

Look at this worked example.

A thermal power station uses 11 600 kWh of energy from fuel to generate electricity. A total of 4500 kWh of energy is output as electricity. Calculate the percentage of energy 'wasted' (dissipated in heating the surroundings).

You must calculate the energy wasted using the value for useful energy output:

$$\text{percentage energy wasted} = \frac{(\text{total energy input - energy output as electricity})}{\text{total energy input}} \times 100$$

$$\text{percentage energy wasted} = \frac{(11600 - 4500)}{11600} \times 100 = 61.2\% = 61\% \text{ (2 s.f.)}$$

Practice questions

5 Calculate the percentage efficiency of a motor that does 8400 J of work to lift a load.
The electrical energy supplied is 11 200 J.

6 An 850 W microwave oven has a power consumption of 1.2 kW.
Calculate the efficiency, as a percentage.

7 Use your answer to question 4 above to calculate the percentage efficiency of the motor. (The motor, rated at 8.0 kW, lifts a 2500 N load 15 m in 5.0 s.)

8 Determine the time it takes for a 92% efficient 55 W electric motor take to lift a 15 N weight 2.5 m.

Answers to maths skills practice questions

1 Measurements

1

Physical quantity	Equation used to derive unit	Unit	Symbol and name (if there is one)
frequency	$period^{-1}$	s^{-1}	Hz, hertz
volume	$length^3$	m^3	–
density	mass ÷ volume	kg m^{-3}	–
acceleration	velocity ÷ time	m s^{-2}	–
force	mass × acceleration	kg m s^{-2}	N newton
work and energy	force × distance	N m (or kg m^2 s^{-2})	J joule

2 **a** 19 m **b** 21 s
c 1.7×10^{-27} kg **d** 5.0 s

3 Resistance $= \dfrac{12\text{ V}}{1.8\text{ mA}} = \dfrac{12\text{ V}}{0.0018\text{ A}} = 6666.666...\Omega = 6.66666...\text{k}\Omega = 6.67\Omega$

4 **a** 5.7 cm ± 2% **b** 450 kg ± 0.4%
c 10.6 s ± 0.5% **d** 366 000 J ± 0.3%

5 **a** 1200 ± 120 W **b** 330 000 ± 1650 Ω

6 **D** 1400 ± 5 mm (Did you calculate them all? The same absolute error means the percentage error will be smallest in the largest measurement, so no need to calculate.)

2 Standard form and prefixes

1 **a** 1.35×10^3 W (or 1.350×10^3 W to 4 s.f.) **b** 1.3×10^5 Pa
c 6.96×10^8 s **d** 1.76×10^{11} C kg^{-1}

2 **a** 2 260 000 J in 1 kg, so there will be 1000 times fewer J in 1 g: $\dfrac{2\,260\,000}{1000} = 2260$ J/g

b 1 kJ = 1000 J, $2\,260\,000\text{ J/kg} = \dfrac{2\,260\,000}{1000}\text{kJ/kg} = 2260\text{ kJ/kg}$

c 1 MJ = 1000 kJ, so $2260\text{ kJ/kg} = \dfrac{2260}{1000}\text{MJ/kg} = 2.26\text{ MJ/kg}$

3 **a** 2.5×10^{-3} m **b** 1.60×10^{-15} m
c 1×10^{-8} J **d** 5×10^3 m
e 6.2×10^{-1} N

4 **a** 2.5 μm **b** 1.60 f m
c 10 nJ **or** 0.01 μJ **d** 5 km
e 0.62 N **or** 62 cN

5 **a** 0.009 m = 9×10^{-3} m = 9 mm
b 1×10^{-5} m = $1 \times 10 \times 10^{-6}$ m = 10×10^{-6} m = 10 μm
c 4.7×10^{-7} m = $4.7 \times 100 \times 10^{-9}$ m = 470×10^{-9} m = 470 nm

6 **a** 64000000 **or** 6.4×10^7 **b** 99.99

c 800 **d** 10^3

7 **a** 3.0×10^{8} m s^{-1} ÷ 3.03×10^{-7} m = 1.0×10^{15} Hz

b 3.0×10^{8} m s^{-1} ÷ 1000 m = 3.0×10^{5} Hz

c 3.0×10^{8} m s^{-1} ÷ 1.0×10^{-10} m = 3.0×10^{18} Hz

3 Resolving vectors

1 **Scalars:** density, electric charge, electrical resistance, energy, frequency, mass, power, temperature, voltage, volume, work done

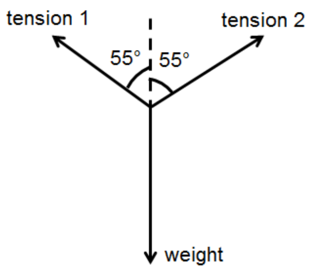
Vectors: field strength, force, friction, momentum, weight

2 **Scalars:** 3 ms^{-1}, 50 km, 273 °C, 50 kg, 3 A

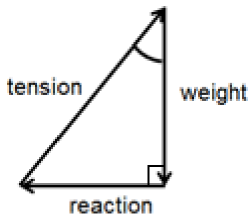
Vectors: +20 ms^{-1}, 100 m NE, −5 cm, 10 km S 30°W, 3 × 10^8 m/s upwards

3 13 kN

4 **Free body force diagram:**



Triangle of forces:



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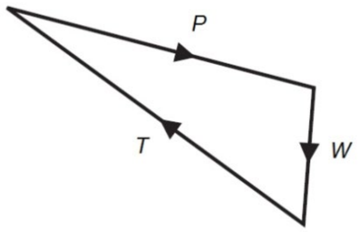

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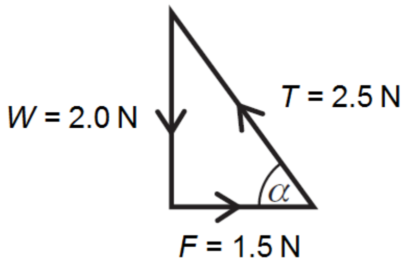

7 **a** 5.0 N at 37° to the 4.0 N force **b** 13 N at 23° to the 12.0 N force

4 Rearranging equations

1 V = 12 V and I = 0.25 A

$V = I R$ so $12 = 0.25 \times R$

$$R = \frac{V}{I} = \frac{12}{0.25} = 48\ \Omega$$

2 λ = 650 nm = 650×10^{-9} m and $v = 3.0\times10^{8}$ m/s

$v = f\lambda$ so $3.0\times10^{8} = f \times 650\times10^{-9}$

$f = \frac{v}{\lambda} = \frac{3.0\times10^{8}}{650\times10^{-9}} = 0.00462\times10^{17} = 4.62\times10^{14}$ Hz

3 $E = 4.01\times10^{4}$ J and $m = 0.120$ g = 0.120 kg

$E = mL$ so $4.01\times10^{4} = 0.120 \times L$

$L = \frac{E}{m} = \frac{4.01\times10^{4}}{0.120} = 334\,166$ J/kg = 3.34×10^{5} J/kg in standard form

5 Work done, power, and efficiency

1 22×10^{3} N $\times$ 2×10^{3} m = 44 000 000 J = 44 MJ

2 $\frac{62.5\times10^{3}\text{ J}}{500\text{ N}} = 125$ m

3 $\frac{260\,000\text{ N}\times25\text{ m}}{48\text{ s}} = 13\,541.6$ W = 14 000 W or 14 kW (2 s.f.)

4 $\frac{2500\text{ N}\times15\text{ m}}{5\text{ s}} = 7500$ W = 7.5 kW

5 $\frac{8400}{11200}\times100 = 75\%$

6 $\frac{850}{1.2\times10^{3}}\times100 = 71\%$

7 $\frac{7.5}{8.0}\times100 = 94\%$

8 0.74 s