PHYSICS

DURHAM JOHNSTON

AS and A LEVEL PHYSICS

Congratulations on choosing A-level physics. It is a challenging yet rewarding subject. We hope you will find it enjoyable and interesting.

What is Physics?

The word ‘physics’ comes from ancient Greek, literally meaning ‘knowledge of nature’. It is the branch of science that studies matter, forces and energy to understand how everything in the universe behaves. If you are the type of person that is always asking ‘Why?’ then physics is for you!

Why should you study physics?

Using a few basic principles, theories and laws, you will become capable of explaining events and occurrences that you have never come across before. This ability to predict how the physical world works is a powerful tool not only to scientific research and industry but also to you, enabling you to 'think on your feet'. This makes physicists valued both for what they know and how they apply their knowledge

An A-level in physics is useful for when applying for virtually any higher education courses whether they are arts or science based. It will not tie you down to do physics forever. If you are already interested in a particular aspect of physics e.g. electronics, medical physics, astronomy etc or applied physics i.e. engineering then do not feel that you have to specialise now, higher education institutions will teach your specialism from the beginning.

Career opportunities

Physics A-level is a requirement of the majority of physical sciences and engineering courses in higher education. Physicists find employment in many scientific areas, such as engineering, renewable energy, astronomy, space exploration, meteorology and climate change, aeronautics, the automotive industry, electronics, laboratory work, radiography, medicine, veterinary science, telecommunications, forensic science, armed forces and nanotechnology.

Outside of science, physicists are valued in many other careers because of their skills in analysing information and solving complex problems, and their high levels of numeracy and computer literacy. Many physicists find employment in banking, insurance, accountancy, software and computing.

Minimum Course Entry Requirements

- **6-6 in dual award GCSE science or equivalent, or level 6 in single science physics**
- **6 in GCSE maths or equivalent**
  A level maths is an ideal companion subject, though not essential. Every year a handful of pupils study physics without maths.

Exam Board and Course

OCR [Oxford Cambridge and RSA Examinations], Physics A (H156/H556)

All students will be taught the AS physics content in year 12. This will allow them to sit the two AS exams at the end of the year.
The remaining content, which is necessary for the A level qualification, is taught in year 13. To obtain an A level, students will sit three exams covering all the work from year 12 and 13. If sitting the A level, any mark obtained at AS in year 12 is disregarded. The grade depends solely upon the marks achieved in the three year 13 exams.
Pupils need to pass a teacher assessed set of practical of tasks in order to achieve a Practical Endorsement in Physics. Though it does not carry any marks contributing to a final grade, many universities require the Practical Endorsement as an entry requirement.

AS Level Specification (H156)

Year 12 modules:

1. Development of practical skills.
2. Foundations of physics.
3. Forces and motion.
4. Electron, waves and photons.

Year 12 exams:

- Breadth in Physics
- Depth in Physics.
  Both 1 hour 30 minutes, both assessing all material.

A Level Specification (H556)

Year 13 modules:

1. Development of practical skills.
5. Newtonian world and astrophysics.
6. Particles and medical physics.
   (Content taught in modules 2, 3 and 4 is also used throughout year 13)

Year 13 exams:

- Modelling Physics (2 hours 15 minutes, 100 marks, assessing modules 1, 2, 3 and 5)
- Exploring Physics (2 hours 15 minutes, 100 marks, assessing modules 1, 2, 4 and 6)
- Unified Physics (1 hour 30 minutes, assessing all modules)

The first term of year 12 and transition material

You will be taught all year 12 modules concurrently by two teachers. One teacher will teach modules 2 and 3, the other teaching module 4.

The topics taught in the first term build upon work already covered at GCSE.

From modules 2 and 3:

- Physical quantities and units
- Making measurements and analysing data
- Nature of quantities
- Motion
- Forces in action
- Work, energy and power

From module 4:

- Charge and current
- Electrical energy, power and resistance
- Electrical circuits

Module 1 (practical skills) is taught throughout the course.

You should complete the transition work provided below before the start of the course. There is work covering some of the maths skills you should have acquired at GCSE and need for year 12 physics, along with some revision of energy and electricity topics met at GCSE but covered again in more depth in year 12. **You do not need to print the work, but you should at least write answers to all questions on paper, with clear working shown when appropriate.**

As well as the transition work, if you wish to stimulate your interest in physics over the summer, try the following Youtube channels:

- Sixty Symbols
- Minutephysics
- Physics Girl

If you are already considering studying the physical sciences or engineering at university, we would advise you to start reading around your areas of interest. Evidence of a deeper understanding beyond the curriculum and a genuine passion for your subject is what makes candidates stand out at interview.

Year 12 Physics Course Preparation
Some important maths and calculator skills

Name: ________________________________

Physics Year 12 Induction

Objectives:
- *To give you the skills needed for the successful study of physics at A level.*
- *To help you to identify areas in which you might need help.*

There are several areas in which students initially struggle at A level:
- Use of symbols
- Use of SI units
- Use of a calculator
- Use of formulae

These notes and activities are to help you to become confident with these basic skills, which will help the start of your physics studies to be more productive and enjoyable.

Using Symbols

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

In physics problems we are given certain quantities and use them to find an unknown quantity with an equation.

Symbols

At GCSE you were often given equations in words: $distance = speed \times time$

At A level you will be provided with a data sheet in your examinations. The data sheet will provide you with equations that are given in **symbols.** The symbols all mean something; they are abbreviations. The symbols used in exams and most textbooks are those agreed by the Association of Science Education.

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

1. What are the meanings for these symbols?
a
v
F
t
Q

You will come across symbols written in Greek letters. The normal (Latin) alphabet has 26 characters. The Greek alphabet adds another 24.

The Greek Alphabet

Greek	***Name***	***Greek***	***Name***
α	alpha	ν	nu
β	beta	ξ	xi
γ	gamma	ο	omicron
δ (Δ)	delta	π	pi
ε	epsilon	ρ	rho
ζ	zeta	σ (Σ)	sigma
η	eta	τ	tau
θ	theta	υ	upsilon
ι	iota	ϕ	phi
κ	kappa	χ	chi
λ	lambda	ψ	psi
μ	mu	ω (Ω)	omega

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

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

2. The wave equation is $v = f\lambda$. What do the symbols refer to?
v
f
λ

The most common uses of Greek letters are:

- α – as in alpha particle
- β – as in beta particle
- γ – as in gamma ray
- Δ – change in (Δt is time interval)
- θ – angle
- π – 3.1415…
- μ – as in micro (x10^{-6})

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

Units

Physics formulae use **SI** (Système International) units

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

Prefix	***Symbol***	***Meaning***	***Example***
pico	p	$\times 10^{-12}$	1 pF
nano	n	$\times 10^{-9}$	1 nF
micro	μ	$\times 10^{-6}$	1 μg
milli	m	$\times 10^{-3}$	1 mm
centi	c	$\times 10^{-2}$	1 cm
kilo	k	$\times 10^{3}$	1 km
mega	M	$\times 10^{6}$	1 MΩ
giga	G	$\times 10^{9}$	1 GWh

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

$$250 \text{ nm} = 250 \times 10^{-9} \text{ m} = 2.5 \times 10^{-7} \text{ m}$$

3. Convert the following quantities to SI units:	
15 cm	
3 km	
35 mV	
220 nF	

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

Converting areas and volumes causes a lot of problems.

Area:

$$1m^2 \neq 100cm^2$$

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

Volume:

$$\mathbf{1m^3 = 100cm \times 100cm \times 100cm = 1000,000cm^3 = 10^6cm^3}$$

4. Convert the following:	
1 m^2 =	mm^2
45 000 mm^2 =	m^2
6 000 000 cm^3 =	m^3

Standard Form

Standard form consists of a number between 1 and 10 multiplied by a **power** of 10. For big numbers and very small numbers standard form is very useful.

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

$$\mathbf{3.28 \times 10^5}$$
$$= 3.28 \times 100\ 000 = 328\ 000$$

Look at this number:

$$4\ 505\ 000\ 000\ 000\ 000\ 000$$

Start counting from here to get the power of 10.

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

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

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

$$0.00000342$$

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

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

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

5. Convert these numbers to standard form:
86
381
45300
1 500 000 000
0.03
0.00045
0.0000000782

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

- numbers greater than 100 000
- numbers less than 0.001

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

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

Using a Calculator

A **scientific calculator** is an essential tool in Physics, just like a chisel is to a carpenter. All physics exams assume you have a calculator, and you should always bring a calculator to every lesson. They are not expensive, so there is no excuse for not having one.

The calculator should be able to handle:

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

Most scientific calculators have this and much more.

We are assuming that you know the basic functions of your calculator, but we need to draw your attention to a couple of points on the next page.

Use the standard form button at the bottom of the number pad. It is either:

$\boxed{\text{EXP}}$

Or

$\boxed{\text{x } 10^{x}}$

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

2	.	3	1	EXP	7

Or

2	.	3	1	x10^x	7

Do **NOT** key it in like this:

2	.	3	1	×	1	0	EXP	7

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

Too Many Significant Figures

Consider this calculation: $$V_{rms} = \frac{13.6}{\sqrt{2}}$$

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

There is no reason at all in A-level Physics to write any answer to any more than 3 significant figures. Three significant figures is claiming accuracy to about one part in 1000. Blindly writing your calculator answer is claiming that you can be accurate to one part in 100 million, which is absurd.

The **examination mark schemes** give answers that are either 2 or 3 significant figures. So our answer above could be written as:

V_{rms} = 9.62 V (3 s.f.)
V_{rms} = 9.6 V (2 s.f.)

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

6. Use your calculator to do the following calculations. Write your answers to **three** significant figures.	
	ANSWER
(a) $\frac{3.40\times10^{-3}\times6.02\times10^{23}}{235}$	
(b) $\frac{27.3^2-24.8^2}{\sqrt{38}}$	
(c) 1.4509^3	
(d) $sin\ 56.4^0$	
(e) Reciprocal of 2.34×10^5	
(f) $45sin10^0$	

Some other tips on use of calculators:

- Take one step at a time and write intermediate results.
- It is easy to make a mistake such as pressing the × key rather than the ÷ key. It is a good idea to do the calculation again as a check.
- As you get more experienced, you will get a feel for what is a reasonable answer. 1000 N is a reasonable force that a car would use to accelerate; 2×10^{-10} N is most certainly not.

Transposition of Formulae

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

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

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

Key Points:

- What you do on one side you have to do on the other side. It applies whether you are working with numbers, symbols, or both.
- Do not try to do too many stages at once.

Transposing Simple Formulae

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

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

We want to get rid of the R on the RHS so that I is left on its own. So we divide both sides by *R* which gives us:

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

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

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

It does not matter which way the equation ends up, as long as it is rearranged properly.

7. Rearrange these equations:		
Equation	***Subject***	***Answer***
$V = IR$	*R*	
$p = mv$	*v*	
$\rho = \frac{m}{V}$	*m*	
$Q = CV$	*C*	

Formulae with Four Terms

8. Rearrange these equations:		
Equation	***Subject***	***Answer***
$pV = nRT$	V	
$E_p = mg\Delta h$	Δh (Δh is a single term)	
$V = \frac{-Gm}{r}$	G	
$\lambda = \frac{ax}{D}$	D	

Equations with + or -

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

$$Ek = hf - \Phi$$

We want to find *h*.

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

$$Ek + \Phi = hf - \Phi + \Phi$$
$$Ek + \Phi = hf$$

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

$$\frac{(Ek + \Phi)}{f} = \frac{hf}{f}$$

Which gives us our final result of:

$$h = \frac{(Ek + \Phi)}{f}$$

9. Rearrange these equations:		
Equation	***Subject***	***Answer***
$v = u + at$	t	
$E = V + Ir$	r	

Now mark your work. Ensure that it is ticked and that you have written up your corrections.

ANSWERS

1. What are the meanings for these symbols?
a *acceleration*
v *velocity*
F *force*
t *time*
Q *amount of charge*

2. The wave equation is $= f\lambda$. What do the symbols refer to?
v *speed*
f *frequency*
λ *wavelength*

3. Convert the following quantities to SI units:	
15 cm	*0.15 m*
3 km	*3000 m*
35 mV	*0.035 V*
220 nF	2.2×10^{-7} *F*

4. Convert the following:
1 m^2 = *1 000 000* mm^2 *(1 x* 10^6 mm^2*)*
45 000 mm^2 = *0.045* m^2
6 000 000 cm^3 = *6* m^3

5. Convert these numbers to standard form:
86 = 8.6×10^1
381 = 3.81×10^2
45300 = 4.53×10^4
1 500 000 000 = 1.5×10^9
0.03 = 3.0×10^{-2}
0.00045 = 4.5×10^{-4}
0.0000000782 = 7.82×10^{-8}

6. Use your calculator to do the following calculations. Write your answers to no more than **three** significant figures.	
(a) $\frac{3.4\times10^{-3}\times6.0\times10^{23}}{235}$	8.71×10^{18}
(b) $\frac{27.3^2-24.8^2}{\sqrt{38}}$	21.1

(c) 1.4509^3	3.05
(d) $sin\,56.4^0$	0.833
(e) Reciprocal of 2.34×10^5	4.27×10^{-6}
(f) $45sin10^0$	7.81

7. Rearrange these equations:		
$V = IR$	R	$R = \frac{V}{I}$
$p = mv$	v	$v = \frac{p}{m}$
$\rho = \frac{m}{V}$	m	$m = \rho V$
$Q = CV$	C	$C = \frac{Q}{V}$

8. Rearrange these equations:		
$pV = nRT$	V	$V = \frac{nRT}{p}$
$E_p = mg\Delta h$	Δh (Δh is a single term)	$\Delta h = \frac{E_p}{mg}$
$V = \frac{-Gm}{r}$	G	$G = -\frac{Vr}{m}$
$\lambda = \frac{ax}{D}$	D	$D = \frac{ax}{\lambda}$

9. Rearrange these equations:		
$v = u + at$	t	$t = \frac{v-u}{a}$
$E = V + Ir$	r	$r = \frac{E-V}{I}$

Kinetic and Gravitational Potential Energy

Kinetic Energy

Energy is a curious thing. You can't pick it up and look at it.

One thing's for certain though — if you're moving then you have energy.

This movement energy is more properly known as kinetic energy, and there's a formula for working it out:

If a body of mass m (in kilograms) is moving with speed v (in metres per second) then its kinetic energy (in joules) is given by:

$$\text{kinetic energy} = \tfrac{1}{2} \times \text{mass} \times \text{speed}^2$$

Or, in symbols:

$$E_k = \tfrac{1}{2} \times m \times v^2$$

Have a look at the following examples, and then try the questions after them.

Examples:

1) A car of mass 800 kg is travelling with a speed of 20 ms^{-1}.
   What is its kinetic energy?
   $E_k = \frac{1}{2} \times m \times v^2$, so $E_k = \frac{1}{2} \times 800\ kg \times (20\ ms^{-1})^2 = \frac{1}{2} \times 800\ kg \times 400\ m^2s^{-2}$
   $= 1.6 \times 10^5\ J$.
2) A ball has a speed of 2.5 ms^{-1} and has kinetic energy equal to 0.8 J.
   What is the mass of the ball?
   $E_k = \frac{1}{2} \times m \times v^2$. Multiplying both sides by 2 gives $2 \times E_k = m \times v^2$, then dividing both sides by v^2 gives $(2 \times E_k)/v^2 = m$, so $m = (2 \times E_k)/v^2 = (2 \times 0.8\ J) / (2.5\ ms^{-1})^2$
   $= 1.6\ J / (6.25\ m^2s^{-2}) = 0.256\ kg$
3) A bullet has kinetic energy equal to 1200 J. If its mass is 0.01 kg, what is its speed?
   From example 2) $2 \times E_k = m \times v^2$. Dividing both sides by m gives $(2 \times E_k)/m = v^2$, then taking square roots of both sides gives $\sqrt{(2 \times E_k)/m} = v$,
   so $v = \sqrt{(2 \times E_k)/m} = \sqrt{(2 \times 1200\ J) / 0.01\ kg} = 490\ ms^{-1}$ (to the nearest ms^{-1}).

Now try these questions:

1) An arrow of mass 0.4 kg is travelling at a speed of 80 ms^{-1}.
   What is its kinetic energy?
2) A ship has kinetic energy equal to 6×10^7 J when moving at 15 ms^{-1}. What is its mass?
3) A snail of mass 0.05 kg has a kinetic energy of 1×10^{-6} J. What is its speed?

Answers

1) 1280 J
2) 5.3×10^5 kg
3) 0.006 ms^{-1} (or 0.6 cms^{-1})

Kinetic and Gravitational Potential Energy

Gravitational Potential Energy

When an object falls, its speed increases. As its speed increases, so does its kinetic energy.
Where does it get this energy from?
Answer: from the gravitational potential energy it had before it fell:

If a body of mass m (in kilograms) is raised through a height h (in metres) the gravitational potential energy (in joules) it gains is given by:

gravitational potential energy (J) = mass (kg) × gravitational field strength (Nkg^{-1}) × height (m)

So, in symbols it reads:

$$E_p = m \times g \times h$$

where the gravitational field strength is the ratio of an object's weight to its mass (in newtons per kilogram). It is given the symbol g, and at the surface of the Earth has an approximate value of 9.8 Nkg^{-1}.

Examples:

1) An 80 kilogram person in a lift is raised 45 metres. Assuming $g = 9.8\ Nkg^{-1}$, what is the increase in gravitational potential energy?
$E_p = mgh$, so $E_p = 80\ kg \times 9.8\ Nkg^{-1} \times 45\ m = 35\ 280\ J$

2) A mass raised 10 metres gains gravitational potential energy equal to 50 joules. What is that mass?
$E_p = mgh$. Dividing both sides by gh gives $E_p/gh = m$,
so $m = E_p/gh = 50\ J / (9.8\ Nkg^{-1} \times 10\ m) = 0.51\ kg$.

3) 600 kilograms of bricks are given 29 400 joules of gravitational potential energy. Through what height have they been raised?
$E_p = mgh$. Dividing both sides by mg gives $E_p/mg = h$,
so $h = E_p/mg = 29\ 400\ J / (600\ kg \times 9.8\ Nkg^{-1}) = 5\ m$.

Now try these questions:

1) How much more gravitational potential energy does a 750 kilogram car have at the top of a 300 metre than at the bottom of the hill?
2) What mass, when raised through 7 metres, gains gravitational potential energy equal to 1715 joules?
3) A 60 kilogram person gains 24 696 joules of gravitational potential energy. How high have they climbed?

Answers
1) 2.205×10^6 J or 2.205 MJ
2) 25 kg
3) 42 m

Kinetic and Gravitational Potential Energy

The Conservation of Energy Applied to Falling Bodies

The principle of conservation of energy states that:

"Energy cannot be created or destroyed — it can only converted into other forms"

So as long as you ignore air resistance...

...for a falling object:

Kinetic Energy Gained (in joules) = Gravitational Potential Energy Lost (in joules)

...and for an object thrown or catapulted upwards:

Gravitational Potential Energy Gained (in joules) = Kinetic Energy Lost (in joules)

This can be very useful in solving problems.
Read through the examples and then have a go at the questions afterwards.
(In all the questions, you can ignore air resistance.)

Examples:

1) *An apple of mass 0.1 kilograms falls from a tree of height 2 metres. With what speed does it hit the ground? Give your answer to 2 decimal places.*

   E_p lost = mgh = 0.1 kg × 9.8 Nkg^{-1} × 2 m = 1.96 J
   Therefore E_k gained = 1.96 J, so $E_k = \frac{1}{2} \times m \times v^2 = 1.96$ J.
   From page 15, $v = \sqrt{((2 \times E_k)/m)}$, so $v = \sqrt{((2 \times 1.96\text{ J}) / 0.1\text{ kg})} = 6.26\ ms^{-1}$

2) *A ball of mass 0.2 kilograms is thrown upwards at 10 metres per second. How high does it get?*

   E_k lost = $\frac{1}{2} \times m \times v^2 = \frac{1}{2} \times 0.2\text{ kg} \times (10\ ms^{-1})^2 = 10$ J.
   Therefore, E_p gained = 10 J, so E_p = mgh = 10 J.
   From page 16, $h = E_p/mg$, so $h = 10\text{ J} / (0.2\text{ kg} \times 9.8\ Nkg^{-1}) = 5.10$ m.

Now try these (give your answers to 3 significant figures):

1) *A book of mass 0.5 kilograms falls off a table top 1 metre from the floor. With what speed is it travelling when it lands?*
2) *A bullet of mass 0.01 kilograms is fired upwards at 400 ms^{-1}. What height does it reach?*

Answers

1) 4.43 ms^{-1}
2) 8160 m (or 8.16 km)

Work

Work — the Amount of Energy a Force Gives an Object

When you push an object you can increase its energy by:

1) Pushing it up hill,
2) Accelerating it,
3) Doing both at once.

In any case, the amount of energy (in joules) that a force gives an object is called the work done, and can be calculated using the formula:

Work Done by a Force = Size of Force × Distance Moved in the Direction of the Force
(in joules) (in newtons) While the Force is Acting (in metres)

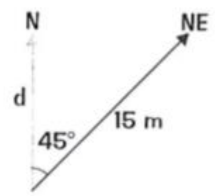
Or, in symbols: $W = F \times d$

Examples:

1) A 5 newton force to the north pushes an object 3 metres in the same direction. What is the work done?

$\boxed{W = F \times d, \text{ so } W = 5\ N \times 3\ m = 15\ J.}$

2) A 10 newton force to the north pushes an object 15 metres in a north-easterly direction. What is the work done?
N.B. You need to use trigonometry to find the distance travelled in the direction of the force (i.e. north).



$d = 15 \cos 45^\circ = 10.6\ m$
So, $W = F \times d = 10\ N \times 10.6\ m = 106\ J.$

3) A force of 35 newtons north acts on an object as it moves 7 m in a westerly direction. What is the work done by the force?
The object is moving at 90° to the force, so $d = 0$ m.

$\boxed{\text{Therefore, } W = F \times d = 35\ N \times 0\ m = 0\ J.}$

Have a go at these questions:

1) A force of 25 newtons to the west moves an object 40 metres in the same direction. What is the work done?
2) A force of 10 newtons to the north-east acts on an object as it moves 25 metres to the south-east. What is the work done by the force?
3) A force of 3 newtons to the west acts on an object as it moves 10 metres to the south-west. What is the work done by the force?

Answers
1) 1000 J
2) 0 J
3) 21.2 J

Work

Work Done = Increase in Gravitational and Kinetic Energy

Here are three possible situations:

1) *The work done goes entirely into the gravitational potential energy of an object.*
E.g. if you are lifting an object straight upwards.

Work done = force × distance

= weight of object × height lifted

= mass of object × gravitational field strength × height

So: work done = mgh = the increase in gravitational energy

2) *The work done goes entirely into the kinetic energy of an object.*
E.g. if a 5 newton force acts on a 3 kilogram body over a distance of 10 metres, what is its final speed if it was initially at rest?

Work done = increase in kinetic energy

$F \times d = \frac{1}{2} \times m \times v^2$. *Dividing both sides by m gives:*

$(F \times d)/m = \frac{1}{2} \times v^2$. *Multiplying both sides by 2 gives:*

$2 \times (F \times d)/m = v^2$. *Finally, taking the square root of both sides gives:*

$v = \sqrt{2 \times (F \times d)/m} = \sqrt{2 \times (5\ N \times 10\ m) / 3\ kg} = \underline{5.8\ ms^{-1}}$

3) *The work done goes into increasing both the kinetic and the gravitational energy.*

Work done = increase in E_k *+ increase in* E_p

$F \times d = \frac{1}{2} \times m \times v^2 + mgh$

Work done can also go into increasing the elastic potential energy of something (if you stretch or squash it).

Have a go at these questions:

1) *A 100 newton force lifts a 5 kilogram object 2 metres. When the force is removed, the object continues to move upwards. Calculate: (a) the work done by the force; (b) the gain in gravitational potential energy (using* $g = 9.8\ Nkg^{-1}$*); (c) the gain in kinetic energy.*
2) *A 10 newton force pushes an object of mass 2 kilograms horizontally on a frictionless surface for 25 metres. Calculate: (a) the work done; (b) the final speed of the object if it was initially at rest.*

Answers

1) (a) 200 J
(b) 98 J
(c) 102 J
2) (a) 250 J
(b) 15.8 ms^{-1}

Power

Power — the Work Done Every Second

In mechanical situations, whenever energy is converted, work is being done.

For example, when an object is falling, the force of gravity is doing work on that object equal to the increase in kinetic energy (ignoring air resistance).

The rate at which this work is being done is called the power.

You can calculate it using:

Power (in watts) = Work Done (in joules) / Time Taken (in seconds)

Or, in symbols:

$$P = W / t$$

No one dared suggest Rhona had PW!

Consider the following examples:

1) *If 10 joules of work is done in 2 seconds, what is the power?*

   $\boxed{P = W/t = 10\text{ J} / 2\text{ s} = 5\text{ W.}}$

2) *A force of 100 newtons pushes an object 5 metres in 4 seconds. What is the power? (Assume the motion is in the same direction as the force.)*

   $W = F \times d = 100\text{ N} \times 5\text{ m} = 500\text{ J}$

   $\boxed{P = W/t = 500\text{ J} / 4\text{ s} = 125\text{ W.}}$

3) *For how long must a 5 kilowatt (5000 watt) engine run to do 200 kilojoules (2×10^5 joules) of work?*

   $P = W/t$. Multiplying both sides by t gives $P \times t = W$, then dividing both sides by P gives: $t = W/P$.

   $\boxed{\text{So, } t = W/P = 2 \times 10^5\text{ J} / 5000\text{ W} = 40\text{ s.}}$

Try these:

1) *If a lift mechanism works at 15 kilowatts, how long does it take to do 100 kilojoules of work?*
2) *What is the power output of a motor if it does 250 joules of work in 4 seconds?*
3) *If a force of 200 newtons pushes an object 1.5 kilometres in a minute, at what power is it working? (Assume the motion is in the same direction as the force.)*

Answers

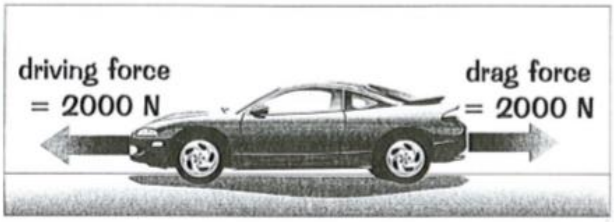
1) 6.7 s
2) 62.5 W
3) 5000 W

Power

The Power Developed by a Moving Force

There's a useful equation you can derive for the work done by a force every second on a moving object. Follow through the working below:

Example: At what power is a car engine working if it produces a driving force of 2000 newtons when moving at a steady speed of 30 metres per second?



The power of the engine is given by: $P = W/t$

$W = F \times d$, *so we can substitute for the work done, giving* $P = (F \times d)/t$.

Now, $(F \times d)/t$ *is the same as* $F \times (d/t)$, *so* $P = F \times (d/t)$.

Finally we use the fact that d/t = *distance travelled/time taken = the speed,* v.

So, $$P = F \times (d/t) = F \times v$$

Power (in watts) = Force (in newtons) × Speed (in metres per second)

For our example, $P = 2000\ \text{N} \times 30\ \text{ms}^{-1} = \underline{60\ 000\ \text{W}}$ *(or 60 kW)*

IMPORTANT:
The formula $P = Fv$ *is only true when the object is moving at a constant velocity in the same direction as the force.*

Have a go at these:

1) *What is the power developed by a train engine if its driving force of* 1.8×10^5 *newtons produces a constant speed of 40 metres per second?*
2) *A skydiver is falling at a terminal velocity of 45 metres per second. If her weight is 700 newtons, at what rate is gravity doing work on her?*

Answers
1) 7.2×10^6 W, or 7.2 MW
2) 31 500 W, or 31.5 kW

Efficiency

How Much of What You Put In Do You Get Out?

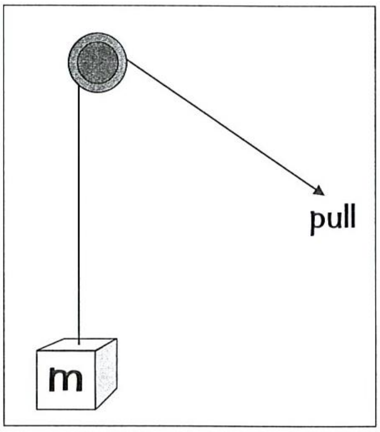
For most mechanical systems you put in energy in one form and it gives out energy in another.

However, some energy is always converted into forms that aren't useful.

For example, an electric motor converts electrical energy into heat and sound as well as useful kinetic energy.

You can measure the efficiency of a system by the percentage of total energy put in that is converted to useful forms.

Example: Raising a load using a pulley



The energy you put in is the work you do pulling the rope.

The useful energy out is the gravitational potential energy gained by the load.

Some energy is converted into heat and sound by friction at the pulley.

Say the mass of the load is 10 kilograms and it's raised 5 metres. You pull with a force of 120 newtons.

(Take $g = 9.8\ Nkg^{-1}$.)

Energy in = Work done = $F \times d = 120\ N \times 5\ m = \underline{600\ J}$

Useful energy out = Potential energy gained = $mgh = 10\ kg \times 9.8\ Nkg^{-1} \times 5\ m = \underline{490\ J}$

Efficiency = (Useful energy out / Total energy in) × 100%

$= (490/600) \times 100\% = \underline{81.7\%}$

Have a go at these questions:

1) A motor uses 300 joules of electrical energy in lifting a 10 kilogram mass through 2 metres. What is its efficiency? (Take $g = 9.8\ Nkg^{-1}$.)
2) It takes 800 kilojoules (8×10^5 joules) of chemical energy from the petrol in a car engine to accelerate a 500 kilogram vehicle from rest to 20 metres per second on a flat road:
   (a) What is the gain in kinetic energy?
   (b) What is the efficiency of the car?

Answers
1) 65.3%
2) (a) 1×10^5 J (or 100 kJ)
   (b) 12.5%

Current

Electric Current — The Flow of Charge

If you connect a wire to a battery, negatively charged electrons flow through the wire from the negative end of the battery to the positive end. This flow of charge is an electric current, and, as you know, the charge will only flow if there's a complete circuit.

The electric current at a point in the wire can be defined as:

Current (in amps) = the amount of charge passing the point (in coulombs) / the time it takes for the charge to pass (in seconds)

Or, equivalently, as the amount of charge passing the point per second.

In symbols you can write this as:

$$I = \Delta Q/\Delta t$$

The "Δ" sign is a capital Greek "delta", and just means "the change in".

Here are a few examples:

1) *6 coulombs of charge flow through a lamp in one minute.*
   What is the current through the lamp?
   $I = \Delta Q/\Delta t$, so $I = 6\text{ C} / 60\text{ s} = 0.1\text{ A}$

2) *There is a current of 2 amps in a wire. How much charge will flow in 5 minutes?*
   $I = \Delta Q/\Delta t$. *Multiplying both sides by* Δt *gives* $I \times \Delta t = \Delta Q$, *so* $\Delta Q = 2\text{ A} \times 300\text{ s} = 600\text{ C}$

3) *There is a current of 0.5 amps through a resistor.*
   How long does it take for 0.1 coulombs to pass through it?
   From example 2, $I \times \Delta t = \Delta Q$. *Dividing both sides by* I *gives* $\Delta t = \Delta Q/I$,
   so $\Delta t = 0.1\text{ C} / 0.5\text{ A} = 0.2\text{ s}$

Now have a go at these:

1) *There is a current of 0.2 amps at a point in a circuit. How much charge will flow past that point in 2 minutes?*
2) *0.01 coulombs of charge flows through a wire in 20 seconds. What is the current?*
3) *There is a current of 0.005 amps through a lamp. How long does it take for 1 coulomb of charge to pass through it?*

Answers
1) 24 C
2) 5×10^{-4} A (or 0.5 mA)
3) 200 s (or 3 min 20 s)

Potential Difference

Potential Difference (Voltage) — Energy Per Unit Charge

In any circuit energy is transferred from the power supply to the components (lamps, motors etc.), where it's converted into other forms, e.g. light. This energy is carried around the circuit by the charged particles. If you think about one coulomb of charge flowing around a circuit then:

(a) The amount of energy it's given by the power supply is the voltage across the power supply.

(b) The amount of energy it gives to each individual component in the circuit is the voltage across that component.

In other words, the voltage, or potential difference, across a component is the amount of energy (in joules) that it converts for every coulomb of charge that passes through it.

Voltage across component (in volts) = Energy converted (in joules) / Charge that passes through it (in coulombs)

Or, in symbols:

$$V = E/Q$$

Here are a few examples:

1) *A lamp gives out 10 joules of energy when 0.5 coulombs pass through it. What is the potential difference across the lamp?*

   $\boxed{V = E/Q = 10\ J / 0.5\ C = 20\ V}$

2) *What is the maximum amount of energy an electric heater could produce at 200 volts if the amount of charge that passes through it is 10 coulombs?*

   $V = E/Q$. Multiplying both sides by Q gives $V \times Q = E$, so $\boxed{E = 200\ V \times 10\ C = 2000\ J}$

3) *How much charge has passed through a 12 volt motor if the energy it has converted is 3 joules?*

   From example 2, $V \times Q = E$

   Dividing both sides by V gives $Q = E/V$, so $\boxed{Q = 3\ J / 12\ V = 0.25\ C}$

Have a go at these problems:

1) *What is the maximum amount of energy that a lamp could give out if the voltage across it is 6 volts and the amount of charge that passes through it is 0.5 coulombs?*
2) *How much charge has passed through a circuit if 100 joules of energy have been converted across a potential difference of 8 volts?*
3) *An electric motor converts 1 joule of energy when 0.04 coulombs of charge pass through it. What is the potential difference across the motor?*

Answers

1) 3 J
2) 12.5 C
3) 25 V

Energy in Electrical Circuits

Conservation of Energy in Electrical Circuits

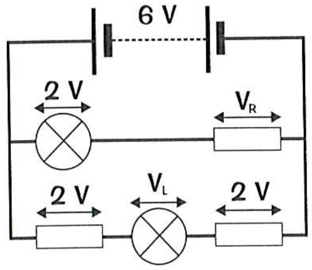
Energy is given to charged particles by the power supply and taken off them by the components in the circuit. Since energy is conserved, the amount of energy one coulomb of charge loses when going around the circuit must be equal to the energy it's given by the power supply.

And more than that, this must be true regardless of the route the charge takes around the circuit. So, you can say that:

> *For any closed loop in a circuit the sum of the potential differences across the components equals the voltage of the power supply.*

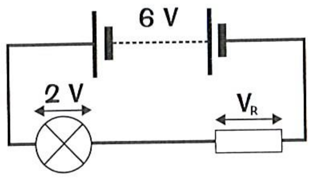
This is a case of Kirchhoff's second rule.

Have a look at this example:



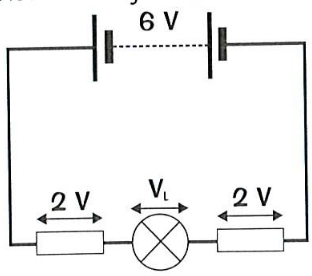
What are the voltages across the resistor, V_R, and the lamp, V_L?

First look at just the top loop:



$6\text{ V} = 2\text{ V} + V_R$
$6\text{ V} - 2\text{ V} = V_R$
$4\text{ V} = V_R$

Now look at just the outside loop:



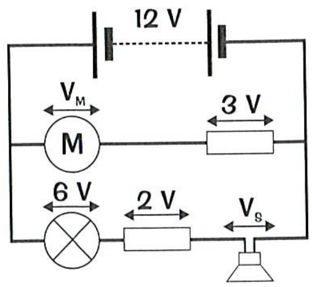
$6\text{ V} = 2\text{ V} + V_L + 2\text{ V}$
$6\text{ V} = 4\text{ V} + V_L$
$6\text{ V} - 4\text{ V} = V_L$
$2\text{ V} = V_L$

Now you do this one:

For the circuit on the right, calculate:

(a) the voltage across the motor, V_M

(b) the voltage across the loudspeaker, V_S



Answers
(a) $V_M = 9\text{ V}$
(b) $V_S = 4\text{ V}$

Resistance

Resistance — The Ratio of Voltage / Current

Generally speaking, when there's a voltage across a component there'll be a current through it. Usually, as the voltage is increased the current increases — this makes sense if you think of the voltage as a kind of force pushing the charged particles. You can formalise the relationship between current and voltage by defining "resistance":

Resistance of a component = Voltage across it / Current passing through it
(in ohms) (in volts) (in amps)

Or, in symbols:

$$R = V / I$$

Multiplying both sides by I gives:

$$V = I \times R$$

Ed got in there while Lucy's resistance was low...

Components with a low resistance allow a large current to flow through them, while components with a high resistance allow only a small current. The resistance isn't usually a constant though — it can take different values as the current and voltage change, or it can change with conditions like temperature and light level.

Here are some examples:

1) *If a potential difference of 12 volts across a component causes a current of 0.001 amps to flow, what is the resistance?*
   $\boxed{R = V/I, \text{ so } R = 12\text{ V} / 0.001\text{ A} = 12\,000\ \Omega, \text{ or } 12\text{ k}\Omega}$

2) *If a current of 0.2 amps passes through a resistance of 200 ohms, what is the voltage?*
   $\boxed{V = I \times R, \text{ so } V = 0.2\text{ A} \times 200\ \Omega = 40\text{ V}}$

3) *What current will flow through a resistance of 800 ohms if the voltage across it is 6 volts?*
   $V = I \times R$. Dividing both sides by R gives $\boxed{I = V/R, \text{ so } I = 6\text{ V} / 800\ \Omega = 0.0075\text{ A (or 7.5 mA)}}$

Here are some for you to do:

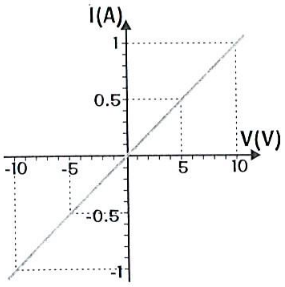
1) *If a current of 2.5 amps passes through a component with a resistance of 10 ohms, what is the voltage?*
2) *What current will flow through a resistance of 2500 ohms if the voltage across it is 6 volts?*
3) *What is the resistance of a component if 1.5 volts drives a current of 0.02 amps through it?*

Answers
1) 25 V
2) 0.0024 A or 2.4 mA
3) 75 Ω

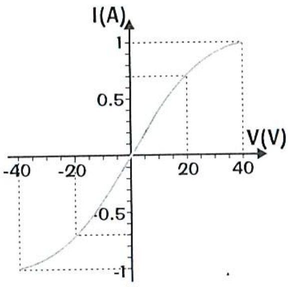
Resistance

Voltage-Current Graphs

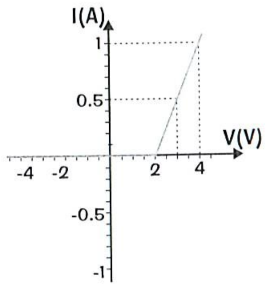
Look at the following graphs showing the current through different components as the voltage across them is changed (negative values refer to charges flowing the other way):



Resistor



Filament Lamp



Diode

We can use the graphs to determine the resistance at different voltages as follows:

Example:
What is the resistance of the resistor at:
(a) –10 V?
(b) –5 V?
(c) 5 V?
(d) 10 V?

(a) $R = V/I = -10\ V / -1\ A = 10\ \Omega$
(b) $R = V/I = -5\ V / -0.5\ A = 10\ \Omega$
(c) $R = V/I = 5\ V / 0.5\ A = 10\ \Omega$
(d) $R = V/I = 10\ V / 1\ A = 10\ \Omega$

Now you have a go at the other two:

1) *What is the resistance of the filament lamp at:*
   (a) 10 V?
   (b) 20 V?
   (c) 30 V?
   (d) 40 V?

2) *What is the resistance of the diode at:*
   (a) 1 V?
   (b) 2 V?
   (c) 3 V?
   (d) 4 V?

Answers

1) (a) 25 Ω
   (b) 29 Ω
   (c) 33 Ω
   (d) 40 Ω

The resistance of the lamp increases as the current increases (due to the increased temperature).

2) (a) Very high (infinite)
   (b) Very high (infinite)
   (c) 6 Ω
   (d) 4 Ω

2 V is the "breakdown potential" of this diode. Up to this voltage (virtually) no current will flow, and (virtually) no current will flow in the other direction for any voltage.

Power in Circuits

Power — The Energy Converted Every Second

Components in electrical circuits convert the energy carried by electrons into other forms.
The amount of energy, in joules, that's converted every second is the <u>power</u> of that component:

Power (in watts) = Amount of Energy Converted (in joules) / Time Taken (in seconds)

Or, in symbols:

$$P = E / t$$

The energy converted is equal to the voltage across the component x the amount of charge that has flowed through it ($E = V \times Q$) — see p27.

So: $\boxed{P = V \times Q / t}$

and the amount of charge that flows through a component is equal to the current through it x the time taken ($Q = I \times t$)

So: $\boxed{P = V \times I \times t / t}$

Cancelling the "t"s gives: $P = V \times I$

Power (in watts) = Voltage Across Component (in volts) x Current Through Component (in amps)

Here are some examples:

1) A lift motor converts 3×10^5 joules of electrical energy into gravitational potential energy in a single one-minute journey. At what power is it working?

$\boxed{P = E/t, \text{ so } P = 3 \times 10^5 \text{ J} / 60 \text{ s} = 5000 \text{ W (or 5 kW).}}$

2) If the voltage across a component is 6 volts and the current through it is 0.5 milliamps (5×10^{-4} amps), at what rate is it converting electrical energy to other forms?

$\boxed{P = I \times V, \text{ so } P = 5 \times 10^{-4} \text{ A} \times 6 \text{ V} = 0.003 \text{ W (or 3 mW).}}$

3) If a 12 watt lamp has a current through it of 1.5 amps, what is the voltage across it?

$\boxed{P = I \times V. \text{ Dividing both sides by } I \text{ gives } V = P/I, \text{ so } V = 12 \text{ W} / 1.5 \text{ A} = 8 \text{ V.}}$

Have a go at these questions:

1) What is the power output of a component if the current through it is 0.12 amps when the voltage across it is 6 volts?
2) What current passes through a 40 watt heater when the voltage across it is 10 volts?
3) How much electrical energy would be converted by the 40 watt heater in 10 seconds?

<u>Answers</u>

1) 0.72 W
2) 4 A
3) 400 J

Power in Circuits

Power — More Equations

*You can combine the last equation for the power of an electrical component, $P = V \times I$, with the resistance equation (**see p29**) to create two more useful equations.*

First, replace V with $I \times R$ to give: $P = I \times R \times I = I^2R$

Power (in watts) = [Current (in amps)]^2 × Resistance (in ohms)

Second, replace I with V/R to give: $P = V \times V/R = V^2/R$

Power (in watts) = [Voltage (in volts)]^2 / Resistance (in ohms)

Here are some examples — the key here is choosing the right equation to use. If the question gives you the value of two variables and asks you to find another, you should choose the equation that relates these three variables. You might have to rearrange it before using it.

1) *What is the power output of a component of resistance 100 ohms if the current through it is 0.2 amps?*
   $P = I^2R$, so $\boxed{P = (0.2\ \text{A})^2 \times 100\ \Omega = 4\ \text{W}.}$ *($P = V^2/R$ wouldn't have been any use here.)*

2) *How much energy is converted in 10 s if the voltage is 100 V and the resistance is 5000 Ω?*
   $P = V^2/R$, so $P = 100^2/5000 = 2$ W. *But power is the energy converted per second, so the energy converted in 10 s is* $\boxed{2\ \text{W} \times 10\ \text{s} = 20\ \text{J}.}$ *($P = I^2R$ wouldn't have helped much.)*

3) *Resistors get hotter when a current flows through them. If you double the current through a resistor, what happens to the amount of heat energy produced every second?*
   It increases by a factor of 4 — this is because the current is squared in the expression for the power (you can substitute some values of I and R in to check this).

4) *If a lamp has a power rating of 6 W and the voltage across it is 12 V, what is its resistance?*
   You don't have an expression for the resistance so far, so you'll need to rearrange one. You need the equation that relates P, V and R, i.e. $P = V^2/R$.
   Multiplying both sides by R gives $P \times R = V^2$, and dividing by P gives:
   $$\boxed{R = V^2/P,\ \text{so}\ R = (12\ \text{V})^2/6\ \text{W} = 24\ \Omega}$$

Now have a go at these:

1) *What is the power output of a component of resistance 2000 ohms if the current through it is 1.2 amps?*
2) *How much energy is converted in 1 minute if the resistance is 100 Ω and the current is 2 A?*
3) *If a lamp has a power rating of 6 watts and the current through it is 0.5 amps, what is the resistance?*

Answers
1) 2880 W 2) 24 000 J, or 24 kJ 3) 24 Ω

Reflection on the transition work and the AS physics course you are about to undertake:

Which exercises I found the easiest and why?
Which exercises I found the hardest and why?
Concerns I have about the AS Physics course in Year 12: