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Chapter 7: Motion and energy

Pages 155–178

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Introducing the chapter

This chapter builds on students’ previous encounters with motion and energy: the Forces unit in Year 7 and the Energy unit in Year 8. Students are also introduced to Newton’s three laws of motion and the concept of momentum. They apply these concepts in a range of familiar situations including the design of car safety features. Students also learn how to apply the principles of the conservation of energy and the conservation of momentum. Compared with previous learning in this area, a much more quantitative approach is taken: students are required to draw and interpret graphs, as well as use basic algebraic skills to rearrange formulas and solve for the missing value.

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7.1 Displacement is change in position with direction

Pages 156–157

Introducing the topic

In this topic, students learn the difference between distance and displacement. This is used to demonstrate the difference between scalar and vector quantities. Motion graphs are introduced as students learn how to draw and interpret position/displacement-time graphs.

Teaching tip: Distance and displacement

Walk around the classroom while you describe distance and displacement to visually reinforce the difference between these two quantities. Stop at each corner and ask students: What is the total distance travelled? What is the displacement from your starting point? When you return to where you started, this will be the maximum distance travelled, but the displacement will be zero. This will help clarify the difference between these two quantities. The same result can be obtained by simply walking forwards and backwards at the front on the class.

Teaching tip: Slow motion video clips

This branch of physics can easily be demonstrated with real-life situations. The use of slow motion video clips will help many students visualise the laws of motion, and energy transfers and transformations in action. A quick internet search will result in numerous appropriate clips to show.

Teaching tip: Key features of a position/displacement–time graph

Graph interpretation is prominent in this chapter, so it is important to scaffold these skills. Many students can confuse the various motion graphs; therefore, it is important to identify the key features for each type of graph and not make assumptions, because position–time graphs are easily confused with speed–time graphs in the next section.

The key features of position–time graphs are:

• The horizontal *x*-axis measures time.

• The vertical *y*-axis measures distance from the starting point.

• A horizontal line section shows a stationary object.

• A non-horizontal straight line shows constant speed.

• A positive gradient shows movement in the identified direction.

• A negative gradient shows movement in the opposite direction.

• The gradient of the line is a measure of the speed.

• A curve represents change in speed (acceleration or deceleration).

• The area under the graph has no meaning.

• A change of direction is indicated by a change in direction of the gradient.

Teaching tip: Systematic analysis of graphs

Students need to be carefully trained to interpret graphs. Translating a graphed relationship into words requires skill, particularly with motion graphs, where there the object’s motion may be constantly changing. This results in a lot of information which needs to be processed. Students often just look at the graph and make an overall judgement about what’s going on, instead of systematically analysing the pattern. Encourage students to have a consistent step-by-step process to interpret motion graphs (or any graphs for that matter).

Here is a suggested series of steps:

• Identify what properties the *x-* and *y*-axis represent – before looking at the trend of the line.

• Split the graph into sections – e.g. horizontal line, diagonal line with positive gradient, etc.

• Analyse one section at a time.

• Ask themselves ‘as the *x*-axis value increases, what is the *y*-axis value doing’? – e.g. as *x* increases, *y* stays the same.

• State this in terms of the properties represented by the *x-* and *y*-axis – e.g. as time increases, position is constant.

• Draw a conclusion consistent with the analysis – e.g. the object is stationary.

• Move onto the next section of the graph and repeat the process.

This may seem laborious when written in words, but can be quickly done when the steps are thought through rather than written.

Additional activity: Practise systematic analysis of graphs

Students can practise using the step-by-step analysis of graphs (see teaching tip above). Give them a few different position-time graphs and ask them to interpret the motion. This can be done in pairs. They can take turns verbally interpreting the graph while their partner checks that the steps are being followed systematically.

Additional activity: Mapping journey to school

Using Google Maps or a physical street map, have students map their journey from home to school each day. From their map, students can calculate the total distance and displacement of their journey.

Differentiation

Further examples requiring calculation of the total distance and displacement for the motion of an object could be given.

For less able students:

• Simple examples should be used: (e.g. walking three sides of a square block). To extend without overwhelming them, students should be able to cope with simple examples of some circular motion which requires the use of the formula for the circumference of a circle (e.g. running halfway around a circular track).

For more able students:

• More challenging examples can be used which require the use of Pythagoras theorem (e.g. walking two sides of a square block). This is also an opportunity for students to practise their trigonometry skills with some more difficult examples. A good understanding of trigonometry is required for Year 11 and 12 Physics, therefore, this is good preparation for those students who may pursue Physics further.

Going further: Trigonometry

As mentioned above, solving more difficult displacement problems requires the use of trigonometry.

Students can revise and consolidate their understanding of this important mathematical tool, which is often required in Physics, at the BBC Bitesize website.

<http://www.bbc.co.uk/education/guides/zq4w7ty/revision>

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7.2 Velocity is speed with direction

Pages 158–159

Introducing the topic

In this topic, students learn the difference between another scalar/vector pair of quantities – speed and velocity. They also encounter their first formula in this unit (speed = distance/time) and utilise their algebra skills as they practise manipulating this formula to find the missing value. Another type of motion graph is added to the students’ repertoire, as they practise drawing and interpreting speed/velocity-time graphs. They also discover that velocity can be calculated from the gradient of a position/displacement-time graph.

Teaching tip: Vectors

This is likely to be the first time students are introduced to the concept of a vector. Many will need regular reminding about the difference between scalar and vector values. Also, encourage students to remember to give the direction as well as magnitude if their final answer is a vector quantity. The direction depends on the context of the question. For example, the velocity could be 10 m/s north/south, up/down, left/right, etc.

Teaching tip: Speed-time and position-time graphs

Speed–time graphs and the speed formula are introduced in this section. The graphs can easily be confused with the position–time graphs from the previous section. Therefore, make sure differences in the key features are highlighted (see below), as well as the differences in information they contain. This will help ensure students do not confuse them.

Teaching tip: Key features of a speed/velocity–time graph

The key features of speed/velocity–time graphs are:

• The horizontal *x*-axis measures time.

• The vertical *y*-axis measures speed.

• A horizontal non-zero line shows constant speed (not a stationary object).

• A non-horizontal straight line shows a changing speed.

• A positive gradient above zero shows acceleration in the identified direction.

• A negative gradient above zero shows deceleration in the identified direction.

• A positive gradient below zero shows deceleration in the opposite direction.

• A negative gradient below zero shows acceleration in the opposite direction.

• A change of direction happens at the *x*-axis intercept.

• The area under the graph is a measure of the displacement/distance.

• The gradient of the line is a measure of the acceleration/deceleration.

Teaching tip: Measuring gradients

Be aware that, depending on ability and previous learning, some students may not know how to find the gradient of a straight line graph. Therefore, this may need to be taught at this stage.

Teaching tip: Acting out motion graphs

Students may be surprised to discover that all of the graphs in this module only show linear motion. This may be confusing for some students who may interpret changes in motion on the graph as non-linear. For example, a linear change in direction may be incorrectly interpreted as turning a corner. To reinforce the linear nature of the motion, physically ‘act out’ a variety of graphs. Draw each graph on the board and split it into sections for each change in motion. Label each section (A, B, C etc.). Then simply walk backwards and forwards parallel to your whiteboard in one plane matching the motion pattern depicted on the graph. As you move, describe what you are doing and link to this to the corresponding labelled section on the graph. Any possible graphed scenario can be demonstrated by this method. By simply walking backwards and forwards, all of the different aspects of the graph can be visualised (i.e. constant speed, stationary, acceleration, deceleration, increased/decreased acceleration/deceleration and change of direction).

Teaching tip: Velocity calculation misconception

When working out the total distance and the displacement for the same journey, a common misconception can lead to problems.Many students find it difficult to comprehend that time is a common factor in both calculations. Take the example of someone who walks around three sides of a 10 m square block, with each side taking 10 s to walk. The distance travelled is 30 m and the time taken is 30 s. Therefore, the *speed* is 30/30 = 1 m/s. As the person is now 10 m away from their starting position, the displacement is 10 m. Therefore, the *velocity* is 10/30 = 0.33 m/s (say, west). Students often struggle with the fact that time is the same in both calculations. Their logic goes something like this: if they are 10 m from where they started, then the time used in the velocity calculation must be 10 s, since it takes 10 s to travel 10 m (which is their displacement). This is a classic example of blindly applying maths without thinking about the logic of the problem. Reinforce the fact they are describing the same real event in time. It did take 30 s. There was no journey undertaken which took 10 s.

Teaching tip: Speed is not measured directly

Speed is a quantity that has to be calculated and cannot be measured directly. Devices that produce a reading for the speed of an object are typically measuring a distance, and the time taken to travel this distance. This data is then used to calculate the speed of the object. Speedometers in cars simply count how many times the wheels turn around per second and, based on the circumference of the wheels, the speed can be found. Note that this presents problems when people change their car wheel diameters, as the speedometer will no longer read the correct speed. Even speed cameras, which appear to measure speed instantaneously, measure the time taken for an electromagnetic wave to travel a measured distance as it bounces off a potentially speeding vehicle.

Teaching tip: Ticker timers and motion sensors

Both motion sensors and ticker timers are useful devices for calculating speed. Motion sensors are a great way of integrating IT use in this module and students will acquire new skills as they learn how to operate these devices effectively. However, the motion sensor experiment should be completed after the ticker timer experiment as there is the danger that students will view the apparatus as ‘black box’ technology, meaning that the laptop spits out the answers without any thinking about how the answers are produced. Although ticker timers are an older, more laborious technology, that is also one of their advantages. It forces students to manually calculate the speed from the measured time and distance. There is a place for both these devices.

Additional activity: Research how speed is measured

Students could research how the speeds of objects are measured. Starting points could be the speed of aeroplanes, rockets, sound, the Moon, blood flow and light.

Additional activity: Experiments with radio-controlled cars

A fun and effective way to give students practice calculating velocities is to use radio-controlled model cars. Take them outside (weather permitting) and ask students to mark out and measure a length of track. They can then time the car over the set measured course. Be aware that if the cars are being used close to each other, and are operating over the same frequency, they will interfere with each other. This problem can be overcome by spreading groups of students widely apart. Alternatively, when purchasing a class set, make sure to get a range of different frequencies.

Additional activity: Area under a velocity–time graph

Students will need practice calculating both the total distance travelled and displacement from velocity–time graphs. However, get them to calculate both of these quantities using the *same* graphs. This will reinforce the different treatment required. In both cases, the area under the graph will need to be split into rectangular and triangular sections. Then calculate the area of each individual section. To find the total distance, all of the areas are added together regardless of direction (i.e. both above and below the *x*-axis). In contrast, use the same individual areas to calculate displacement, but this time the combined area below the *x*-axis is deducted from the combined area above the *x*-axis. Note that if the final figure is zero, the displacement is zero.

Differentiation

Give students plenty of graphing practice – both drawing and interpreting distance–time and velocity–time graphs.

For those with lower abilities:

• Using the key features lists, encourage students to create a cheat sheet highlighting the key features of a position–time graph and the all the information it can tell you. Give less complex graphs with a limited number of changes of motion.

For those with higher abilities:

• Provide extension questions where students are required to draw the distance–time graphs and velocity–time graphs for more complex scenarios with lots of changes of motion. This should include multi-step calculations of distance travelled (and displacement) from the area under a velocity–time graph.

Going further: Vehicle safety

An understanding of the laws of physics is vital for vehicle safety. At the end of this chapter, car safely design features are considered. Vehicle speed is another factor which is important in reducing the likelihood of serious injury or death in car accidents. Students can extend their understanding of some the important practical applications of the physics covered in this module at the Nova website. This article investigates the physics of speeding cars. This will stretch students with its quantitative analysis of this important variable.

<http://www.nova.org.au/technology-future/physics-speeding-cars>

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7.3 Acceleration is change in velocity over time

Pages 160–161

Introducing the topic

Just as velocity is the rate of change of displacement, acceleration is the rate of change of velocity.

Students manipulate the formula for acceleration (acceleration = change in speed/time) to find the missing value for objects with uniformly changing velocity. Also, just as the gradient of a displacement–time graph represents velocity, students discover that acceleration can be calculated from the gradient of a velocity–time graph. The concept of acceleration due to gravity is also considered.

Teaching tip: Link acceleration to car performance statistics

Linking acceleration to car performance statistics can be an effective way to engage the class. Typically, values of car acceleration are quoted as 0–100 km/h in so many seconds. By converting the speed of these values into metres per second (m/s) and, hence, acceleration into metres per second per second (m/s2), students can compare the acceleration of different cars with the acceleration of objects on Earth. Microsoft Excel spreadsheets can be used here to generate the acceleration in m/s2 from the published car statistics.

Teaching tip: SI units

Students often forget (or worse – don’t realise) that when performing calculations, they need to make sure all the figures they substitute into a formula are in SI units. This is a habit that often lingers past Year 10. When setting question practice, make sure to give plenty of examples with figures that require conversion to SI units.

Teaching tip: Check answer for ‘reasonableness’

Often students will blindly plug figures into a calculator and accept whatever the final result shows. Most of the time – if they think about it – they should have an idea of roughly what their final answer should be, at least within an order of magnitude. For example, if they are calculating the speed of a sprinter and their answer is 100 m/s, this unexpectedly high value should alert them to an error in their calculations. Students should be encouraged to get into the habit of checking their answers for ‘reasonableness’. The error highlighted in this teaching tip is often related to the previous one, since unreasonable answers often result from omitting conversion of figures to SI units.

Teaching tip: Velocity and acceleration misconception

A common mistake that students make is thinking that acceleration due to gravity has a different numerical value for an object going up and one coming down. Students will often state that it is -9.8 m/s2 (negative value) for an object moving up and 9.8 m/s2 (positive value) for an object falling down (or vice versa depending on the convention adopted for motion in the up and down plane). This results from a confusion in their understanding of velocity and acceleration. The value for the velocity of an object will have a different sign (+ or -) depending on whether it is moving up or down. Velocity is a vector quantity and, as such, the sign will indicate the direction of motion. However, force is also a vector quantity and the force of gravity always acts in the same direction – down. Therefore, applying the same logic, the direction of the resulting acceleration (also a vector) does not change either – nor does its sign. The value is always negative (if we adopt the convention that ‘down’ is negative and ‘up’ is positive). Students may also believe that when an object is instantaneously stationary, as it reaches its peak height, that its acceleration is zero. Some students find it difficult to accept that, even at the moment it is stationary, its acceleration is still -9.8 m/s2. The velocity is zero at its peak height, but its acceleration hasn’t changed, because gravity hasn’t changed. For example, let’s take an object travelling up at 30 m/s (going up). It we add -10.0 m/s (to approximate ‘g’) to its velocity each second then, over the next six seconds, its velocity will be: 30 m/s, 20 m/s, 10 m/s, 0 m/s, -10 m/s, -20 m/s, -30 m/s. Each second its velocity is changing by the same amount: -10.0 m/s. In words, there is a constant acceleration acting on an object causing it to decelerate, stop, then accelerate in the opposite direction. Get students to plot this data on a velocity–time graph and carefully interpret it. They will see *one* straight line sloping down, passing through the *x*-axis. Their interpretation should match the description of motion stated above. They should also measure the gradient of this line. This will, of course, be -10 m/s2.

Additional activity: Car accelerator

The accelerator pedal in a car is poorly named. Ask students to explain what the accelerator pedal does to the motion of a car. If it were truly an accelerator, holding the pedal steady would cause the vehicle to continue to increase in speed at a steady rate rather than maintain a steady speed. Students can propose alternative, more scientifically accurate names for the pedal.

Additional activity: Investigating vehicle acceleration

Students can investigate the acceleration of various vehicles including cars, motorbikes, aeroplanes and space shuttles and create a chart comparing the values. Students can suggest reasons why the different vehicles have different acceleration (power to weight ratio), which will lead into the Newtonian laws of motion in the next section.

Additional activity: Excitement of acceleration

Much of the excitement experienced on theme park rides is the result of acceleration rather than speed alone. Students should consider how exciting a long haul airplane flight is, bearing in mind that the speed of travel is very high. Brainstorming the types of activities that are exciting due to movement and forces will elicit some correct and some false ideas. Identifying these misconceptions early will help to structure their concept building.

Going further: Projectile motion

Students can go further than the requirements of the curriculum by looking at projectile motion. They can investigate the physics involved when the motion of the projectile is only in the vertical plane, such as throwing a ball straight up and catching it. For the more ambitious students, they can take it one step further and look at projectile motion for objects which are also moving horizontally – for example, firing a cannon or hitting a golf ball. They will be able to apply the formulas they have learned so far (and a few more) in more complex physics problems. In both cases, the only force involved is gravity. A good starting point can be found at the ‘Physics Classroom’ website.

<http://www.physicsclassroom.com/class/vectors/Lesson-2/What-is-a-Projectile>

Teacher notes

7.4 An object in motion remains in motion until a force acts on it

Pages 162–163

Introducing the topic

This topic introduces students to the concept of inertia and the first of Newton’s three laws. The first law states than an object remains at rest or in constant motion in a straight line unless acted on by a net unbalanced force. This principle is applied in various familiar situations.

Teaching tip: Demonstrating inertia

The classic way of illustrating the principle of inertia (often seen in films or performed by magicians) involves quickly pulling a table cloth from under the dishes and glasses on a table set for a meal. If done quickly enough, the dishes and glasses remain in place. A simplified version can be performed in the science laboratory. Instead of a table cloth, use a piece of paper. What you put on top of the paper depends on your skill at performing this ‘trick’. Perhaps try it with a 1 litre conical flask. Then turn the flask upside down with the narrow end on the paper! This does require a bit of practice, but can be quite an impressive way of demonstrating the tendency of objects to resist a change in motion.

Teaching tip: Unbalanced forces

A common mistake that students can make when discussing Newton’s first law is thinking that there are no forces acting on an object if it is stationary. This needs to be questioned and replaced with the notion that if a body is not moving, then the *net* force is zero. Develop this idea further by explaining that if there is a non-zero net force, then there must be an overall push in one direction, and that is why the velocity increases in that direction – or decreases if the net force is opposing the object’s motion. This idea of a net force of zero can now explain why cars have a top speed, for example. In this case, students will realise that there must be forces involved if the car is moving. Now they should also be able to deduce that the net force is zero, as this is when the air resistance is the same size as the engine’s thrust force.

Teaching tip: Unbalanced forces and change in velocity

Like most aspects of this module, the link between unbalanced forces and changes in velocity can be reinforced by relating the concepts to students’ everyday experience. Ask them about what they ‘felt’ on their journey to school. Here is a possible sequence of questions (and expected answers).

• What did you feel when your car started off? (pushed back into your seat)

• How long did you feel this for? (until reaching a constant speed)

• What did you feel when your car slowed to a stop at traffic lights? (pushed forwards)

• How long did you feel this for? (until the car stopped)

• What did you feel when your car drove through a school zone at a constant 40 km/h? (nothing)

• What did you feel when your car drove on the freeway at a constant 100 km/h? (nothing)

• Was there any difference travelling at a constant 40 km/h and 100 km/h? (no)

• What did you feel when you went around a roundabout? (pushed to the side)

• How long did you feel this for? (until exiting the roundabout)

They should notice that they only feel something when they are changing velocity. What they feel is a result of the unbalanced force.

Teaching tip: Unbalanced forces and circular motion

Linked to the above teaching tip, a common misconception is that there cannot be an unbalanced force if speed is constant. Students will quickly grasp the connection between unbalanced forces and acceleration when travelling in a straight line, as the acceleration is obvious (either when the car speeds up or slows down). However, they may question how there can be an unbalanced force while going around a roundabout if the car is travelling at a constant speed. Remind them of the difference between speed and velocity: velocity has direction as well as magnitude. Acceleration is also a vector quantity. Therefore, even though speed is constant, velocity must be changing since the direction is changing. Consequently, the only logical conclusion is that the car is accelerating at a constant speed! Relating this concept to their own experience helps manoeuvre some tricky physics. Suggest that they should keep going around the roundabout a few times on the way home – at a constant speed. They should report the next lesson that they felt pushed to the side of the car for the whole time that they were going around the roundabout. Therefore, they have proved for themselves that there must be an unbalanced force even though their speed remained constant.

Teaching tip: Air resistance and terminal velocity

An important force introduced in the section is friction. This is often the opposing force that has to be subtracted from another force to find the net unbalanced force. This force, which includes air resistance, is often misunderstood by students. It should be made clear that friction is not always a constant force. This can be illustrated by comparing the forces acting on a parachutist. As a parachutist accelerates towards the ground due to a constant gravitational force, the opposing force of air resistance increases the faster she goes. This continues up to the point when the two forces are equal (balanced) and the parachutist now falls at a constant speed –terminal velocity. When she opens the parachute, the force due to air resistance increases dramatically and is now much greater than the gravitational force. This resulting unbalanced force (directed upwards) slows the parachutist. As a result of this decrease in speed, air resistance again changes, decreasing this time, until the point where it is now equal to gravity again. The parachutist is now travelling at a constant speed again as a new terminal velocity is reached, though obviously the magnitude of this second period of terminal velocity is less than the first. Note that throughout the whole process, gravitational force is constant. This sequence is best understood by drawing free body diagrams of the different stages. An internet search will also provide these diagrams, even animated ones.

Teaching tip: Falling objects

By Year 10, students will probably have overcome a common misconception and realise that if objects of different mass are dropped from the same height, they hit the ground at the same time. They will also realise that this is not always the case, but that this is not due to a difference in mass, but due to the effect that air resistance has on objects with a high surface area to mass ratio. Therefore, if a feather and a bowling ball are dropped, the bowling ball will fall much faster. Also, if this wasn’t the case, parachutes would wouldn’t work! However, students are usually surprised to discover that if a feather and a bowling ball were to be dropped at the same time on the Moon, they would hit the ground at the same time. The Moon has no atmosphere and hence there is no air resistance. That also means that parachutes would indeed be useless on the Moon! This phenomenon can be demonstrated on Earth if the feather and bowling ball are dropped in a vacuum. An internet search will provide a fascinating video clip of Professor Brian Cox demonstrating this principle at the world’s biggest vacuum chamber at NASA’s space power facility in Ohio. Analysing scenarios like this will help students to apply their physics understanding to problems (particularly where one of the factors changes in a scenario that they think they are familiar with), rather than make incorrect assumptions or take an expected outcome for granted.

Teaching tip: Newton’s laws in space

Newton’s first law states that if you apply an unbalanced force, a stationary object will start to move and accelerate while the force is being applied. Then, if you stop applying the force, it will continue at whatever speed it has reached until another force acts on it. This should be relatively easy for students to grasp as they see this happen all the time. For example, they could easily tell you what happens if you stand on one spot, push a shopping trolley and then let go of it. It will accelerate away from you, then quickly decelerate and stop. However, asking students what would happen if you carried out the same action in space is less likely to elicit the correct response. Newton’s laws predict the trolley would continue in a straight line – forever! This will come as a surprise for many students. However, providing unfamiliar scenarios like this one will force students to apply Newton’s laws logically and methodically, no matter how unusual the outcome may seem.

Additional activity: Free body diagrams

Individual forces can be added together to calculate the net force – whether this results in an overall balanced or unbalanced force. It will help students to grasp this concept if the mathematical treatment is supplemented by drawing free body diagrams. These diagrams show all the forces acting on the object. The forces are shown by straight lines with arrows indicating the direction of the force. The length of the line should be proportional to the magnitude of the force. The size of the force in Newtons should also be written next to the arrow. This visual tool will make it much easier to grasp the logic underpinning the maths which is used to calculate the overall unbalanced force.

Differentiation

Students can both interpret and draw free body diagrams showing the forces in various situations. Then they can calculate the net force. These can either be made up or an internet search will provide examples to use.

For less able students:

• Simple examples can be used (e.g. a car with the vertical forces balanced and the horizontal forces of thrust and drag unbalanced).

For more able students:

• More challenging examples can be used which may require the use of Pythagoras’ theorem (e.g. a plane taking off where both the opposing vertical and opposing horizontal forces are unbalanced). This is also an opportunity for students to practise their trigonometry skills with some more difficult examples. As mentioned previously, a good understanding of trigonometry is required for Year 11 and 12 Physics.

Going further: Circular motion

In relation to the circular motion teaching tip (above), some students may want to extend themselves beyond the requirements of this course. The phenomenon of accelerating while circling a roundabout at constant speed is due to centripetal force. Centripetal force and the resulting centripetal acceleration is actually directed towards the centre of the circle. Students can find out more about this at the ‘Physics Classroom’ website.

<http://www.physicsclassroom.com/class/circles/Lesson-1/The-Centripetal-Force-Requirement>

Teacher notes

7.5 Force equals mass x acceleration

Pages 164–165

Introducing the topic

Newton’s second law states that if an unbalanced force acts on an object, its velocity will change. Students manipulate the associated formula (force = mass x acceleration) to find the missing value in a range of familiar situations. They also discover that Newton’s second law also explains the connection between mass and weight.

Teaching tip: Relate Newton’s second law to the first law

Newton’s second law is the mathematical application of the first law. If the net force is not zero, then there is an acceleration (i.e. the velocity will change). Reassuring students that this is really the first law presented in numbers can reduce concern that the laws are complicated.

Teaching tip: Use examples to illustrate Newton’s second law

Provide recognisable examples to demonstrate the relationship between the variables force, mass and acceleration. For example, if we want a high acceleration (e.g. on a motorbike), we apply a large force and reduce the mass as much as possible. This is also why a golf ball accelerates much faster when hit with a golf club than a football would, and why a stronger person can kick a football further than a weaker one can.

Teaching tip: Mass and weight misconception

The misconception that weight is measured in kilograms results from the misuse of this term in our everyday experience. Any confusion between mass and weight should be laid to rest at this stage. We weigh ourselves on a set of scales and the result is given in kilograms. Scales really measure weight (a force) which the scales convert to mass and give a reading in kilograms. Reinforce the idea that mass never changes and is related to the amount of matter present and that weight is the force due to gravity on that matter. This gravitational force doesn’t change in our everyday experience. However, the force of gravity would be different on the Moon, for example (since it’s mass is smaller). An interesting question to pose to students is to ask them that if mass doesn’t change, does that mean that the amount of kilograms recorded by a set of scales would be the same if someone stood on the same scales on Earth and on the Moon. Students should recognise that the readings (in kilograms) will be different. If they also conclude that the reading on the Moon is not correct since the scales were designed only to give a correct mass reading if used on Earth, then they have definitely got the idea. To push this point home, even if the Earth scales did give a reading in Newtons they still would not give the correct reading on the Moon!

Additional activity: Demonstrating Inertia

Building on students’ understanding of inertia, demonstrate the difference in acceleration and motion of a 5c and $2 coin. On a smooth surface use a ruler to push both coins at once (same force). The 5c coin should travel further. Ask students to explain why this is (greater masses have greater inertia). Challenge them to describe how to move both coins the same distance at the same speed (alter the force of the push).

Additional activity: Isaac Newton assignment

Much of the material in this module is based on the work of perhaps the most well-known scientist in history – Isaac Newton. He has made an important contribution to physics and other disciplines. As a result, he has had a major impact on society, which affects all of our day-to-day lives in so many ways. Students can carry out a research project on this great scientist. This could even be the subject of an assessed assignment. Ask them to research Newton’s life and achievements beyond the confines of his laws of motion. This could include:

• background information (his family, education, awards, positions held, religious views, etc.)

• his scientific discoveries (motion, optics, gravity and mathematics)

• how his discoveries affect our lives today (air travel, seat belts, the telescope, etc.)

• a description of the famous ‘apple incident’!

Rather than produce a paper report, an engaging way for students to present this information is to design a website. This can be done with free versions of easy to use drag-and-drop website builders, such as Weebly or Wix.

Going further: Isaac Newton biography

For students who want to find out more about Isaac Newton or perhaps as a starting point for the suggested activity/assignment mentioned above, the How Stuff Works website has a great short biography on Newton. This combines an interesting insight into both Isaac Newton as a person as well as his work and discoveries.

<http://science.howstuffworks.com/dictionary/famous-scientists/physicists/isaac-newton.htm>

Teacher notes

7.6 Each action has an equal and opposite reaction

Pages 166–167

Introducing the topic

This topic introduces students to the last of Newton’s three laws which states that ‘for every action there is an equal and opposite reaction on the other object’. Newton’s third law is investigated in a variety of familiar situations. Students also learn how this law explains the operation of rockets, missiles and how jet engines work.

Teaching tip: Applying Newton’s third law to firing a cannon

This is the most conceptually challenging law to fully grasp. In every head-on collision, the forces applied to each object are the same size but opposite in direction. This is easy to visualise when two objects collide and stop, but less so when, for example, a bullet passes through a target. However, even in this case, the target applies a force to the bullet (decelerating it slightly) of the same size as the force the bullet applies to the target (deforming it).

A good way to reinforce this and Newton’s second law is to model a cannon firing a cannonball. Write on the board:

cannon ↔ cannonball

*m x a = F = m x a*

Newton’s third law states that the forces must be equal. Newton’s second law shows that if an object has a large mass, then it must have a small acceleration. Therefore, it can be seen that the cannon does not accelerate back as much as the cannonball accelerates forwards. The same logic applies no matter how large the difference in mass between two objects. For example, when you jump up in the air, the force of gravity accelerates you back to Earth. Likewise, your mass pulls the Earth towards you. Obviously, this isn’t noticed because the massive difference in mass between you and the Earth results in a massive difference in the acceleration of the Earth compared to you.

Additional activity: Balloon rocket

Blow up a balloon and let it go to fly around the room. Encourage students to attempt to explain why this happens.

Additional activity: Water rockets

The most engaging and exciting way to demonstrate Newton’s third law practically is to build (and launch) a water rocket. An internet search will provide instructions on how to do this safely and inexpensively. This could be set as a competitive challenge, with the group who achieves the greatest height being the winner. This can also be linked to NASA’s water rocket activity (Rocket research 101) which can be found at its Space Flight Systems website.

Going further: Does the EM drive defy Newton’s third law?

The EM (electromagnetic) drive is a proposed propulsion system which uses reflected microwaves, instead of rocket fuel, to generate thrust. It has been estimated that the EM drive could power a manned mission to Mars in just 70 days. However, this proposed propulsion system at first *appears* to defy Newton’s third law! Student can connect their work on Newton’s third law with the latest developments in space technology. A web search will produce recent news articles relating to this story.

Teacher notes

7.7 Momentum is conserved in a collision

Pages 168–169

Introducing the topic

This topic introduces students to momentum, a new concept which they have not encountered before. Momentum is the product of the mass and velocity of an object. Students manipulate the momentum formula to find the missing value in a range of familiar situations. They also learn how to describe the law of conservation of momentum qualitatively and apply it quantitatively to find an unknown momentum, mass or velocity.

Teaching tip: Describing momentum

Momentum can be thought of as how difficult it is to stop an object. A large mass moving slowly (e.g. a bus rolling backwards) is very difficult to stop as it has a large momentum. Equally, a cannonball fired from a cannon is difficult to stop due to its high speed, so it also has a large momentum.

Teaching tip: Explaining conservation of momentum

This is a difficult idea to communicate, but it does explain why guns recoil and why snooker balls move as they do. If objects are allowed to collide without interference (i.e. no external forces added), then the total momentum will be the same at the start as at the finish; that is, the total of all the masses of each object multiplied by their velocities will add to the same amount. As momentum is a vector quantity, this requires the addition of vectors if collisions are glancing. For this reason, only linear momentum is quantified.

Teaching tip: Demonstrating momentum

One of the best ways to demonstrate the principle of conservation of momentum is with a good quality Newton’s cradle. Give the students the opportunity to try it for themselves. Everyone loves playing with these fascinating devices. As always, learning is always more likely when doing something which is fun.

Teaching tip: Common mistakes

Students can make the common error of adding all the masses and all the velocities and then multiplying them together. They can also find individual momentums and add them regardless of direction. Use of the technique of always making motion to the right a positive number and motion to the left a negative number will avoid many mistakes. This also reveals the final direction of the objects by the sign of the answer.

Teaching tip: Units

The units of quantities in physics often give an indication of how to calculate a quantity. In this case, the unit of momentum (p) is kg.m/s: a multiplication of kg (mass) and m/s (velocity). The unit for the change in momentum (Δp), or impulse (I), is Ns: a multiplication of N (force) and s (time). Also, note that as impulse is the same as change in momentum, either unit choice is correct. Conversely, the unit for a quantity can often be found if the formula is known. The formula for momentum is mass x velocity, therefore, the unit is a multiplication of the unit for mass (kg) and the unit for velocity (m/s). Hence, the unit must be kg.m/s.

Additional activity: Stationary trolley experiment

An interesting experiment which can be performed with dynamic trolleys (as used in experiment 7.5B) is to investigate what happens when we start with both trolleys stationary. Push in the spring loaded bolt of one (or both) trolleys and place them in contact with each other on the bench. Since they are both stationary, the total momentum must be zero. Then press one of the release buttons to release the spring loaded bolt. Both trolleys will move away from each other rapidly, in opposite directions. However, according to the principle of the conservation of momentum, the total momentum must be zero, as it was before the collision. This may be counter-intuitive to students, as the trolleys are moving. This is obviously reconciled by the fact that momentum is a vector quantity and the trolleys are moving in opposite directions. Therefore, the values for momentum will cancel each other out when added together. This experiment also shows how important it is to get the sign right (+ or –) when performing conservation of momentum calculations.

Going further: Elastic and inelastic collisions

Momentum is always conserved according to the law of conservation of momentum. Furthermore, the law of conservation of energy (see section 7.9) states that energy is also conserved in a collision. However, kinetic energy is only conserved in elastic collision. Students can extend their understanding of this topic by investigating elastic and inelastic collisions. An internet search will provide the required information.

Teacher notes

7.8 Work occurs when an object is moved or rearranged. Energy can be calculated

Pages 170–171

Introducing the topic

In this section, students discover the scientific meaning of ‘work’. They also meet two forms of energy that they previously encountered in Year 8: kinetic energy and potential energy. However, in Year 10, a much more quantitative approach is taken. Students manipulate the formulas for work, kinetic energy and potential energy to find the missing value in a range of familiar situations.

Teaching tip: Bridging with previous work on energy

It is assumed that students will be at least vaguely familiar with the different forms of energy related to motion. However, it may be appropriate to direct some students back to Chapter 3 of *Oxford Science 8* to brush up on their understanding of the different forms of energy. Chapters 4 and 5 of *Oxford Science 9* cover the transfer and transformation of energy in terms of light, sound, heat and electricity. Again, it may be useful for some students to revise this content to help them progress with the concepts of work and energy in motion.

Teaching tip: Demonstrating work done

Work and energy are difficult terms to define without referring to one another. Energy is the ability of an object to do work, and work done is the change of energy. Importantly, if work is done on an object it must have moved; without movement no work is done. An engaging way to demonstrate this is to ask for a student volunteer to come forward. Ask the student to hold their arms out horizontally and place an uncomfortably heavy pile of books on their outstretched arms. Discuss the fact the no work is being done on the books as the student visibly strains trying to keep the books stationary under the load. It may feel like hard work for the student, but is a dramatic way of reinforcing the fact that no work is being done on the books, since the energy of the books is not changing.

Teaching tip: The size of a joule

A way to remember the approximate size of a joule and newton is to remind the students of the story of Isaac Newton seeing the apple fall. A newton is about the weight of a small apple and the joule is the amount of gravitational energy it would lose when it falls one metre.

Teaching tip: Energy is never lost

Some students believe that when energy is ‘lost’, it disappears and ceases to exist. It is important to remind students that while energy may be lost from a specific object or system, it is simply transformed or transferred to a different object or system. Most often, the lost energy is in the form of heat, often as a result of friction between objects.

Teaching tip: The squared relationship

The faster an object moves, the more energy it must have. As the speed of an object increases, its energy also increases, but not directly proportionately. A doubling of speed leads to a quadrupling of energy. This squared relationship (from the equation *Ek ½mv2*) becomes important when analysing the ‘Wipe off 5’ speed reduction campaign.

Additional activity: Forms of energy

To introduce the topic of energy, get students to recall previous learning. Give students three minutes to write down as many forms of energy as they can remember. Students then find a partner and compare their lists. Give students another minute to add any further forms of energy to their lists. Collate lists into a class set.

Differentiation

Students should be given as much practice as possible applying the three equations in this section.

For the less able:

• Provide more simple problems, but lots of them. Some students may feel overwhelmed manipulating these formulas. Encourage them to use the formula triangles to find the unknown value.

For the more able students:

• More complex examples should be given which apply the principle of conservation of momentum: e.g. If you drop a 10 kg object from a 100 m cliff, at what speed will it hit the ground? In this example, the potential energy (mgh) can be calculated. Assuming there are no energy losses, then the potential energy at the top of the cliff will equal the kinetic energy at the bottom. Therefore, mgh = ½ mv2. Velocity can then be found by rearranging to give the answer in terms of v.

Going further: Einstein

As students approach the end of this module, they have learned a lot about Isaac Newton and his amazing contribution to our understanding of forces, motion and energy. This could be a good time to introduce them to another giant in physics – Albert Einstein. Einstein has also contributed much to our understanding of motion, energy and forces, including his famous theory of relativity. He developed a more thorough model of how the laws of physics operate in the universe (particularly at velocities approaching the speed of light) that Newtonian physics can only provide an approximation of. Students will find Einstein’s ideas sometimes conceptually challenging, but always interesting. An internet search will provide a wealth of information.

Teacher notes

7.9 Energy is always conserved

Pages 172–173

Introducing the topic

In this topic, the principle of energy transformations is extended to show that that when these transformations take place, energy is never created or destroyed. Students apply this law of conservation of energy qualitatively and quantitatively in a variety of familiar situations.

Teaching tip: Revisit triangle technique

Again, this section requires strong numeracy support. While the structure of the energy efficiency formula is the same as most of the other three variable formulas seen in this chapter, some students will require assistance in rearranging the equations to solve for the unknown value. Redemonstrate the ‘triangle’ technique to assist students with lower abilities.

Teaching tip: Conservation of energy

It may not always appear obvious that energy is always conserved. If you drop a brick, it’s easy to reason that the gravitational potential energy is being converted into kinetic energy. But when the motionless brick is sitting on the ground, where did the kinetic energy go? Some students may believe that when energy is ‘lost’ it disappears and ceases to exist. Others may realise that it hasn’t been destroyed, but will not be able to explain where it has gone. If they answer, ‘it was converted to sound’, ask them, ‘what has happened to the sound energy from the now silent brick?’. It often takes a lot of questioning before they realise that it is dissipated into heat in the atmosphere. This could lead onto a discussion about ‘saving’ energy. Ask them why we should worry about energy use when it is always conserved. Some students may ask why the heat that is dissipated into the atmosphere cannot be reused. This is because it would require more energy to extract the heat than would be extracted!

Additional activity: Rollercoaster physics

It is always advantageous if you can relate physics to something students enjoy doing – for example, sports. Most will also enjoy riding rollercoasters. Students can investigate the physics of rollercoasters. They will find that energy transfers and transformations and the law of conservation of energy are important factors in the design of rollercoasters. For those who carried out the ‘going further’ exercise suggested in section 7.4 teacher notes, they will recognise that circular motion and centripetal acceleration are also important factors in achieving a thrilling ride. An internet search will provide the information required. To take this one step further, there are many interesting experiments which can be carried out with rollercoaster model kits. These are available from science education suppliers.

Additional activity: Comparing the efficiency of different bouncing balls

Students can carry out an investigation into the efficiency of a variety of balls. Using a range of different types of balls, students can predict which ones will bounce the highest. Then they can drop the balls from the same height and measure how high the balls bounce up to. The efficiency for each type of ball can then be calculated. Students can also extend this exercise to determine if the efficiency is the same for subsequent bounces. This could be presented as a complete lab report or it could be the subject of an assessed investigation. If students carried out the going further research exercise suggested in teachers notes 7.7, ask them to also comment on the elasticity of the balls. Which one was the most elastic?

Additional activity: Perpetual motion!

Throughout history, there have been many claims that a perpetual motion machine has been invented. Students can investigate some of these claims and explain how the physics principles they are learning (in particular, the law of conservation of energy) proves that these claims are impossible.

Going further: Finding ‘g’ with a pendulum

In experiment 7.9, students work out the efficiency of a simple pendulum. They can carry out an extension experiment which also uses the simple pendulum to experimentally calculate a value for ‘g’, acceleration due to gravity. If done carefully, this will give quite an accurate value.

<http://www.fofweb.com/onfiles/seof/science_experiments/6-33.pdf>

Teacher notes

7.10 Car safety features require an understanding of Newtons Laws and momentum

Pages 174–175

Introducing the topic

To conclude this unit, students apply much of what they have learned so far about Newton’s laws and momentum – qualitatively and quantitatively – to the design of car safety features.

Teaching tip: Airbags

The use of cushioning with an airbag simply extends the time of the deceleration. In keeping with *F* = *ma*, for a smaller ‘*a*’, a smaller force will be experienced. Interestingly, airbags are designed to have an impact after they are fully inflated. If impact occurs too early (e.g. if the person is not wearing a seatbelt), the airbag will still be too hard, so more injury will result.

Teaching tip: Reducing the force

Some students believe that a rigid vehicle that does not sustain much external damage in a collision would be safer than one that has significant crumple zones. It is important to remind them that the damage to the car does not always relate to the damage to the people inside. Reiterate the purpose of crumple zones and airbags as methods of extending the impact time to reduce the force of the impact.

Teaching tip: Impulse

Some of the safety features in cars result in a reduction of force during the impact of a crash. To understand this better, it is helpful to teach the concept of impulse and its mathematical application. The formula for impulse is *I = F x Δt*, where F is the force applied and *Δt* is the time interval over which the force occurs. Also, the change in momentum equals the impulse. To explain this further, it is better to illustrate with an example.

A car of mass 1000 kg travelling at 25 m/s (90 km/h) hits a wall. The change in momentum of the car, *Δ*p = *m x Δv* = 1000 x 25 = 25,000 kg.m/s. Since *Δ*p = I, then *m x Δv = F x Δt*. Therefore:

If t = 0.1 s

Then, 25,000 = F x 0.1 hence, F = 250,000 N

**and**

If t = 1.0 s

Then, 25,000 = F x 1.0 hence, F = 25,000 N

You can’t change the amount of momentum or the impulse, but you can change the time over which the crash occurs. Therefore, using the concept of change in momentum equals impulse *(m x Δv = F x Δt),* it can be seen that, in this case, a 10-fold increase in time will result in a 10-fold decrease in force. This is the mathematical principle which governs the use of airbags and crumple zones.

Additional activity: Safety feature poster

Design a poster to illustrate the safety features of a modern car. Label each feature on the poster and provide a short description of the physics underpinning its design.

Going further: Physics of car safety teaching resources

The National Road and Motorists Association (NRMA) provides a comprehensive set of resources for teachers aimed at engaging Year 9 and 10 students in the science of car safety. The ‘Car Safety: the physics of staying safe on the road’ pdf can be found at the NRMA website.

<https://www.mynrma.com.au/images/About-PDF/NRMA_Car_Safety_(Years_9-10).pdf>