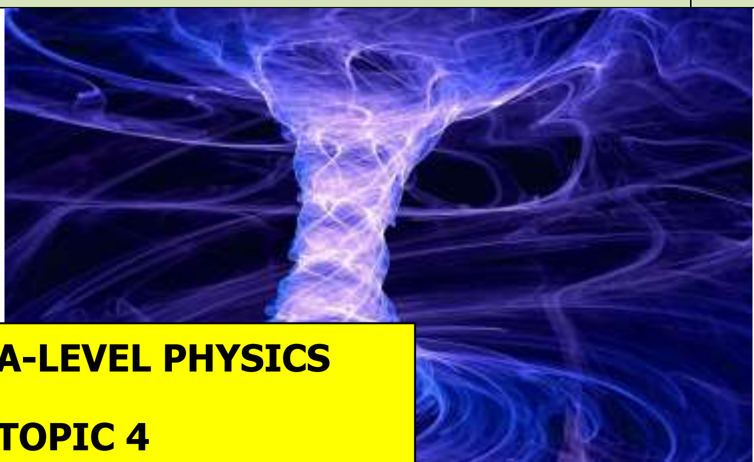
Volume

Two

A LEVEL PHYSICS **YEAR 1**
PREPARATORY READING BOOK
3.4.1: FORCES, ENERGY AND MOMENTUM
VOLUME **TWO**

NAME	
PHYSICS CLASS	
MODULE TEACHER	
ALPS GRADE	



A-LEVEL PHYSICS

TOPIC 4

PREP READING 1

THIS MUST BE BROUGHT TO ALL PHYSICS LESSONS.

Contents

Vectors and their treatment are introduced followed by development of the student's knowledge and understanding of forces, energy and momentum.

The section continues with a study of materials considered in terms of their bulk properties and tensile strength.

IMPORTANT NOTE
This booklet, along with the student workbook, must be brought to all Physics lessons with the appropriate teacher.

This booklet may be used as a learning resource in lessons; you are not fully equipped to learn if this is not used in lesson.

This booklet may also be used as a revision resource for intervention, internal assessments and external assessments.
Please keep this in your student file.

As part of this course you are expected to **read through this preparatory reading book** and **complete the independent study tasks**.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher.

Definition List

Definitions you must learn for this module are…

Acceleration, change of velocity per unit time.

Acceleration of free fall, acceleration of an object acted on only by the force of gravity.

Centre of mass, the centre of mass of a body is the point through which a single force on the body has no turning effect.

Couple, pair of equal and opposite forces acting on a body but not along the same line.

Displacement, distance in a given direction.

Drag force, the force of fluid resistance on an object moving through the fluid.

Efficiency, the ration of useful energy transferred by a machine or a device to the energy supplied to it.

Effort, the force applied to a machine to make it move.

Energy, the capacity to do work.

Equilibrium, state of an object when at rest or in uniform motion.

Force, any interaction that can change the velocity of an object.

Free Body Force Diagram, a diagram of an object showing only the forces acting on the object.

Friction, force opposing the motion of a surface that moves or tries to move across another surface.

Inertia, resistance of an object to change of its motion.

Load, the force to be overcome by a machine when it shifts or raises an object.

Mass, measure of inertia or resistance to change of motion of an object.

Moment of a force about a point, force x perpendicular distance from the line of action of the force to a point.

Momentum, mass x velocity.

Motive force, the force that drives a vehicle.

Newton's 1st Law of Motion, an object remains at rest or in uniform motion unless acted on by a resultant force.

Newton's 2nd Law of Motion, the rate of change of momentum of an object is proportional to the resultant force.

Power, rate of transfer of energy.

Principle of conservation of energy, energy cannot be created or destroyed.

Projectile, a projected object in motion acted on only by the force of gravity.

Scalar, a physical quantity with magnitude only.

Speed, change of distance per unit time.

Terminal speed, the maximum speed reached by an object when the drag force on it is equal and opposite to the force causing the motion of the object.

Useful energy, energy transferred to where it is wanted when it is wanted.

Vector, a physical quantity with magnitude and direction.

Velocity, change of displacement per unit time.

Weight, the force of gravity acting on an object.

Work, force x distance moved in the direction of the force.

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on your knowledge of these definitions.

The Language of Measurement

The following subject specific vocabulary provides definitions of key terms used in the A-level Science specifications.

Accuracy
A measurement result is considered accurate if it is judged to be close to the true value.

Calibration
Marking a scale on a measuring instrument.
This involves establishing the relationship between indications of a measuring instrument and standard or reference quantity values, which must be applied.
For example, placing a thermometer in melting ice to see whether it reads 0 °C, to check if it has been calibrated correctly.

Data
Information, either qualitative or quantitative, that has been collected.

Errors
See also uncertainties.

Measurement error
The difference between a measured value and the true value.
anomalies
These are values in a set of results which are judged not to be part of the variation caused by random uncertainty.

Random error
These cause readings to be spread about the true value, due to results varying in an unpredictable way from one measurement to the next.
Random errors are present when any measurement is made, and cannot be corrected. The effect of random errors can be reduced by making more measurements and calculating a new mean.

Systematic error
These cause readings to differ from the true value by a consistent amount each time a measurement is made.
Sources of systematic error can include the environment, methods of observation or instruments used.
Systematic errors cannot be dealt with by simple repeats. If a systematic error is suspected, the data collection should be repeated using a different technique or a different set of equipment, and the results compared.

Zero error
Any indication that a measuring system gives a false reading when the true value of a measured quantity is zero, e.g. the needle on an ammeter failing to return to zero when no current flows.
A zero error may result in a systematic uncertainty.

Evidence
Data which has been shown to be valid.

Fair test
A fair test is one in which only the independent variable has been allowed to affect the dependent variable.

Hypothesis
A proposal intended to explain certain facts or observations.

Interval
The quantity between readings, e.g. a set of 11 readings equally spaced over a distance of 1 metre would give an interval of 10 centimetres.

Precision
Precise measurements are ones in which there is very little spread about the mean value. Precision depends only on the extent of random errors – it gives no indication of how close results are to the true value.

Prediction
A prediction is a statement suggesting what will happen in the future, based on observation, experience or a hypothesis.

Range
The maximum and minimum values of the independent or dependent variables; important in ensuring that any pattern is detected.
For example, a range of distances may be quoted as either:
'From 10 cm to 50 cm'
or
'From 50 cm to 10 cm'

Repeatable
A measurement is repeatable if the original experimenter repeats the investigation using same method and equipment and obtains the same results.

Reproducible
A measurement is reproducible if the investigation is repeated by another person, or by using different equipment or techniques, and the same results are obtained.

Resolution
This is the smallest change in the quantity being measured (input) of a measuring instrument that gives a perceptible change in the reading.

Sketch graph
A line graph, not necessarily on a grid, that shows the general shape of the relationship between two variables. It will not have any points plotted and although the axes should be labelled they may not be scaled.

True value
This is the value that would be obtained in an ideal measurement.

Uncertainty
The interval within which the true value can be expected to lie, with a given level of confidence or probability, e.g. “the temperature is 20 °C ± 2 °C, at a level of confidence of 95%.

Validity
Suitability of the investigative procedure to answer the question being asked. For example, an investigation to find out if the rate of a chemical reaction depended upon the concentration of one of the reactants would not be a valid procedure if the temperature of the reactants was not controlled.

Valid conclusion
A conclusion supported by valid data, obtained from an appropriate experimental design and based on sound reasoning.

Variables
These are physical, chemical or biological quantities or characteristics.

Categoric variables
Categoric variables have values that are labels. E.g. names of plants or types of material.

Continuous variables
Continuous variables can have values (called a quantity) that can be given a magnitude either by counting (as in the case of the number of shrimp) or by measurement (e.g. light intensity, flow rate etc.).

Control variables
A control variable is one which may, in addition to the independent variable, affect the outcome of the investigation and therefore must be kept constant or at least monitored.

Dependent variables
The dependent variable is the variable of which the value is measured for each change in the independent variable.

Independent variables
The independent variable is the variable for which values are changed or selected by the investigator.

IMPORTANT NOTE
These definitions must be memorised by students.

You will be tested on your knowledge of these definitions.

VIDEO

COURSE OVERVIEW

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TOPIC: 3.4.1.5 Newton's Laws of Motion

SPEC CHECK

Specification	Completed?
Knowledge and application of the three laws of motion in appropriate situations.	
F = ma for situations where the mass is constant.	
Students can verify Newton's second law of motion.	
Students can use free-body diagrams.	

Student Checklist

Have I…….	Yes or No?
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	

NOTES

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

Newton's 1st Law

An object will remain at rest, or continue to move with uniform velocity, unless it is acted upon by an external resultant force.

Newton's 2nd Law

The rate of change of an object's linear momentum is directly proportional to the resultant external force. The change in the momentum takes place in the direction of the force.

Newton's 3rd Law

If an object A exerts a force on object B, then object B exerts an equal but opposite force on object A.

Force is measured in Newtons, N

Say What?

Newton's 1st Law

If the forward and backward forces cancel out, a stationary object will remain stationary.
If the forward forces are greater than the backwards forces, a stationary object will begin to move forwards.
If the forward and backward forces cancel out, a moving object will continue to move with constant velocity.
If the forward forces are greater than the backward forces, a moving object will speed up.
If the backward forces are greater than the forward forces, a moving object will slow down.

Newton's 2nd Law

The acceleration of an object increases when the force is increased but decreases when the mass is increased: $a = \frac{F}{m}$ but we rearrange this and use

$$F = ma$$

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what the equation represents.

The shows the resultant force and inertial acceleration of a moving object.

Physics Tip
This equation crops up all over the place in physics, so make sure you learn it and know how to use it.

Physics Tip
Newton's 2nd Law applies to objects with a constant mass.

Study Tip
This topic is common content with the A-Level Mathematics specification.

Newton's 3rd Law

Forces are created in pairs.
As you sit on the chair your weight pushes down on the chair, the chair also pushes up against you.
As the chair rests on the floor its weight pushes down on the floor, the floor also pushes up against the chair.

The forces have the same size but opposite directions.

Riding the Bus

Newton's 1st Law

You get on a bus and stand up. When the bus is stationary you feel no force, when the bus accelerates you feel a backwards force. You want to stay where you are but the bus forces you to move. When the bus is at a constant speed you feel no forwards or backwards forces. The bus slows down and you feel a forward force. You want to keep moving at the same speed but the bus is slowing down so you fall forwards. If the bus turns left you want to keep moving in a straight line so you are forced to the right (in comparison to the bus). If the bus turns right you want to keep moving in a straight line so you are forced left (in comparison to the bus).

Newton's 2nd Law

As more people get on the bus its mass increases, if the driving force of the bus's engine is constant we can see that it takes longer for the bus to gain speed.

Newton's 3rd Law

As you stand on the bus you are pushing down on the floor with a force that is equal to your weight. If this was the only force acting you would begin to move through the floor. The floor is exerting a force of equal magnitude but upwards (in the opposite direction).

Physics Tip

Many examples of Newton's Laws use ice skaters are this is a common way of saying there is no friction involved – the only force is from where they push against each other.

Examination Tip

It is a common examination question to state one way in which a pair of forces referred to in Newton's Third Law are the same.

they have the same line of action (1 mark)

they have the same magnitude (not size) (1 mark)

the forces are of the same kind (1 mark)

Examination Tip

It is a common examination question to state one way in which a pair of Newton's 3rd Law forces are different.

they are in opposite directions (1 mark)

they act on different bodies (1 mark)

Taking the Lift

Newton's 1st Law

When you get in the lift and when it moves at a constant speed you feel no force up or down. When it sets off going up you feel like you are pushed down, you want to stay where you are. When it sets off going down you feel like you are lighter, you feel pulled up.

Newton's 2nd Law

As more people get in the lift its mass increases, if the lifting force is constant we can see that it takes longer for the lift to get moving. Or we can see that with more people the greater the lifting force must be.

Newton's 3rd Law

As you stand in the lift you push down on the floor, the floor pushes back.

Examination Tip

You could be asked to apply these concepts to a variety of situations.

For example… Air enters a jet engine at A and is heated before leaving B at a much higher speed.

It is common to ask what happens to the momentum as it passes through the engine.

(momentum of air) increases (1 mark)

It is common to ask why the air exerts a force on the engine in the forward direction.

(rate of change of momentum so) force acting on the air (Newton 2) (1 mark)

it/air exerts force (on engine) of the same/equal magnitude/size (1 mark)

but opposite in direction (Newton 3) (1 mark)

It is common to ask why momentum changes if the direction of the object changes.

momentum/velocity is a vector OR momentum/velocity has direction (1 mark)

there is a change (in the air's)direction (1 mark)

Examination Tip

It is a common examination question to state one reason why two forces shown are not a pair of forces as referred to in Newton's Third Law.

they do not have the same magnitude/size (1 mark)

the forces are of different types (1 mark)

they do not act on different bodies (1 mark)

drag is greater than the weight (1 mark)

there is a resultant force (as deceleration occurs) (1 mark)

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TOPIC: 3.4.1.6 Momentum
SPEC CHECK

Specification	Completed?
momentum = mass × velocity	
Conservation of linear momentum. Principle applied quantitatively to problems in one dimension.	
Force as the rate of change of momentum, $F = \frac{\Delta mv}{\Delta t}$	
Impulse = change in momentum $F\Delta t = \Delta mv$, where F is constant.	
Significance of the area under a force–time graph.	
Quantitative questions may be set on forces that vary with time. Impact forces are related to contact times (e.g. kicking a football, crumple zones, packaging).	
Elastic and inelastic collisions; explosions.	
Appreciation of momentum conservation issues in the context of ethical transport design.	
Students can apply conservation of momentum and rate of change of momentum to a range of examples.	

Student Checklist

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	

NOTES
Momentum

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

The momentum of an object is given by the equation:

momentum = mass x *velocity*

$$p = mv$$

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what the equation represents.

The shows the momentum of a moving object.

Physics Tip

You can be asked to derive mass from the density equation – Mass = Density x Volume

Since it depends on the velocity and not speed, momentum is a vector quantity. If we assign a direction to be positive for example if → was positive, an object with negative velocity would be moving ←. It would also have a negative momentum.

Momentum is measured in kilogram metres per second, kg m/s or kg m s^{-1}

Conservation

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

In an isolated system (if no external forces are acting) the linear momentum is conserved.

We can say that: *the total momentum before = the total momentum after*

The total momentum before and after what? A collision or an explosion.

Physics Tip

You might see momentum referred to as 'linear momentum'.

The other kind is 'angular momentum' but that is not required until A Level Year 2.

Examination Tip

It is a common examination question to explain how a bouncing object alters the motion of the Earth is bounces upon.

As ball falls momentum of object toward the Earth (always) = momentum of Earth toward the object

(1 mark)

On impact the momentum of both object and Earth become zero (1 mark)

After impact momentum of object away from Earth =momentum of Earth in opposite direction (1 mark)

Collisions

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

There are two types of collisions; in both cases the momentum is conserved.

Elastic *– kinetic energy in conserved, no energy is transferred to the surroundings*

If a ball is dropped, hits the floor and bounces back to the same height it would be an elastic collision with the floor. The kinetic energy before the collision is the same as the kinetic energy after the collision.

Physics Tip

Collisions between gas particles are elastic, otherwise air would get colder and colder until there was no motion left.

Inelastic *– kinetic energy is not conserved, energy is transferred to the surroundings*

If a ball is dropped, hits the floor and bounces back to a lower height than released it would be an inelastic collision. The kinetic energy before the collision would be greater than the kinetic energy after the collision.

Before **After**

In the situation above, car 1 and car 2 travel to the right with initial velocities u_1 and u_2 respectively. Car 1 catches up to car 2 and they collide. After the collision, the cars continue to move to the right but car 1 now travels at velocity v_1 and car 2 travels a velocity v_2. [→ is positive]

Since momentum is conserved the total momentum before the crash = the total momentum after the crash.

The total momentum before is the momentum of A + the momentum of B

The total momentum after is the new momentum of A + the new momentum of B

We can represent this with the equation: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Physics Tip

Before you start a momentum calculation, always draw a quick sketch of the relevant objects, before and after the collision – then its much easier to figure out what is going on.

Study Tip

This topic is common content with the A-Level Mathematics specification.

Examination Tip

It is a common examination question to state the quantity that is not conserved in an inelastic collision.

(Total) kinetic energy (1 mark)

Explosions

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

We look at explosions in the same way as we look at collisions, the total momentum before is equal to the total momentum after.
In explosions, the total momentum before is zero. [→ is positive]

Before **After**

If we look at the example above we can see that the whole system is not moving, so the momentum before is zero. After the explosion, the shell travels right with velocity v_2 and the cannon recoils with a velocity v_1.

The momentum of the system is given as: $m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

So, the equation for this diagram would be: $0 = m_1v_1 + m_2v_2$

But remember, v_1 is negative so: $0 = -m_1v_1 + m_2v_2$ → $m_1v_1 = m_2v_2$

Physics Tip

In a collision or explosion, remember that the more massive the object, the faster the object moves – this is because momentum is conserved in collisions and explosions.

Study Tip
This topic is common content with the A-Level Mathematics specification.

Examination Tip

It is a common examination question to state what happens to trucks after a head on collision if the collision was elastic.

Trucks move in opposite directions/rebound (1 mark)

velocity of B is greater than that of A because total momentum is to the right OR B has lower mass (1 mark)

or

Momentum of B after collision is same as that of A before the collision (1 mark).

Force

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**
This is **not found** on the **Combined Science GCSE**.

If we start at *F* = *ma* we can derive an equation that links force and momentum.

$F = ma$ we can replace *a* in this equation with $a = \frac{(v-u)}{t}$ from Unit 2

$F = m\frac{(v-u)}{t}$ multiplying out makes the equation

$F = \frac{mv - mu}{t}$ or $\boxed{F = \frac{\Delta(mv)}{\Delta t}}$ where Δ means 'the change in'

This states that the force is a measure of change of momentum with respect to time. This is Newton's Second Law of Motion:

The rate of change of an object's linear momentum is directly proportional to the resultant external force. The change in the momentum takes place in the direction of the force.

If we have a trolley and we increase its velocity from rest to 3m/s in 10 seconds, we know that it takes a bigger force to do the same with a trolley that's full of shopping. Ever tried turning a trolley around a corner when empty and then when full?

Force is measured in Newtons, N

Physics Tip

Resultant force can also be in units of $kgms^{-2}$ although it is normally just in N.

Physics Tip

The unit of the rate of change of momentum ($kg\ ms^{-2}$) are the same as those for m x a.

Study Tip
This topic is common content with the A-Level Mathematics specification.

Examination Tip

It is a common examination question to state what happens to the momentum of a truck as it moves if it collects rainwater on its journey.

rain has no (initial) horizontal momentum (1 mark)

vertical momentum of rainwater decreases (1 mark)

there is no external (horizontal) impulse/force on the truck (and water system) (1 mark)

mass (of truck) increases but speed/velocity decreases (1 mark)

horizontal momentum of water increases (but horizontal momentum of truck decreases by same amount) (1 mark)

(so) no change in (horizontal) momentum of truck and collected water/total momentum (1 mark)

Car Safety

Many of the safety features of a car rely on the above equation. Airbags, seatbelts and the crumple zone increase the time taken for the car and the people inside to stop moving. Increasing the time taken to change the momentum to zero reduces the force experienced.

Catching

An Egg: If we held our hand out and didn't move it the egg would smash. The change in momentum happens in a short time, making the force large. If we cup the egg and move our hands down as we catch it we make it take longer to come to a complete stop. Increasing the time taken decreases the force and the egg remains intact.

Cricket Ball: If we didn't move our hands it would hurt when the ball stopped in our hands. If we make it take longer to stop we reduce the force on our hands from the ball.

Impulse

$F = \frac{mv - mu}{t}$ multiply both sides by t → $Ft = mv - mu$

$F = \frac{\Delta(mv)}{\Delta t}$ multiply both sides by t → $\boxed{F\Delta t = \Delta(mv)}$

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what these equations represents.

The shows the impulse of a moving object due to a collision.

We now have an equation for impulse. Impulse is the product of the force and the time it is applied for. An impulse causes a change in momentum.

Impulse is measured in Newton seconds, Ns

Since $F\Delta t = \Delta(mv)$, the same impulse (same force applied for the same amount of time) can be applied to a small mass to cause a large velocity or to a large mass to cause a small velocity

$$Ft = \mathit{M}v = m\mathit{V}$$

Physics Tip

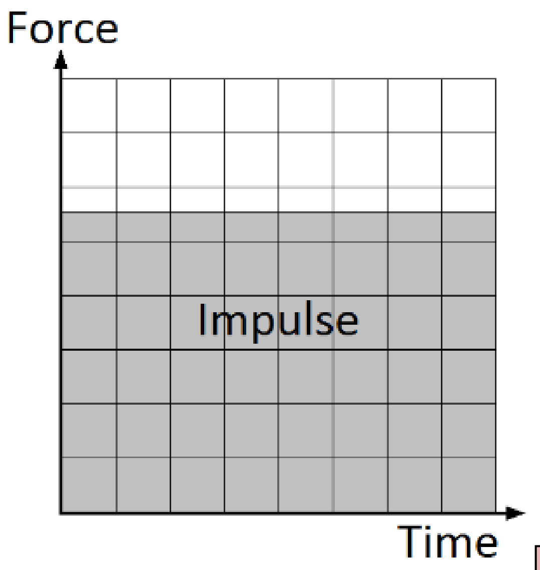
Remember to convert velocities to ms^{-1} before doing any other calculations.

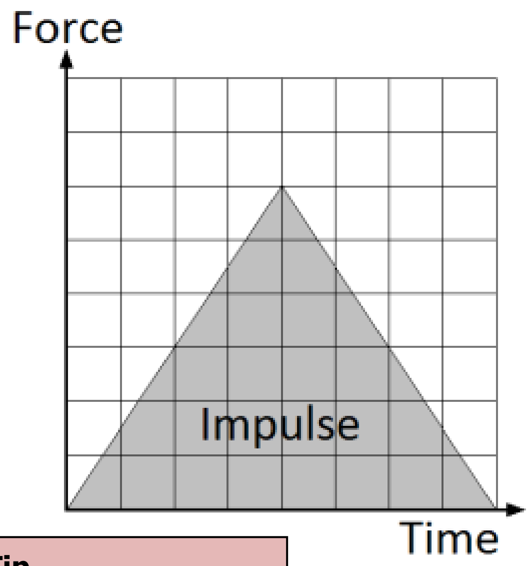
Study Tip
This topic is common content with the A-Level Mathematics specification.

Force-Time Graphs

The impulse can be calculated from a force-time graph, it is the same as the area under the graph. The area of the first graph is given by:

height x length = Force x time = Impulse





Working Scientifically Link

Remember how to determine values from this graph.

Study Tip
Always learn what the gradient and area under the line represent on a graph.

Physics Tip

For more complicated force-time graphs, you might need to estimate the area under the graph by counting squares or approximating curves as straight lines.

Physics Tip

The mass before and after is the same, so the velocity is the only thing that changes.

Examination Tip

It is a common examination question to ask how the material of an object affects the force applied to an object.

Impact time can be increased if the material is not stiff (1 mark)

Increased impact time would reduce the force of the impact. (1 mark)

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TOPIC: 3.4.1.7 Work, Energy and Power
SPEC CHECK

Specification	Completed?
Energy transferred, $W = Fs\cos\theta$	
rate of doing work = rate of energy transfer, $P = \frac{\Delta W}{\Delta t} = Fv$ Quantitative questions may be set on variable forces.	
Significance of the area under a force–displacement graph.	
efficiency = $\frac{\text{useful output power}}{\text{input power}}$ Efficiency can be expressed as a percentage.	
Investigate the efficiency of an electric motor being used to raise a mass through a measured height. Students should be able to identify random and systematic errors in the experiment and suggest ways to remove them.	

Student Checklist

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	

NOTES
Energy

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Energy.**

We already know that it appears in several different forms and may be transformed from one form to another.
But what is energy? **Energy is the ability to do work**.
We can say that the work done is equal to the energy transferred

Work done = energy transferred

$$W = E$$

Work Done

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Forces.**

In Physics, we say that work is done when a force moves through a distance and established the equation

Work Done = Force x Distance moved in the direction of the force

$$W = Fs$$

Work Done is measured in Joules, J
Force is measured in Newtons, N
Distance is measured in metres, m

Physics Tip

Force is a vector, so can be resolved into components.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

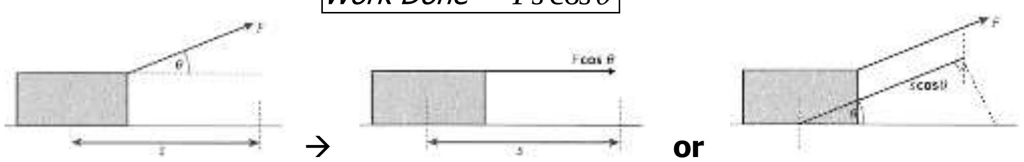
Learn what these equations represents.

The shows the work done in an energy system.

The distance moved is not always in the direction of the force.
In the diagram, we can see that the block moves in a direction that is θ away from the 'line of action' of the force. To calculate the work done we must calculate the distance we move in the direction of the force or the size of the force in the direction of the distance moved. Both are calculated by resolving into horizontal and vertical components.

Work Done = Force x Distance moved in the direction of the force
Work Done = Size of Force in the direction of movement x Distance moved

$$\text{Work Done} = Fs\cos\theta$$



Now that we can calculate Work Done we can derive another equation for calculating power:

Study Tip
This topic is common content with the A-Level Mathematics specification.

Working Scientifically Link

Remember how to consider the angle at which the force is acting in all situations.

Power

Prior Knowledge Link
This is a topic found in previous GCSE modules **– Forces and Energy.**

Power is a measure of how quickly something can transfer energy. Power is linked to energy by the equation:

$$Power = \frac{EnergyTransferred}{timetaken}$$

$$P = \frac{\Delta E}{\Delta t}$$

Power is measured in Watts, W
Energy is measured in Joules, J
Time is measured in seconds, s

But Work Done = Energy Transferred so we can say that power is a measure of how quickly work can be done.

$$Power = \frac{WorkDone}{timetaken}$$

$$P = \frac{\Delta W}{\Delta t}$$

We can substitute $W = Fs$ into $P = \frac{W}{t}$ to become $P = \frac{Fs}{t}$ this can be separated into $P = F\frac{s}{t}$.

$\frac{s}{t} = v$ so, we can write

$$P = Fv\cos\theta$$

Working Scientifically Link

Remember how to consider the angle at which the force is acting in all situations.

Velocity is measured in metres per second, m/s or ms^{-1}

Physics Tip

This equation does not appear in the data and formula booklet. Make sure you know how to find the power of a moving object when the force is not in the direction of the object's motion.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what these equations represents.

The shows the power of an object.

Efficiency

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Energy.**

We already know that the efficiency of a device is a measure of how much of the energy we put in is wasted.

$$\text{Efficiency} = \frac{\text{useful energy transferred by the device}}{\text{total energy supplied to the device}}$$

this will give us a number less than 1

Useful energy means the energy transferred for a purpose, the energy transferred into the desired form.
Since power is calculated from energy we can express efficiency as:

$$\text{Efficiency} = \frac{\text{useful output power of the device}}{\text{input power to the device}}$$

again this will give us a number less than 1

To calculate the efficiency as a percentage, use the following:

percentage efficiency = efficiency x 100%

Physics Tip

It goes the other way too – you might need to divide a percentage by 100 to gain the answer in a fraction.

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Study Tip

Learn what these equations represents.

The shows the efficiency of an energy transformation.

VIDEO

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TOPIC: 3.4.1.8 Conservation of Energy

SPEC CHECK

Specification	Completed?
Principle of conservation of energy. $\Delta E_p = mg\Delta h$ and $E_k = ½ mv^2$	
Quantitative and qualitative application of energy conservation to examples involving gravitational potential energy, kinetic energy, and work done against resistive forces.	
Estimate the energy that can be derived from food consumption.	

Student Checklist

Have I…….	**Yes or No?**
Read through the notes of this section?	
Highlighted/underlined the key concepts of this section?	
Made my own notes based on the notes of this section?	
Brought the notes to be used in lesson?	

Energy Transformations

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Energy.**

We already know that energy cannot be created or destroyed, only transformed from one type to another and transferred from one thing to another.
E.g. a speaker transforms electrical energy to sound energy with the energy itself is being transferred to the surroundings.

An isolated (or closed) system means an energy transformation is occurring where none of the energy is lost to the surroundings. All transformations/transfers are not isolated, and all of them waste energy to the surroundings.

Kinetic Energy

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Energy.**

Kinetic energy is the energy a moving object has. Let us consider a car that accelerates from being stationary (u=0) to travelling at a velocity v when a force, F, is applied.

The time it takes to reach this velocity is given by $v = u + at$ → $v = at$ → $t = \frac{v}{a}$

The distance moved in this time is given by $s = \frac{1}{2}(u+v)t$ → $s = \frac{1}{2}(v)t$ → $s = \frac{1}{2}(v)\frac{v}{a}$ → $s = \frac{1}{2}\frac{v^2}{a}$

Energy transferred = Work Done, Work Done = Force x distance moved and Force = mass x acceleration

$E = W$ → $E = Fs$ → $E = mas$ → $E = ma\frac{1}{2}\frac{v^2}{a}$

Study Tip

Learn what these equations represents.

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

Study Tip
Learn the base units for this equation and the context in which it can be used in.

Velocity is measured in metres per second, m/s
Mass is measured in kilograms, kg
Kinetic Energy is measured in Joules, J

Gravitational Potential Energy

Prior Knowledge Link
This is a topic found in a previous GCSE module **– Energy.**

This type of potential (stored) energy is due to the position of an object. If an object of mass m is lifted at a constant speed by a height of h we can say that the acceleration is zero. Since $F=ma$ we can also say that the overall force is zero, this means that the lifting force is equal to the weight of the object → $F=mg$
We can now calculate the work done in lifting the object through a height, h.

$WD = Fs$ → $WD = (mg)h$ → $WD = mgh$

Since work done = energy transferred

$$\Delta E_P = mg\Delta h$$

Height is a measure of distance which is measured in metres, m
Gravitational Potential Energy is measured in Joules, J

Physics Tip

An object loses gravitational potential energy when it falls.

Work Done against….

In many situations gravitational potential energy is converted into kinetic energy, or vice versa. Some everyday examples of this are:

Swings and pendulums

If we pull a pendulum back we give it GPE, when it is released it falls, losing its GPE but speeding up and gaining KE. When it passes the lowest point of the swing it begins to rise (gaining GPE) and slow down (losing KE).

Bouncing or throwing a ball

Holding a ball in the air gives it GPE, when we release this it transforms this into KE. As it rises it loses KE and gains GPE.

Slides and ramps

A ball at the top of a slide will have GPE. When it reaches the bottom of the slide it has lost all its GPE, but gained KE.

In each of these cases it appears we have lost energy. The pendulum doesn't swing back to its original height and the ball never bounces to the height it was released from. This is because work is being done against resistive forces.

The swing must overcome air resistance whilst moving and the friction from the top support.

The ball transforms some energy into sound and overcoming the air resistance.

Travelling down a slide transforms energy into heat due to friction and air resistance

The *total* energy before a transformation = The *total* energy after a transformation

Physics Tip

In these examples, the total energy is always the same, it just alternates between potential and kinetic energy.

Physics Tip

You could be asked to apply this stuff to just about anything in the exam.

Roller coasters are an exam favourite.

Study Tip

This topic is common content with the A-Level Mathematics specification.

Examination Tip

You could be asked to apply these concepts to a variety of situations.

For example… The speed of an air rifle pellet is measured by firing it into a wooden block suspended from a rigid support. A wooden block is replaced by a steel block of the same mass.

The experiment is repeated with the steel block and an identical pellet. The pellet rebounds after striking the block.

As pellet rebounds, change in momentum of pellet greater and therefore the change in momentum of the block is greater (1 mark)

Initial speed of block is greater (1 mark)

(Mass stays the same)

Initial KE of block greater (1 mark)

Therefore, height reached by steel block is greater than with wooden block (1 mark)

Examination Tip

It is a common examination question to state the law of conservation of energy.

energy cannot be created or destroyed (1 mark)

it can only be transferred/changed/converted from one form to another (1 mark)

Examination Tip

It is a common examination question to state why energy never fully transfers usefully in situations…

(work done) by friction \ drag \ air resistance \ resistive forces (1 mark)

(Energy converted) to internal \ thermal energy (1 mark)

VIDEO

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UPGRADE YOUR PHYSICS

The following section include information beyond the A-Level Physics.
This information will further your understanding and provide a bridge to University Level Physics.

1.1.1.1 Kinematics

Mechanics is all about motion. We start with the simplest kind of motion – the motion of small dots or particles. Such a particle is described completely by its mass (the amount of stuff it contains) and its position. There is no internal structure to worry about, and as for rotation, even if it tried it, no-one would see. The most convenient way of labelling the position is with a vector **r** showing its position with respect to some convenient agreed stationary point.

If the particle is moving, its position will change. If its speed and direction are steady, then we can write its position after time t as

$$\mathbf{r} = \mathbf{s} + \mathbf{u}t,$$

where **s** is the starting point (the position of the particle at t=0) and **u** as the change in position each second – otherwise known as the velocity. If the velocity is not constant, then we can't measure it by seeing how far the object goes in one second, since the velocity will have changed by then. Rather, we say that u how far the object would go in one second if the speed or direction remained unchanged that long. In practice, if the motion remains constant for some small time (called δt), and during this small time, the particle's position changes δ**r**, then the change in position if this were maintained for a whole second (otherwise known as the velocity) is

$$\mathbf{u} = \delta \mathrm{r} \times \text{number of } \delta t \text{ periods in one second} = \delta \mathrm{r} \div \delta \mathrm{t}.$$

Similarly, if the velocity is changing, we define the acceleration as the change in velocity each second (if the rate of change of acceleration were constant. Accordingly, our equation for acceleration becomes

$$\mathbf{a} = \delta \mathbf{u} \div \delta t.$$

Hopefully, it is apparent that as the motion becomes more complex, and the δt periods need to be made shorter and shorter, we end up with the differential equations linking position, velocity and acceleration:

$$\mathbf{u} = \frac{d}{dt}\mathbf{r} \quad \mathbf{r} = \int \mathbf{u}\, dt$$
$$\mathbf{a} = \frac{d}{dt}\mathbf{u} \quad \mathbf{u} = \int \mathbf{a}\, dt$$

1.1.1.2 Dynamics

Now we have a way of describing motion, we need a way of predicting or explaining the motion which occurs – changing our question from 'what is happening?' to 'why?' and our explanation is going to involve the activity of forces. What do forces do to an object?

The first essential point is that forces are only needed to change (not maintain) motion. In other words – unless there is a change of velocity, no force is needed. But how much force is needed?

Newton made the assumption (which we find to be helpful and true) that the force causes a change in what he called the 'motion' –we now call it momentum. Suppose an object has mass *m* and velocity **u** (we shall clarify what we mean by mass later) – then its momentum is equal to *m***u**, and is frequently referred to by physicists by the letter **p**. Newton's second law states that if a constant force **F** is applied to an object for a short time δt, then the change in the momentum is given by **F** δt. In differential notation d(*m***u**)/d*t* = **F**.

In the case of a single object of constant mass it follows that

$$\mathbf{F} = \frac{d(m\mathbf{u})}{dt} = m\frac{d\mathbf{u}}{dt} = m\mathbf{a}\ .$$

His next assumption tells us more about forces and allows us to define 'mass' properly. Imagine two bricks are being pulled together by a strong spring. The brick on the left is being pulled to the right, the brick on the right is being pulled to the left.

Newton assumed that the force pulling the left brick rightwards is equal and opposite to the force pulling the right brick leftwards. To use more mathematical notation, if the force on block no.1 caused by block no.2 is called $\mathbf{f}_{12}$, then $\mathbf{f}_{12}=-\mathbf{f}_{21}$. If this were not the case, then if we looked at the bricks together as a whole object, the two internal forces would not cancel out, and there would be some 'left over' force which could accelerate the whole object.[1]

It makes sense that if the bricks are identical then they will accelerate together at the same rate. But what if they are not? This is where Newton's second law is helpful. If the resultant force on an object of constant mass equals its mass times its acceleration, and if the two forces are equal and opposite, we say

$$\mathbf{f}_{12} = -\mathbf{f}_{21}$$
$$m_1\mathbf{a}_1 = -m_2\mathbf{a}_2 \,,$$
$$\frac{a_1}{a_2} = \frac{m_2}{m_1}$$

and so the 'more massive' block accelerates less. This is the definition of mass. Using this equation, the mass of any object can be measured with respect to a standard kilogram. If a mystery mass experiences an acceleration of 2m/s^2 while pushing a standard kilogram in the absence of other forces, and at the same time the kilogram experiences an acceleration of 4m/s^2 the other way, then the mystery mass must be 2kg.

When we have a group of objects, we have the option of applying Newton's law to the objects individually or together. If we take a large group of objects, we find that the total force

$$\mathbf{F}_{\text{total}} = \sum_i \mathbf{F}_i = \frac{d}{dt}\sum_i m_i\mathbf{u}_i$$

changes the total momentum (just like the individual forces change the individual momenta). Note the simplification, though – there are no $\mathbf{f}_{ij}$ in the equation. This is because $\mathbf{f}_{ij} + \mathbf{f}_{ji} = 0$, so when we add up the forces, the internal forces sum to zero, and the total momentum is only affected by the external forces $\mathbf{F}_i$.

1.1.1.3 Energy and Power

Work is done (or energy is transferred) when a force moves something. The amount of work done (or amount of energy transformed) is given by the dot product of the force and the distance moved.

$$W = \mathbf{F} \bullet \mathbf{r} = F\, r \cos\theta \qquad (1)$$

where θ is the angle between the force vector **F** and the distance vector **r**. This means that if the force is perpendicular to the distance, there is no work done, no energy is transferred, and no fuel supply is needed.

If the force is constant in time, then equation (1) is all very well and good, however if the force is changing, we need to break the motion up into little parts, so that the force is more or less constant for each part. We may then write, more generally,

$$\delta W = \mathbf{F} \bullet \delta\mathbf{r} = F\, \delta r \cos\theta \qquad (1a)$$

Two useful differential equations can be formed from here.

1.1.1.4 *Virtual Work*

From equation (1a) it is clear that if the motion is in the direction of the force applied to the object (i.e. θ=0), then

$$\frac{\delta W}{\delta r} = F \ ,$$

where W is the work done on the object. Accordingly, we can calculate the force on an object if we know the energy change involved in moving it. Let's give an example.

An electron (with charge *q*) is forced through a resistor (of length *L*) by a battery of voltage *V*. As it goes through, it must lose energy *qV*, since *V* is the energy loss per coulomb of charge passing through the resistor. Therefore, assuming that the force on the electron is constant (which we assume by the symmetry of the situation), then the force must be given by $\delta W / \delta d = qV / L$. If we define the electric field strength to be the force per coulomb of charge (*F/q*), then it follows that the electric field strength $E = V/L$.

So far, we have ignored the sign of *F*. It can not have escaped your attention that things generally fall downwards – in the direction of decreasing [gravitational] energy. In equations (1) and (1a), we used the vector **F** to represent the externally applied force we use to drag the object along. In the case of lifting a hodful of bricks to the top of a wall, this force will be directed upwards. If we are interested in the force of gravity **G** acting on the object (whether we drag it or not), this will be in the opposite direction. Therefore **F** = –**G**, and

$$\delta W = -\mathbf{G} \bullet \delta \mathrm{r}, \qquad (1b)$$

$$G = -\frac{\delta W}{\delta r} .$$

In other words, if an object can lose potential energy by moving from one place to another, there will always be a force trying to push it in this direction.

1.1.1.5 *Power*

Another useful equation can be derived if we differentiate (1a) with respect to time. The rate of 'working' is the power P, and so

$$P = \frac{\delta W}{\delta t} = \frac{\mathbf{F} \bullet \delta r}{\delta t} = \mathbf{F} \bullet \frac{\delta r}{\delta t} .$$

As we let the time period tend to zero, δr/δt becomes the velocity, and so we have:

$$P = \mathbf{F} \bullet \mathbf{u} = F\,u\cos\theta \qquad (2)$$

where θ is now best thought of as the angle between force and direction of motion. Again we see that if the force is perpendicular to the direction of motion, no power is needed. This makes sense: think of a bike going round a corner at constant speed. A force is needed to turn the corner - that's why you lean into the bend, so that a component of your weight does the job. However no work is done – you don't need to pedal any harder, and your speed (and hence kinetic energy) does not change.

Equation (2) is also useful for working out the amount of fuel needed if a working force is to be maintained. Suppose a car engine is combating a friction force of 200N, and the car is travelling at a steady 30m/s. The engine power will be 200N × 30m/s = 6 kW.

Our equation can also be used to derive the kinetic energy. Think of starting the object from rest, and calculating the work needed to get it going at speed *U*. The force, causing the acceleration, will be **F**=m**a**. The work done is given by

$$\begin{aligned} W &= \int P\,dt = \int \mathbf{F} \bullet \mathbf{v}\,dt = \int m\frac{d\mathbf{v}}{dt} \bullet \mathbf{v}\,dt \\ &= \int m\mathbf{v} \bullet d\mathbf{v} = \left[\tfrac{1}{2}mv^2\right]_0^U = \tfrac{1}{2}mU^2 \end{aligned} \qquad (3)$$

although care needs to be taken justifying the integration stage in the multi-dimensional case.[2]

1.1.2 Changing Masses

The application of Newton's Laws to mechanics problems should pose you no trouble at all. However there are a couple of extra considerations which are worth thinking about, and which don't often get much attention at school.

The first situation we'll consider is when the mass of a moving object changes. In practice the mass of any self-propelling object will change as it uses up its fuel, and for accurate calculations we need to take this into account. There are two cases when this *must* be considered to get the answer even roughly right – jet aeroplanes and rockets. In the case of rockets, the fuel probably makes up 90% of the mass, so it must not be ignored.

Changing mass makes the physics interesting, because you need to think more carefully about Newton's second law. There are two ways of stating it – either

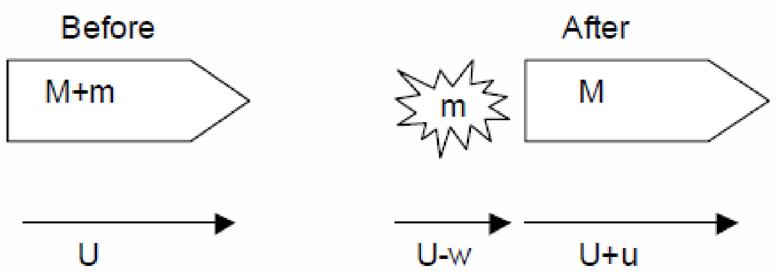
(i) Force on an object is equal to the rate of change of its momentum
(ii) Force on an object is equal to mass × acceleration

The first says $F = d(mu)/dt = m\dot{u} + \dot{m}u = ma + \dot{m}u$, whereas the second simply states $F=ma$. Clearly they can't both be correct, since they are different. Which is right? The first: which was actually the way Newton stated it in the first place! The good old $F=ma$ will still work – but you have to break the rocket into parts (say grams of fuel) – so that the rocket loses parts, but each part does not lose mass – and then apply $F=ma$ to each individual part. However if you want to apply a law of motion to the rocket as a whole, you have to use the more complicated form of equation.

This may be the first time that you encounter the fact that momentum is a more 'friendly' and fundamental quantity to work with mathematically than force. We shall see this in a more extreme form when looking at special relativity.

Let us now try and calculate how a rocket works. We'll ignore gravity and resistive forces to start with, and see how fast a rocket will go after it has burnt some fuel. To work this out we need to know two things – the exhaust speed of the combustion gas (w), which is always measured relative to the rocket; and the rate at which the motor burns fuel (in kg/s), which we shall call α.

We'll think about one part of the motion, when the rocket starts with mass ($M+m$), burns mass m of fuel, where m is very small, and in doing so increases its speed from U to $U+u$. This is shown below in the diagram.



Notice that the velocity of the burnt fuel is U-w, since w is the speed at which the combustion gas leaves the rocket (backwards), and we need to take the rocket speed U into account to find out how fast it is going relative to the ground.

Conservation of momentum tells us that

$$(M+m)\,U = m\,(U-w) + M\,(U+u)$$

so $$m\,w = M\,u. \qquad (4)$$

We can integrate this expression for u to evaluate the total change in speed after burning a large amount of fuel. We treat the u (change in U) as an infinitesimal calculus dU, and the m as a calculus $-dM$. Notice the minus sign – clearly the rocket must lose mass as fuel is burnt. Equation (4) now tells us

$$-w\frac{dM}{M} = dU \qquad (5)$$

This can be integrated to give

$$\begin{aligned} -w\int\frac{1}{M}dM &= \int dU \\ -w[\ln M] &= [U] \\ U_{final} - U_{initial} &= w\ln\left(\frac{M_{initial}}{M_{final}}\right) \end{aligned} \qquad (6)$$

This formula (6) is interesting because it tells us that in the absence of other forces, the gain in rocket speed depends *only* on the fraction of rocket mass that is fuel, and the exhaust speed.

In this calculation, we have ignored other forces. This is not a good idea if we want to work out the motion at blast off, since the Earth's gravity plays a major role! In order to take this, or other forces, into account, we need to calculate the thrust force of the rocket engine – a task we have avoided so far.

The thrust can be calculated by applying $F=ma$ to the (fixed mass) rocket M in our original calculation (4). The acceleration is given by $dU/t = u/t$, where t is the time taken to burn mass m of fuel. The thrust is

$$T = M\times\frac{u}{t} = M\times\frac{mw}{Mt} = \frac{mw}{t} = w\times\frac{m}{t} = w\alpha \qquad (7)$$

given by the product of the exhaust speed and the rate of burning fuel. For a rocket of total mass M to take off vertically, T must be greater than the rocket's weight Mg. Therefore for lift off to occur at all we must have

$$w\alpha > Mg\,. \qquad (8)$$

This explains why 'heavy' hydrocarbon fuels are nearly always used for the first stage of liquid fuel rockets. In the later stages, where absolute thrust is less important, hydrogen is used as it has a better 'kick per kilogram' because of its higher exhaust speed.

REVISION CHECKLIST

Specification reference	Checklist questions	
3.4.1.5	Can you understand and apply the three laws of motion in appropriate situations?	☐
3.4.1.5	Can you apply $F = m a$ for situations where the mass is constant?	☐

Specification reference	Checklist questions	
3.4.1.6	Can you apply the equation *momentum = mass × velocity*?	☐
3.4.1.6	Can you explain the conservation of linear momentum?	☐
3.4.1.6	Can you apply the principle of conservation of linear momentum to problems in one dimension?	☐
3.4.1.6	Can you explain force as the rate of change of momentum?	☐
3.4.1.6	Can you explain that impulse = change in momentum?	☐
3.4.1.6	Can you apply $F\Delta t = \Delta (mv)$, where F is constant?	☐
3.4.1.6	Can you explain the significance of the area under a force–time graph?	☐
3.4.1.6	Can you describe forces that vary with time?	☐
3.4.1.6	Can you explain that impact force is related to contact time, and apply this to problems involving kicking a football, crumple zones and packaging?	☐
3.4.1.6	Can you define and explain elastic and inelastic collisions, and explosions?	☐
3.4.1.6	Can you explain momentum conservation issues in the context of ethical transport design?	☐

Specification reference	Checklist questions	
3.4.1.7	Can you explain that energy transferred, $W = Fs\cos\theta$?	☐
3.4.1.7	Can you use the formulae: *rate of doing work = rate of energy transfer,* $P = \frac{\Delta W}{\Delta t} = Fv$	☐
3.4.1.7	Can you explain variable forces?	☐
3.4.1.7	Can you explain the significance of the area under a force–displacement graph?	☐
3.4.1.7	Can you use the formula efficiency = $\frac{\text{useful ouput power}}{\text{input power}}$?	☐
3.4.1.8	Can you explain the principle of conservation of energy?	☐
3.4.1.8	Can you use the formula $\Delta E_P = mg\Delta h$ and $E_K = \frac{1}{2}mv^2$?	☐
3.4.1.8	Can you explain and apply energy conservation to examples involving gravitational potential energy, kinetic energy, and work done against resistive forces?	☐

INDEPENDENT STUDY TASK 1

Produce an **information sheet** on Newton's laws of motion.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

INDEPENDENT STUDY TASK 2

Produce an **information sheet** on momentum (including conservation of momentum).

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

INDEPENDENT STUDY TASK 3

Produce an **information sheet** on impulse.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

INDEPENDENT STUDY TASK 4

Produce an **information sheet** on the equations of this module.

This is an independent study task to carried out outside of lesson.

This work will not be assessed but will be monitored by your class teacher.

This must be completed by the deadline set by your class teacher

DATASHEET

DATA - FUNDAMENTAL CONSTANTS AND VALUES

Quantity	Symbol	Value	Units
speed of light in vacuo	c	3.00×10^{8}	$\mathrm{m\,s^{-1}}$
permeability of free space	μ_0	$4\pi \times 10^{-7}$	$\mathrm{H\,m^{-1}}$
permittivity of free space	ε_0	8.85×10^{-12}	$\mathrm{F\,m^{-1}}$
magnitude of the charge of electron	e	1.60×10^{-19}	C
the Planck constant	h	6.63×10^{-34}	J s
gravitational constant	G	6.67×10^{-11}	$\mathrm{N\,m^{2}\,kg^{-2}}$
the Avogadro constant	N_A	6.02×10^{23}	$\mathrm{mol^{-1}}$
molar gas constant	R	8.31	$\mathrm{J\,K^{-1}\,mol^{-1}}$
the Boltzmann constant	k	1.38×10^{-23}	$\mathrm{J\,K^{-1}}$
the Stefan constant	σ	5.67×10^{-8}	$\mathrm{W\,m^{-2}\,K^{-4}}$
the Wien constant	α	2.90×10^{-3}	m K
electron rest mass (equivalent to 5.5×10^{-4} u)	m_e	9.11×10^{-31}	kg
electron charge/mass ratio	$\frac{e}{m_e}$	1.76×10^{11}	$\mathrm{C\,kg^{-1}}$
proton rest mass (equivalent to 1.00728 u)	m_p	$1.67(3) \times 10^{-27}$	kg
proton charge/mass ratio	$\frac{e}{m_p}$	9.58×10^{7}	$\mathrm{C\,kg^{-1}}$
neutron rest mass (equivalent to 1.00867 u)	m_n	$1.67(5) \times 10^{-27}$	kg
gravitational field strength	g	9.81	$\mathrm{N\,kg^{-1}}$
acceleration due to gravity	g	9.81	$\mathrm{m\,s^{-2}}$
atomic mass unit (1u is equivalent to 931.5 MeV)	u	1.661×10^{-27}	kg

ALGEBRAIC EQUATION

quadratic equation $$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

ASTRONOMICAL DATA

Body	Mass/kg	Mean radius/m
Sun	1.99×10^{30}	6.96×10^{8}
Earth	5.97×10^{24}	6.37×10^{6}

GEOMETRICAL EQUATIONS

arc length	$= r\theta$
circumference of circle	$= 2\pi r$
area of circle	$= \pi r^2$
curved surface area of cylinder	$= 2\pi rh$
area of sphere	$= 4\pi r^2$
volume of sphere	$= \frac{4}{3}\pi r^3$

Particle Physics

Class	Name	Symbol	Rest energy/MeV
photon	photon	γ	0
lepton	neutrino	ν_e	0
		ν_μ	0
	electron	$e^\pm$	0.510999
	muon	$\mu^\pm$	105.659
mesons	π meson	$\pi^\pm$	139.576
		π^0	134.972
	K meson	$K^\pm$	493.821
		K^0	497.762
baryons	proton	p	938.257
	neutron	n	939.551

Properties of quarks

antiquarks have opposite signs

Type	Charge	Baryon number	Strangeness
u	$+\frac{2}{3}e$	$+\frac{1}{3}$	0
d	$-\frac{1}{3}e$	$+\frac{1}{3}$	0
s	$-\frac{1}{3}e$	$+\frac{1}{3}$	-1

Properties of Leptons

		Lepton number
Particles:	$e^-, \nu_e; \mu^-, \nu_\mu$	$+1$
Antiparticles:	$e^+, \overline{\nu_e}, \mu^+, \overline{\nu_\mu}$	-1

Photons and energy levels

photon energy $E = hf = hc/\lambda$

photoelectricity $hf = \phi + E_{k\,(max)}$

energy levels $hf = E_1 - E_2$

de Broglie wavelength $\lambda = \frac{h}{p} = \frac{h}{mv}$

Waves

wave speed $c = f\lambda$ *period* $f = \frac{1}{T}$

first harmonic $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$

fringe spacing $w = \frac{\lambda D}{s}$ *diffraction grating* $d \sin\theta = n\lambda$

refractive index of a substance s, $n = \frac{c}{c_s}$

for two different substances of refractive indices n_1 *and* n_2,

law of refraction $n_1 \sin\theta_1 = n_2 \sin\theta_2$

critical angle $\sin\theta_c = \frac{n_2}{n_1}$ for $n_1 > n_2$

Mechanics

moments moment $= Fd$

velocity and acceleration $v = \frac{\Delta s}{\Delta t}$ $a = \frac{\Delta v}{\Delta t}$

equations of motion $v = u + at$ $s = \left(\frac{u+v}{2}\right)t$

$v^2 = u^2 + 2as$ $s = ut + \frac{at^2}{2}$

force $F = ma$

force $F = \frac{\Delta(mv)}{\Delta t}$

impulse $F\,\Delta t = \Delta(mv)$

work, energy and power $W = F s \cos\theta$

$E_k = \frac{1}{2} m v^2$ $\Delta E_p = mg\Delta h$

$P = \frac{\Delta W}{\Delta t}$, $P = Fv$

$efficiency = \frac{useful\ output\ power}{input\ power}$

Materials

density $\rho = \frac{m}{V}$ *Hooke's law* $F = k\,\Delta L$

Young modulus $= \frac{tensile\ stress}{tensile\ strain}$ *tensile stress* $= \frac{F}{A}$

tensile strain $= \frac{\Delta L}{L}$

energy stored $E = \frac{1}{2}F\Delta L$

Electricity

current and pd	$I = \frac{\Delta Q}{\Delta t}$ $\quad V = \frac{W}{Q}$ $\quad R = \frac{V}{I}$
resistivity	$\rho = \frac{RA}{L}$
resistors in series	$R_T = R_1 + R_2 + R_3 + \ldots$
resistors in parallel	$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$
power	$P = VI = I^2R = \frac{V^2}{R}$
emf	$\varepsilon = \frac{E}{Q}$ $\quad \varepsilon = I(R + r)$

Circular motion

magnitude of angular speed	$\omega = \frac{v}{r}$
	$\omega = 2\pi f$
centripetal acceleration	$a = \frac{v^2}{r} = \omega^2 r$
centripetal force	$F = \frac{mv^2}{r} = m\omega^2 r$

Simple harmonic motion

acceleration	$a = -\omega^2 x$
displacement	$x = A \cos(\omega t)$
speed	$v = \pm \omega \sqrt{(A^2 - x^2)}$
maximum speed	$v_{max} = \omega A$
maximum acceleration	$a_{max} = \omega^2 A$
for a mass-spring system	$T = 2\pi \sqrt{\frac{m}{k}}$
for a simple pendulum	$T = 2\pi \sqrt{\frac{l}{g}}$

Thermal physics

energy to change temperature	$Q = mc\Delta\theta$
energy to change state	$Q = m\,l$
gas law	$pV = nRT$
	$pV = NkT$
kinetic theory model	$pV = \frac{1}{3} N m (c_{rms})^2$
kinetic energy of gas molecule	$\frac{1}{2} m (c_{rms})^2 = \frac{3}{2} kT = \frac{3RT}{2N_A}$

Gravitational fields

force between two masses	$F = \frac{Gm_1m_2}{r^2}$
gravitational field strength	$g = \frac{F}{m}$
magnitude of gravitational field strength in a radial field	$g = \frac{GM}{r^2}$
work done	$\Delta W = m\Delta V$
gravitational potential	$V = -\frac{GM}{r}$
	$g = -\frac{\Delta V}{\Delta r}$

Electric fields and capacitors

force between two point charges	$F = \frac{1}{4\pi\varepsilon_0} \frac{Q_1Q_2}{r^2}$
force on a charge	$F = EQ$
field strength for a uniform field	$E = \frac{V}{d}$
work done	$\Delta W = Q\Delta V$
field strength for a radial field	$E = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r^2}$
electric potential	$V = \frac{1}{4\pi\varepsilon_0} \frac{Q}{r}$
	$E = \frac{\Delta V}{\Delta r}$
capacitance	$C = \frac{Q}{V}$
	$C = \frac{A\varepsilon_0\varepsilon_r}{d}$
capacitor energy stored	$E = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{1}{2}\frac{Q^2}{C}$
capacitor charging	$Q = Q_0(1 - e^{-t/RC})$
decay of charge	$Q = Q_0 e^{-t/RC}$
time constant	RC

Magnetic fields

force on a current $F = BIl$

force on a moving charge $F = BQv$

magnetic flux $\Phi = BA$

magnetic flux linkage $N\Phi = BAN\cos\theta$

magnitude of induced emf $\varepsilon = N\dfrac{\Delta\Phi}{\Delta t}$

$N\Phi = BAN\cos\theta$

emf induced in a rotating coil $\varepsilon = BAN\omega\sin\omega t$

alternating current $I_{rms} = \dfrac{I_0}{\sqrt{2}}$ $V_{rms} = \dfrac{V_0}{\sqrt{2}}$

transformer equations $\dfrac{N_s}{N_p} = \dfrac{V_s}{V_p}$

$efficiency = \dfrac{I_s V_s}{I_p V_p}$

Nuclear physics

the inverse square law for γ radiation $I = \dfrac{k}{x^2}$

radioactive decay $\dfrac{\Delta N}{\Delta t} = -\lambda N,\ N = N_0 e^{-\lambda t}$

activity $A = \lambda N$

half-life $T_{½} = \dfrac{\ln 2}{\lambda}$

nuclear radius $R = R_0 A^{1/3}$

energy-mass equation $E = mc^2$

OPTIONS

Astrophysics

1 astronomical unit = 1.50×10^{11} m

1 light year = 9.46×10^{15} m

1 parsec = 206265 AU = 3.08×10^{16} m
= 3.26 light year

Hubble constant, H $= 65$ km s^{-1} Mpc^{-1}

$M = \dfrac{\text{angle subtended by image at eye}}{\text{angle subtended by object at unaided eye}}$

in normal adjustment $M = \dfrac{f_o}{f_e}$

Rayleigh criterion $\theta \approx \dfrac{\lambda}{D}$

magnitude equation $m - M = 5\log\dfrac{d}{10}$

Wien's law $\lambda_{max} T = 2.9 \times 10^{-3}$ m K

Stefan's law $P = \sigma A T^4$

Schwarzschild radius $R_s \approx \dfrac{2GM}{c^2}$

Doppler shift for v << c $\dfrac{\Delta f}{f} = -\dfrac{\Delta\lambda}{\lambda} = \dfrac{v}{c}$

red shift $z = -\dfrac{v}{c}$

Hubble's law $v = Hd$

Medical physics

lens equations $P = \dfrac{1}{f}$

$m = \dfrac{v}{u}$

$\dfrac{1}{f} = \dfrac{1}{u} + \dfrac{1}{v}$

threshold of hearing $I_0 = 1.0 \times 10^{-12}$ W m^{-2}

intensity level $intensity\ level = 10\log\dfrac{I}{I_0}$

absorption $I = I_0 e^{-\mu x}$

$\mu_m = \dfrac{\mu}{\rho}$

ultrasound imaging $Z = \rho c$

$\dfrac{I_r}{I_i} = \left(\dfrac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$

half-lives $\dfrac{1}{T_E} = \dfrac{1}{T_B} + \dfrac{1}{T_P}$

Engineering physics

moment of inertia $I = \Sigma mr^2$

angular kinetic energy $E_k = \frac{1}{2} I\omega^2$

equations of angular motion

$\omega_2 = \omega_1 + \alpha t$

$\omega_2{}^2 = \omega_1{}^2 + 2\alpha\theta$

$\theta = \omega_1 t + \frac{\alpha t^2}{2}$

$\theta = \frac{(\omega_1 + \omega_2)\,t}{2}$

torque $T = I\,\alpha$

$T = F\,r$

angular momentum $\text{angular momentum} = I\omega$

angular impulse $T\Delta t = \Delta(I\omega)$

work done $W = T\theta$

power $P = T\omega$

thermodynamics $Q = \Delta U + W$

$W = p\Delta V$

adiabatic change $pV^\gamma = \text{constant}$

isothermal change $pV = \text{constant}$

heat engines

efficiency $= \frac{W}{Q_H} = \frac{Q_H - Q_C}{Q_H}$

maximum theoretical efficiency $= \frac{T_H - T_C}{T_H}$

work done per cycle = area of loop

input power = calorific value × fuel flow rate

indicated power = (area of $p - V$ loop) × (number of cycles per second) × (number of cylinders)

output or brake power $P = T\omega$

friction power = indicated power – brake power

heat pumps and refrigerators

refrigerator: $COP_{ref} = \frac{Q_C}{W} = \frac{Q_C}{Q_H - Q_C}$

heat pump: $COP_{hp} = \frac{Q_H}{W} = \frac{Q_H}{Q_H - Q_C}$

Turning points in physics

electrons in fields $F = \frac{eV}{d}$

$F = Bev$

$r = \frac{mv}{Be}$

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

Millikan's experiment $\frac{QV}{d} = mg$

$F = 6\pi\eta rv$

Maxwell's formula $c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$

$\lambda = \frac{h}{p} = \frac{h}{\sqrt{2meV}}$

special relativity $t = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}}$

$l = l_0 \sqrt{1 - \frac{v^2}{c^2}}$

$E = mc^2 = \frac{m_0 c^2}{\sqrt{1 - \frac{v^2}{c^2}}}$

Electronics

resonant frequency $f_0 = \frac{1}{2\pi\sqrt{LC}}$

Q-factor $Q = \frac{f_0}{f_B}$

operational amplifiers: open loop $V_{out} = A_{OL}(V_+ - V_-)$

inverting amplifier $\frac{V_{out}}{V_{in}} = -\frac{R_f}{R_{in}}$

non-inverting amplifier $\frac{V_{out}}{V_{in}} = 1 + \frac{R_f}{R_1}$

summing amplifier $V_{out} = -R_f\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} + \cdots\right)$

difference amplifier $V_{out} = (V_+ - V_-)\frac{R_f}{R_1}$

Bandwidth requirement:

for AM $\text{bandwidth} = 2f_M$

for FM $\text{bandwidth} = 2(\Delta f + f_M)$

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This document has been produced for educational purposes only.

This document has been produced for the AQA A Level Physics Specification.

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Only constructive and reasoned feedback will be considered.