How can the laws of physics predict our moves?

Levels 9 and 10, Science –   
Physical sciences

A conceptual development of the understanding of forces and motion

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Introduction

The learning activities in this resource are a hands-on quantitative exploration of balanced and unbalanced forces and energy transfer in the context of motion.

At Foundation to Level 2, students are introduced to pushes and pulls as a model for the concept of force. They observe that a push or a pull can result in a change in motion or shape. At Levels 3 and 4, the context for pushes and pulls is extended to include both contact and non-contact forces, including gravity and magnetism*.* At Levels 5 and 6 the role of force in changing the direction of motion is explored and the motion of the planets around the Sun modelled as continuously changing direction due to the attractive force between the Sun and Earth. At Levels 7 and 8, the motion of objects is analysed in terms of all the forces acting on an object, both contact and non-contact. Where the forces on an object do not balance each other out, a change in motion, shape and/or direction is observed. In this resource, for Levels 9 and 10, the connection between force and energy is made and Newton’s laws and the principle of conservation of energy are applied to quantitatively predict and explain motion.

This resource contains five learning activities. Students are provided with opportunities to:

* measure and analyse the motion of an object moving with a constant velocity
* apply Newton’s laws of motion while investigating the effect of gravity
* analyse changes in energy in the context of motion
* quantitatively explore energy transfer in the case of a falling object
* investigate efficiency of energy transfer in relation to a bouncing object.

To see how student learning about forces and motion at Levels 5 and 6 fits into the broader forces and motion story and for some common student misconceptions about forces and motion, see the supporting resource [Making moves and staying still: Connecting forces and motion – An overview of forces and motion in the Victorian Curriculum F–10](https://www.vcaa.vic.edu.au/curriculum/foundation-10/resources/science/Pages/TeachingResources.aspx).

Sample key science concepts

* Motion can be explained by a force model and is described in terms of position, velocity and acceleration.
* **Position** describes the location of an object with respect to a reference point. For example, Ms Briggs lives at house number 25, 200 metres east of my home.
* The average speed of an object is the ratio of the distance travelled to the time taken, and it is directionless. For example, it took Ms Briggs’ dog 40 seconds to run from her house to my house. The dog’s average speed was 5 metres per second (5 m/s).
* The change in position of an object over time describes the direction and size of its **velocity**. For example, the dog’s average velocity was the difference between the final position (0 m east) and starting position (200 m east) divided by the time taken: (0 m east – 200 m east)/40 seconds = –5 m/s east = 5 m/s west.
* The change in velocity of an object over time defines the direction and size of its **acceleration**. For example, Ms Briggs’ dog runs past my house with a starting velocity of 4 m/s west and keeps going west for another 10 seconds to my neighbour’s house where it stops, with a final velocity of 0 m/s west. The average acceleration is the difference between the final velocity (0 m/s west) and initial velocity (5 m/s west) divided by the time taken: (0 m/s – 5m/s west)/10 seconds = –0.5 m/s/s west = 0.5 m/s/s east. Note that the unit for acceleration used here is metres per second per second (m/s/s), since it measures the value of the change in velocity (m/s) every second (s).
* Force diagrams represent the different forces acting on an object using arrows. The length of the arrow shows the relative strength of each force.
* The force on one object by a second object is equal in size and opposite in direction to the force on the second object by the first (Newton’s third law).
* When something stays still or keeps the same speed in the same direction, it experiences forces but the different forces on the object balance each other out.
* If something is moving with a constant velocity, there will be no change in the velocity until the forces on the object become unbalanced (Newton’s first law).
* Unbalanced forces result in a change of motion.
* If the forces on an object are unbalanced, the object will change speed and/or direction or shape. The amount of change in speed and/or direction is affected by the mass of the object and can be calculated using Newton’s second law: where *F* = force, *m* = mass and *a* = acceleration.
* The force on an object with mass *m* due to the gravitational attraction to the mass of Earth is equal to *mg*, where *g* is the gravitational field strength at the surface of Earth, with a value of 9.8 N/kg.
* Potential energy is the energy of a body associated with an interaction with one or more other objects. A change in the position or shape of the body can result in a change in the potential energy. Examples include gravitational potential energy and spring potential energy.
* Kinetic energy is the energy that a body has due to its motion. It is equal to ½*mv*2, where *m* is the mass of the body and *v* is its speed.
* Energy may be transferred from one form to another. Some energy transfers are reversible; others are irreversible. Energy can be transferred in or out of a system of interacting bodies. The principle of energy conservation means that all energy changes must be accounted for.

Vocabulary

The table below indicates relevant vocabulary that can be used at Levels 9 and 10 to describe motion and forces.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Motion descriptors** | **Changing shape** | **Properties of objects** | **Movement** | **Forces** | **Energy** |
| * not moving (still, resting) * stationary * constant speed * constant velocity * accelerating * changing direction * instantaneous * average | * bend * stretch * squash * dent * twist | * springy * squishy | * gliding * falling * bouncing | * push * pull * rub * stick * hang * squash * stretch * drag * buoyancy * friction * tension * air resistance * gravitational * magnetic * electric | * kinetic * gravitational potential * spring or elastic potential * chemical potential * electrical potential * heat * sound * light * work |

The table below indicates relevant inquiry vocabulary that can be used at Levels 9 and 10.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Questioning and predicting** | **Planning and conducting** | **Recording and processing** | **Analysing and evaluating** | **Communicating** |
| * question * predict * suggest * same or different | * fair test * plan * use safely | * draw * video * record * observe * table * graph * represent * measure | * compare * apply * relate * find * suggest reasons * reflect * analyse * evaluate * claim * justify compare * find * suggest reasons * reflect | * display * explain * describe * model * demonstrate |

Links to the Victorian Curriculum F–10

The Victorian Curriculum F–10 content descriptions and achievement standard extracts that are applicable to each of the four learning activities have been mapped in the table below.

Science, Levels 9 and 10

| **Strand** | **Sub-strand** | **Content description** | **Achievement standard (extract)** | **Learning activity** | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **1** | **2** | **3** | **4** | **5** |
| Science Understanding | Physical sciences | The description and explanation of the motion of objects involves the interaction of forces and the exchange of energy and can be described and predicted using the laws of physics ([VCSSU133](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSSU133)) | … explain the concept of energy conservation and model energy transfer and transformation within systems … give both qualitative and quantitative explanations of the relationships between distance, speed, acceleration, mass and force to predict and explain motion | ✓ | ✓ | ✓ | ✓ | ✓ |
| Science Inquiry Skills | Questioning and predicting | Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables [(VCSIS134)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS134) | … develop questions and hypotheses that can be investigated using a range of inquiry skills … independently design appropriate methods of investigation including the control and accurate measurement of variables and systematic collection of data |  | ✓ |  | ✓ |  |
| Science Inquiry Skills | Planning and conducting | Independently plan, select and use appropriate investigation types, including fieldwork and laboratory experimentation, to collect reliable data, assess risk and address ethical issues associated with these investigation types [(VCSIS135)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS135)  Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability [(VCSIS136)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS136) | … independently improve appropriate methods of investigation including the control and accurate measurement of variables and systematic collection of data … explain how they have considered reliability, precision, safety, fairness and ethics in their methods … identify where digital technologies can be used to enhance the quality of data | ✓ | ✓ |  | ✓ | ✓ |
| Science Inquiry Skills | Recording and processing | Construct and use a range of representations, including graphs, keys, models and formulas, to record and summarise data from students’ own investigations and secondary sources, to represent qualitative and quantitative patterns or relationships, and distinguish between discrete and continuous data [(VCSIS137)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS137) | … analyse trends in data, explain relationships between variables and identify sources of uncertainty | ✓ | ✓ | ✓ | ✓ | ✓ |
| Science Inquiry Skills | Analysing and evaluating | Analyse patterns and trends in data, including describing relationships between variables, identifying inconsistencies in data and sources of uncertainty, and drawing conclusions that are consistent with evidence [(VCSIS138)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS138)  Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data [(VCSIS139)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS139) | … when selecting evidence and developing and justifying conclusions, they account for inconsistencies in results and identify alternative explanations for findings … evaluate the validity and reliability of claims made in secondary sources with reference to currently held scientific views, the quality of the methodology and the evidence cited … construct evidence-based arguments | ✓ | ✓ | ✓ | ✓ | ✓ |
| Science Inquiry Skills | Communicating | Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations [(VCSIS140)](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSIS140) | … use appropriate scientific language and representations when communicating their findings and ideas for specific purposes | ✓ | ✓ | ✓ | ✓ | ✓ |

Teacher background information

We can observe motion, changes in motion and shape; however, forces and energy are abstract concepts. We see the effects, not the force or energy specifically, which poses pedagogical challenges.

Students understand the concept of a push or a pull, however, the ‘push’ or ‘pull’ language to describe forces has some unfortunate side effects. It sounds as if forces always involve some kind of muscular effort. It makes it seem that an object has to be active – moving or trying to move – in order to be experiencing force. It also sounds as if forces can only occur where there is contact. None of these ideas are correct.

When we observe the speed of an object affected by air resistance, friction or a non-contact force such as gravity or magnetism, describing the object as affected by a push or pull is an analogy. There is no invisible person touching the object. We just use the words ‘push’ and ‘pull’ because we have such a clear mental picture of their interactive nature and their effect.

A common misconception is that objects that are not moving do not experience force. It is the case that there is no overall force on the object; however, gravity is always acting on any object, so there must be at least one other force acting on the object to balance out the effect of gravity. If gravity were the only force acting on the object, then the object would be speeding up, slowing down or changing direction. This unit identifies and represents multiple other forces that can act on the object in addition to gravity.

A key science principle is the conservation of energy in a system. This provides an alternative lens for analysing change. Energy is associated with motion and with interactions between objects and it can be transferred. From a student point of view, it is often most useful to focus on the act of transfer, rather than the total amount of energy stored in a particular mode. As a ball drops, it gets faster, demonstrating that it has acquired kinetic energy. Because the ball interacts with the mass of Earth, it has gravitational potential energy. The kinetic energy comes from the transfer of gravitational potential energy from the ball–Earth system. However, because the ball also experiences air resistance, some of the kinetic energy of the ball is transferred into kinetic energy of the air – energy that is not readily recoverable. By comparing the expected transfer of gravitational potential energy to kinetic energy of the ball, the amount of energy transferred to the air can be quantified. In this resource we present several diagrammatic tools for describing energy transfer.

Learning activities and resources

Learning activity 1: Moving along

The simplest motion to measure is an object moving in a straight line at a constant speed. What can we deduce about forces in this scenario?

Learning intentions

* Generate, record and represent position versus time data for an object moving with constant velocity
* Quantitatively determine the average speed of the object
* Identify and describe the forces acting on the object
* Explain the motion in terms of Newton’s laws of motion

Key questions

* How can we measure the speed of an object?
* What is the difference between speed and velocity?
* What forces are acting on the object?
* How are Newton’s laws of motion demonstrated in this scenario?

Activity launch

Measuring motion

**Class activity**

* Attach a string to an object such as a car, book or box and pull it across a surface in a straight line with a constant speed.[[1]](#footnote-1) Introduce the term ‘velocity’ to describe the direction of motion of the object and its speed.
* Ask students how to determine the speed of the object. Review the concept that speed or ‘how fast’ can be either how quickly an object traverses a particular distance or how far an object has travelled in a particular time. Finding speed requires knowledge of the distance travelled and the time taken to do it. Some students may already know that speed of an object is defined as the ratio of the distance travelled by the object to the time taken to travel it.
* Ask at least three students to use timing devices to record the time taken by the object to travel a specified distance.[[2]](#footnote-2)
* Calculate the average speed of the object during the motion.
* Calculate the average velocity of the object, namely the change in the position (amount and direction) divided by the time taken to move from one position to another. Note that understanding the difference between velocity and speed is important. When the direction of motion changes, the velocity changes but the speed can remain the same. For example, a runner doing laps might be maintaining the same speed but continuously changes their direction. They push their shoes sideways into the ground, and the ground pushes back, accelerating them in such a way that their direction changes but not their speed.
* In many forms of racing, the times taken to cover shorter, intermediate distances – so-called ‘splits’, such as individual laps – are recorded, as well as the total time. Discuss the advantage of the extra information given by knowledge of the ‘splits’.

Active learning

Using video analysis to measure average velocity

Class or small group activity

**Materials and/or equipment:** digital video camera, toy vehicle, string, timing device

Data acquisition:

* Pull a car across a surface at a constant velocity in front of the striped background provided in [Appendix 1: Tracking motion (template)](#App1). Each stripe has a width of 5.0 cm.
* Video the car using a device with a known frame rate (typical mobile phone video frame rates are approximately 29 fps). Review the video using simple, readily available free photo editing software and save 10 individual frames at equally spaced intervals, for example every third or fifthframe.
* Choose a point on the car as a reference point and record the frame number and the position of that point in the frame in a table (see example in [Appendix 2: Video analysis of motion of a car being pulled at a constant velocity](#App2)).

Data representation:

* Convert the frame number to the time that has passed by dividing the frame number by the frame rate.[[3]](#footnote-3)
* Illustrate on a scatter graph the change in position of the car while being pulled. Assign the time spent in motion to the horizontal axis and the position of the car to the vertical axis.

Data analysis:

* What trend does the data follow? The position will be observed to change by approximately the same amount every second. The more constant the velocity, the closer the data points will be to a linear trendline. Individual data points may lie above and below the trendline due to small variations in the speed as the car is pulled, possibly due to bumps on the surface or inability to maintain an exactly constant pace when walking. Note that a trendline **predicts** what the position of the object is likely to be between the points that were actually measured. The more consistent your data, the more confident you can be that the trendline is a good description of your system.
* Use the trendline to find a physical attribute of the motion of the car. The gradient of the trendline is the ratio of the overall change in the position of the car to the time spent travelling, that is, the average velocity of the car.
* Look at the data on a finer timescale. Calculate the average velocity of the car between saved frames by dividing the change in position between frames by the time difference between frames. Make a column graph of the average velocity versus the time interval. Students will notice that while the average velocity in each time interval is roughly constant, there is still some variation between time intervals, with average velocity in each interval varying above and below the overall average. An example is given in [Appendix 3: How average is average velocity?](#App3)Emphasise that if the measurement time is shorter, then the knowledge of how the speed varies becomes more detailed. Introduce the term ‘instantaneous’ for when the time interval becomes so narrow that the width of the column becomes a spike.
* Discuss how the nature of speed and velocity is reflected in the measurement unit ‘metres per second’. Explore the concept of using different units, for example kilometres per hour, and how to convert from one to another. Emphasise the importance of specifying the unit of measurement so that measurement values can be meaningfully compared.
* Use your data to make predictions. When would one car overtake another? How much of a head start should it be given in a handicap race?

Teacher note: There are many options for equipment choices, data recording methods and analysis tools for this activity. You could use battery-powered cars that are designed to move with a constant speed and stopwatches to measure time intervals. Alternative data-logging devices include ticker tape and ultrasonic motion sensors. Ultrasonic motion sensors can enable measurements to be taken over shorter time intervals. More sophisticated video motion analysis can be undertaken using freely available software such as Tracker.

**Linking motion, interactions and force**

Class discussion

* According to Newton’s second law, an overall force on a body causes it to speed up, slow down and/or change direction of motion. The speed and direction of motion in this case are essentially constant. What does this imply about the overall force on the car?
* Draw a diagram indicating all the contact and non-contact interactions that the car experiences. Identify a force on the car associated with each interaction and draw a corresponding force arrow.
* Conclude that because the car is maintaining the same speed without changing direction, the different forces acting on the car must balance each other out.
* Specify which forces have the same magnitudes and make any necessary adjustments to the diagram. An example diagram and accompanying notes are given in [Appendix 4: Interactions and forces (example diagram and notes)](#App4).
* What does Newton’s first law predict about the future motion of the car? What kind of events could result in a change in speed and/or velocity? What forces would be involved?
* Challenge students to give other examples of an object moving in a straight line at constant speed, identify all the interactions and accompanying forces on the object, and explain how the forces on the object balance each other out.
* When the person stops pulling the car, it slows down, coming to a stop quite quickly. Use Newton’s second law to explain this observation.

Further investigation

How is speed measured in everyday applications? How does a car speedometer work? How accurate is it? What is ‘LIDAR’ and how is it used to measure speed? How do speed cameras work?

Learning activity 2: Gravitational consequences

How big is the gravitational attraction between a mass and Earth, and how does it affect motion? Use simple scenarios of a mass stretching a spring and a ball dropping to the ground to explore the nature of gravity and Newton’s laws of motion.

Learning intentions

* Observe that the size of the gravitational force on an object depends on the mass of the object
* Generate, record and represent velocity versus time data for a falling object
* Quantitatively determine the average acceleration of an object
* Explain the observed motion of a falling object using Newton’s laws of motion

Key questions

* How does the size of the force of gravity depend on the mass of the object?
* What else affects the size of the force of gravity?
* How is motion affected by gravity?

Activity launch

How strong is gravity?

**Materials and/or equipment:**mass, a spring or rubber band, suspension point

Review the concept of balanced versus unbalanced forces and gravitational attraction with the following demonstration.

* Suspend a mass (an object in a cup, or slotted masses on a mass hanger) from a rubber band or spring and wait until the mass has stopped moving.
* Get students to sketch a force diagram showing all the forces on the mass when it has stopped moving, such as the diagram below.

*F*G, gravitational force on mass by Earth’s mass



*F*T, tension force on mass by spring

spring suspended from a rod and stretched by a hanging mass

unstretched spring suspended from a rod



* Note that because the mass is no longer moving, all the forces on the mass must balance each other out.
* Predict what will happen if the value of the mass is increased.
* Increase the mass and observe the change in the length of the spring. Explain your observation. How is the tension in the spring affected by the mass? (As the spring stretches, its tension increases.) How large is the spring tension? (It is the same size as the gravitational force on the mass, but in the opposite direction, balancing it.) How is the gravitational force affected by the value of the hanging mass? (As the mass value increases, the spring stretches, indicating that the tension in the spring and the downward pull on the mass by Earth’s gravity are increasing.)

Active learning

Getting quantitative with gravity

Class or small group activity

**Materials and/or equipment:** Newton meters (spring balances); retort stands with boss heads and clamps or some other point to suspend balance from; sets of hanging masses[[4]](#footnote-4)

A Newton meter, or spring balance, contains a spring that stretches when a force is applied to it. The greater the stretch, the greater the force. The markings on the side of the meter indicate how much force it takes to stretch the spring to a particular length.

* Fix a clamp to a retort stand and hang a Newton meter from the clamp. Adjust the meter so that the force reading is zero newton (0 N) when there is no mass hanging from it.
* Hang a mass of known value from the Newton meter and support it until it hangs freely without moving. Record the value of the mass in kilograms (kg) and the Newton meter force reading in newtons (N) in a table. Repeat this step for a range of masses.
* What trends do students observe? What happens to the force reading on the Newton meter when the mass is doubled? And tripled? Graph the results on a scatter graph.
* Calculate the ratio of the force to mass. Does it change or stay the same?
* Try holding the Newton meters at different heights above the ground. Do the readings change? What does this tell you about the nature of gravitational force?
* What do students conclude about the relationship between the force on the Newton meter and the mass hung from the meter? What does this tell them about the relationship between the force due to gravity on the mass and the value of the mass?
* Discuss the significance of the value of the ratio of the force to the mass. Is this value likely to be the same or different on the surface of the Moon? Explain the reason for your answer.[[5]](#footnote-5)

Measuring the effect of gravity on a falling ball

Class or group activity

**Materials and/or equipment:** digital video camera, table tennis ball

In this activity, the average acceleration of a ball is found by dividing the overall change in velocity of the ball by the time between the initial and final measurement. As the ball drops, the average velocity increases. It can be found by dividing the measured change in position by the time between position measurements.

Teacher note: The following instructions are for using a phone camera and basic photo editor to obtain data, however, the data can also be obtained using a more sophisticated data logger, such as an ultrasonic motion detector, and video data could be analysed with freely available video analysis software such as Tracker.

* Drop a table tennis ball from a height of 2.0 metres in front of a printout of the template in [Appendix 1: Tracking motion (template)](#App1) and video the falling ball.
* Review the video using imaging software and save 5–10 individual frames at equally spaced intervals. The velocity of the ball increases rapidly, causing the image to blur. Using a 30 fps camera, the best results will be obtained using every frame until the motion is too blurry to accurately measure the position of the ball.
* Fill in the following table using the data obtained from the images.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Frame, *n*** | **Time, *t***  **(s)** | **Height, *h***  **(m)** | **Change in time, Δ*t***  **(s)** | **Change in height, Δ*h***  **(m)** | **Velocity, *v***  ***v* = Δ*h*/Δ*t***  **(m/s)** |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

* Use a scatter graph to illustrate how the average velocity varies during the first five time intervals and include a linear trendline for the data.
* Find the average acceleration of the ball by calculating the total change in velocity divided by the interval between the initial and final measurement. Which feature of the graph does this value correspond to? Students should identify that the acceleration is the gradient of the speed versus time graph.
* Newton’s second law says that the overall force on an object is equal to its mass times its acceleration. Sketch a force diagram for the ball. A typical sketch is shown below.

The green arrow indicates the force of gravity on the ball.

The orange arrow indicates the force of air resistance on the ball.

Over such a small distance air resistance is not likely to be significant, so the overall force is essentially the force due to gravity.

*F*G

*F*air resistance

* Based on the Newton meter activity above or on other prior knowledge, calculate the weight of the ball – that is, the value of the force due to gravity on the ball’s mass (9.8 N/kg × the mass of the ball).
* Calculate the overall force on the ball using your value for acceleration and the mass of the ball. Compare with the value from the Newton meter activity.
* In freefall, the only force acting on a falling object is the gravitational force, and the size of the acceleration experienced by the object equals *g*. How close is this scenario to freefall?
* Is air resistance significant in this experiment? Explain. (If air resistance is small enough to be ignored, then the overall force on the ball should equal the force due to gravity on the ball’s mass, which was measured directly using the Newton meter. If there is significant air resistance, then the overall force on the dropping ball will be smaller than the weight measured by the Newton meter.)
* If air resistance is not significant, how does the acceleration depend on the mass of the ball? (If air resistance is not significant, then the overall force on the ball, which by Newton’s second law equals the mass of the ball times its acceleration, is the same as the gravitational force on the ball, *mg*, where *m* is the value of the mass of the ball and *g* is the gravitational field strength. This means that if there is no air resistance, the acceleration of the ball must be the same as the gravitational field strength and that the mass of the ball does not affect its acceleration. The ball is in freefall. If there is no air resistance, a heavy ball gains speed at exactly the same rate as a light one. A spectacular demonstration of this has been filmed by physicist Brian Cox, who drops a feather and a bowling ball in a 50-metre-high tower that has had all of the air pumped out – see the first 3 minutes and 50 seconds of [Brian Cox visits the world's biggest vacuum | Human Universe, BBC, YouTube](https://www.youtube.com/watch?v=E43-CfukEgs). The two objects clearly increase speed at exactly the same rate.)

Further investigation

Safety in vehicle design is concerned with reducing the forces experienced by passengers in vehicles in collisions. Design an experiment to investigate how the structure and choices of materials in vehicle construction affect the average force experienced by a car hitting a stationary object, such as a traffic light, by measuring the time over which the collision occurs.

Learning activity 3: Moving energy

This activity explores motion from an energy viewpoint, unpacking energy changes that occur and representing them in diagrams.

Learning intentions

* Identify, describe and represent energy associated with the motion and position of an object
* Know that moving objects have kinetic energy, which increases as their mass and/or speed increases
* Know that objects that repel or attract each other have potential energy, and that allowing objects attracted to each other to move closer together increases their potential energy and that allowing objects that repel each other to move further apart decreases their potential energy
* Associate processes such as changes in shape, position, motion, temperature, production of sound, heat and/or light with a change in energy
* Use the principle of conservation of energy to qualitatively describe the transfer of energy between parts of a system

Key questions

* What changes occur during motion?
* How is energy transferred during motion?
* How much energy is transferred?

Activity launch

Energy and energy transfer

Class discussion

* Conduct a brainstorm activity. What comes to mind when students think about energy? What are examples of things/phenomena associated with lots of energy? Batteries? Objects moving at high speeds?
* Organise the student responses, possibly using a Venn diagram, according to the key contributions to the energy of the system: energy of motion (kinetic energy), energy associated with attraction or repulsion (potential energy), and energy emitted in the form of light, sound and heat.
* Consider the following scenarios: hitting a window with a ball; hammering in a nail; sliding down a slippery dip; jumping off a diving board; using a water mill to grind flour. What actions are taking place? Is there a change of shape, position, motion or temperature, or a production of sound, light and/or heat? What evidence is there for energy transfer? What has experienced a change in energy? How was that energy transferred?
* Introduce/review the key physics idea that there can be changes in energy but that the total amount of energy stays the same (principle of conservation of energy). If a particle or object gains speed, increasing its kinetic energy, then some other aspect of the system must have decreased in energy. Any gain in energy of one aspect of a system must be matched by a decrease in energy associated with another.
* Scaffold the completion of an energy transfer summary template, using an example such as the following.

|  |  |  |  |
| --- | --- | --- | --- |
| **Scenario** | **Evidence for energy transfer** | **How energy was transferred** | **Energy changes** |
| Ball hits window | 1. Ball changes speed  2. Glass changes form  3. Sound is produced | 1. Ball pushes on window, window pushes back, slowing the ball  2. & 3. Impact of ball stretches the glass, changing the bonds between the particles and making it vibrate | 1. Kinetic energy of the ball decreases  2. Energy of glass increases as it is deformed  3. Sound and heat are produced where components vibrate |

Active learning

Detecting energy transfers – finding clues for energy change

Class or small group activity

**Materials and/or equipment:** A3 paper sheets with energy transfer summary templates (created in the Activity launch); pads with three colours of sticky notes or cards; set of energy transfer scenarios involving gravitational potential energy and kinetic energy (bouncing on a pogo stick, walking up the stairs, dribbling a ball, bungee jumping, being on a swing, riding a rollercoaster, serving a tennis ball, grinding flour with a water mill, downhill skiing, going down a water slide)

* Assign each group an energy transfer scenario.
* Students record evidence for energy transfer on one coloured card, causes of energy transfer on a different coloured card and changes in energy on a third coloured card. They place the cards on the A3 sheet under the appropriate heading.
* Rotate scenarios. Each group annotates the work of the previous group.
* Choose one group to present to the rest of the class their analysis of the scenario and their critique of the contribution of the other students.
* Return the templates to their original groups so that students can make any further additions and finalise their responses before presenting to the class.

Mapping energy changes

* Explore different ways of representing energy transfer in a diagram, such as those described and illustrated in [Appendix 5: Representing energy transfer](#App5).
* In the same groups as for the previous activity, each member of the group should draw a different representation of the flow of energy in the original scenario.
* Discuss and compare the representations made by each group member:
* Is the evidence for energy transfer visible? Does one diagram show it more clearly?
* Which one best describes how the energy is transferred?
* Do all the diagrams show how much energy was transferred? Are they qualitative or quantitative?
* Is the principle of conservation of energy clearly seen in the diagram?

Further investigation

Some energy changes are regarded as more useful than others. In cogeneration, so-called ‘waste energy’ (usually heat produced) is used in a second process. At Ashburton Pool and Recreation Centre, an engine is used to produce electricity for running the centre. Heat produced by the engine, which would usually be regarded as ‘waste’, is used to heat the water for the pool.

Learning activity 4: Energy budgeting

This activity revisits the pulled cart and falling object scenarios quantitatively, from an energy perspective.

Learning intentions

* Express the kinetic energy of an object quantitatively as
* Express gravitational potential quantitatively as , where *h* is the height measured with respect to a reference point
* Analyse the motion of accelerating objects using the principle of conservation of energy

Key questions

* What is the evidence for energy transfer in these scenarios?
* How is energy transferred?
* How much energy is transferred?

Activity launch

Using an energy budget

Class discussion

* Observe the car from Learning activity 1 moving at constant velocity. Is there a change of shape, position, motion or temperature, or a production of sound, light and/or heat?
* Consider the motion and forces experienced by the car and list the associated forms of energy, which should include:
* energy of motion – kinetic energy of the car[[6]](#footnote-6)
* energy used by the person to activate their muscles and exert and maintain pulling force on the car – chemical energy
* energy associated with gravitational interaction between the car and Earth – gravitational potential energy
* energy associated with the interaction between the car and the ground and the air – energy transferred into heat, sound and/or irreversible surface changes, which collectively is described as dissipated energy.
* How is energy transferred here? (The conversion of energy in muscles to maintain pulling force is ultimately the same amount as the energy dissipated in friction and air resistance, processes that will cause some heating of the air and surfaces and initiate some sound.)
* Where are changes occurring?
* Explore the use of diagrams to show the energy transfer. Can the conservation of energy be shown quantitatively (see [Appendix 5: Representing energy transfer](#App5)).
* What happens when the person stops pulling the car? (It is likely to come to a stop quite quickly.) Explain this observation using the principle of energy conservation. How much energy is transferred to friction and air resistance?

Active learning

Energy budgeting for a moving car

Individual or group activity

Consider the following scenario. A car is pulled by a person. The car starts from rest, reaches a steady speed after 2.0 seconds, and continues on at a steady speed for another 4.0 seconds. The person then stops pulling and the car slows to rest by 8.0 seconds. Draw a set of energy transfer bar charts to describe this scenario. An example is given in [Appendix 6: Energy transfer bar charts – charting energy over time (examples)](#App6).

What does the energy value of your food need to be so that you can carry out this activity? (Sample answer: The energy value of your food needs to equal the kinetic energy that the car acquires plus the energy required to overcome friction while pulling at constant speed.)

What would you add to your energy transfer charts if you were describing a motor car starting from rest, accelerating to 30 km/h, continuing at 30 km/h for 50 metres and then coming to a stop? Where is it likely that most of the fuel is consumed?

Extension activity

The transfer of energy that occurs when a force is applied to an object as it changes position is called ‘work’. It is the product of the average force along the direction moved multiplied by the distance moved. Use a Newton meter to measure the force on the car as it is pulled along. How much work is done moving the car along 2.0 metres? How much energy is transferred due to friction and air resistance?

Energy changes for a dropping ball

Individual or group activity

* Draw a sketch illustrating the motion of a falling ball and the forces acting on the ball.
* List the energies that are involved as the ball drops. (The list should include energy of motion of the ball, energy associated with interaction of the mass of the ball with the mass of Earth, energy associated with interaction of the ball with the air.)
* The kinetic energy, , of the ball can be calculated from knowledge of its mass, , and velocity, , using the formula, .
* Use the data from the previous activity to fill in the following table.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Time, *t***  **(s)** | **Height, *h***  **(m)** | **Change in time, Δ*t***  **(s)** | **Change in height, Δ*h***  **(m)** | **Average velocity, *v***  ***v* = Δ*h*/Δ*t***  **(m/s)** | **Kinetic energy, *EK***  ***E*K = ½*mv*2**  **(J)** |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
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|  |  |  |  |  |  |

* Represent the change in forms of energy as the ball drops, using an energy transfer bar chart. An example is given in [Appendix 6](#App6).
* Graph the kinetic energy versus change in height for the first five time steps. Where does the increase in kinetic energy come from? How do you think gravitational potential energy depends upon height?

Up in the air

Individual or small group review activity

When you throw a ball directly upwards, its speed is greatest when it leaves your hand. As the ball gets higher it slows down, until it reaches its maximum height when it is no longer moving. The ball then starts to fall back down towards you, gradually increasing its speed.

Ask students to give two explanations for the behaviour of the ball between when it leaves their hand and when it reaches its maximum height using:

1. Newton’s second law (include a force diagram for the ball in the explanation) and
2. the principle of conservation of energy (include an energy transfer bar chart or other appropriate diagram in the explanation).

Typical explanations will include:

1. The ball has an initial upwards velocity when it leaves your hand. After it leaves your hand, only the force of gravity is acting on the ball, which is pulling it downwards, causing the velocity of the ball to decrease. The velocity is still upwards, but the size is smaller. The ball gets slower as it gets higher until it reaches its maximum height when the velocity of the ball is zero …
2. The ball has an initial kinetic energy when it leaves your hand. As the ball rises, it is getting further away from the surface of Earth, so its gravitational potential energy associated with the interaction between the ball and Earth increases. The increase in gravitational potential energy comes at the expense of the kinetic energy, so the ball slows down, until it reaches a maximum height when all of the kinetic energy has been transferred into gravitational potential energy …

Extension activity: Tilting the table

Using the materials and equipment from Learning activity 1, place the car on a gently sloping plank or table and tape the printed bars (from [Appendix 1](#App1)) along the edge of the table. This will allow the height and change in position of the car to be easily measured. Make sure that the table slope is steep enough that when the car is placed on the slope, it starts to roll. Gravity will now pull the car along the surface of the table. The steeper the slope, the faster the car is moving when it gets to the bottom of the table.

Video the car and graph the average speed versus time and describe how the kinetic energy of the car changes as the height of the car changes. What do you notice? Where does the increased kinetic energy come from?

Teachers may discuss that only some of the gravitational attraction on the car by Earth contributes to the overall force on the car. The steeper the slope, the greater the proportion of the gravitational attraction contributing to the overall force on the car. Alternatively, the steeper the slope, the greater the change in height of the car, so the more gravitational potential energy available for converting into kinetic energy.

Further investigation

Research the freefall achievements of Austrian skydiver and BASE-jumper Felix Baumgartner. What energy changes occurred when he jumped? What speeds was he able to achieve? See the following lesson resource, including a data download, about Baumgartner’s record-breaking ‘Stratosphere jump’: [Stratos Jump Data Analysis (Science World)](https://www.scienceworld.ca/resource/stratos-jump-data-analysis/).

Learning activity 5: Bouncing back

This activity extends the exploration of energy transfer to the rebound of a ball or even a bungee jumper!

Learning intentions

* Monitor transformation from kinetic energy to gravitational potential energy and spring or elastic potential energy
* Distinguish between reversible and irreversible energy transfer
* Evaluate energy transfer efficiency

Key questions

* What affects bounce height?
* What is the difference between a super ball and an ordinary rubber ball?

Activity launch

We observe the transformation of gravitational potential energy to kinetic energy and back again all around us: when a ball bounces, when a child enjoys a swing, when we play with a yo-yo. Discuss these examples and ask: How efficient is the transfer of energy in these cases? Efficiency is the ratio of the amount of desired final energy form to the initial available energy.

Active learning

Measuring efficiency

Small group activity

**Materials and/or equipment:** digital recording device, ball

Ask students to complete the following activity.

* Work with two or three other students and choose a situation to film in which gravitational potential energy is converted to kinetic energy and back again. Your aim is to determine the efficiency of energy transfer for your situation.
* Film the situation. Note, it is important that you maintain a constant zoom throughout the video and that you do not move the camera (unless you have a visual reference point for measuring position).
* From your video, obtain data for the position of the object at suitably spaced times. Measure the mass of the object.
* Keep a record of all your notes, observations and data in your logbook.
* Using this data calculate the kinetic and gravitational potential energy of the system. Graph the kinetic and gravitational potential energy, as well as the sum of the kinetic and gravitational potential energy. Does the total remain constant? Does the total behave as you would expect? Have you accounted for all interactions in this activity? Is air resistance significant? Are there sources of friction? Undertake multiple trials to test the repeatability of your results.
* Compare the transfer of energy from gravitational potential energy to kinetic energy and back to gravitational potential energy. What percentage of the gravitational potential energy is recovered? How efficient is this situation?
* Propose further investigation of factors that could be investigated that might affect efficiency.

Which kinds of energy changes are reversible in your scenario? Which kinds are not? Discuss how reversibility and irreversibility are related to efficiency in this scenario. Note that not all efficient processes are reversible!

**Teacher note:** An advanced version of this activity would be to model a bungee jumper by investigating the motion of a soft toy suspended from an elastic exercise resistance band. The soft toy experiences varying force as the resistance band changes length. Students can observe kinetic energy being transferred to elastic potential energy in the band as the band stretches, and elastic potential energy transformed back to kinetic energy as the band returns to its initial length.

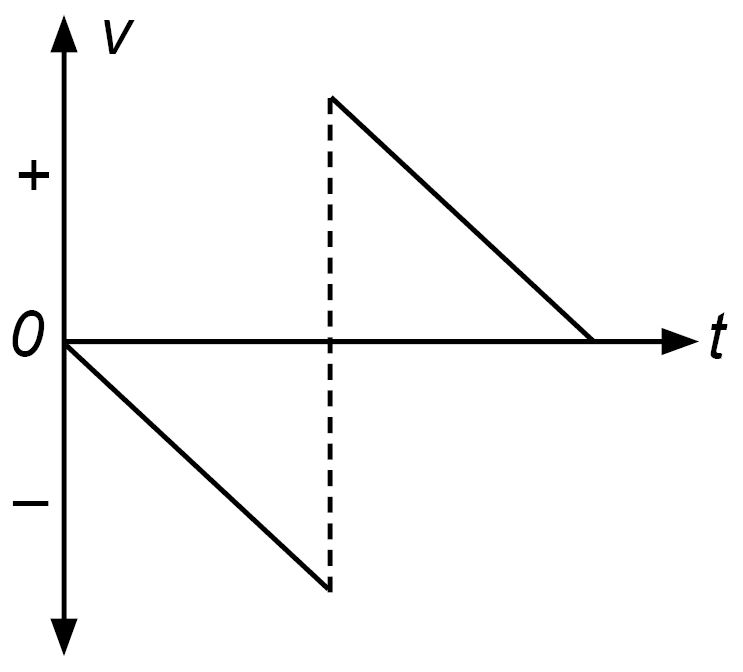
Extension activity

What forces act on the ball as it falls and then bounces?

What does a sketch of the velocity of the ball versus time look like?



Sample response:



Dropped ball has initial velocity of zero. Increases in the downward (negative) direction, contacts the ground, comes to an abrupt stop and then is reset to a high positive velocity (moving upwards) and gradually slows down.

This sketch does not capture the detail of the change in velocity when the ball is in contact with the ground.

As the ball falls it experiences a downward force due to gravitational attraction of Earth and a small amount of air resistance upward. The overall force is downward, so the ball’s velocity keeps increasing in the downward direction until it touches the ground.

When the ball touches the ground, it starts to compress. The ball applies force to the ground both because the gravitational pull of Earth pushes it into the ground and because it is compressing. Applying Newton’s third law, there is an equal-sized upward force on the ball by the ground. The overall force on the ball is the difference between the upward force on the ball by the ground and the downward pull on the ball by Earth’s gravity. The compression of the ball means that the upward force on the ball is greater than the downward force on the ball, so the ball accelerates upwards, first reducing its downward velocity to zero and then increasing its upward velocity and lifting off the ground.

After lift-off, the only forces acting on the ball are the downward pull of Earth’s gravitational attraction and the downward push of air resistance, so the velocity of the ball gradually decreases until it reaches its maximum bounce height.)

Assessment ideas

Pre-assessment

The activity launches in all activities will demonstrate student prior knowledge. In Learning activity 1 the activity launch connects constant velocity motion and experiencing balanced forces; in Learning activity 2 it explores the effect of unbalanced and balanced forces in the context of gravity; in Learning activity 3 it qualitatively probes the concept of sources of energy and energy transfer; in Learning activity 4 it quantitatively explores energy sources and transfers; and in Learning activity 5 it introduces the concept of efficiency in the context of transforming between gravitational potential and kinetic energy.

Ongoing formative assessment

Teachers may find it helpful to refer to the rubric in [Appendix 9: Assessing Science Understanding](#App9) for a guide to assessing conceptual understanding mapped against the Victorian Curriculum F–10: Science.

* Learning activity 1 offers opportunities for formative assessment of representation of forces and motion, the understanding of the effect of friction on the motion of the car, and factors that affect friction.
* Learning activity 2 allows for formative assessment of the concept that when forces are unbalanced there is a change in shape and/or motion and the ability to assign a value and direction to the gravitational force on a mass by Earth.
* Learning activity 3 provides opportunities to assess student comprehension of the nature of energy and the principle of energy of conservation.
* Learning activity 4 allows for formative assessment of the quantitative transfer from gravitational potential energy to kinetic energy.
* Learning activity 5 allows for formative assessment of students’ understanding of the concept of efficiency in the context of energy transfer. The activity also allows for formative assessment of students’ understanding of specific energy transformations involved in motion; for example, when a ball bounces, energy is transferred from gravitational potential energy to kinetic energy to elastic potential energy and back to kinetic energy and then gravitational potential energy.

Summative assessment

Teachers should use relevant sections of the Levels 9 and 10 achievement standard to develop assessment tasks. For example, in assessing the content description ‘The description and explanation of the motion of objects involves the interaction of forces and the exchange of energy and can be described and predicted using the laws of physics ([VCSSU133](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSSU133))’, the relevant part of the achievement standard is ‘They explain the concept of energy conservation and model energy transfer and transformation within systems … [and] give both qualitative and quantitative explanations of the relationships between distance, speed, acceleration, mass and force to predict and explain motion’.

Teachers should note that:

* the term ‘laws of physics’ applies to both Newton’s laws of motion and the law of conservation of energy
* ‘model energy transfer and transformation’ may involve physical modelling or may include other representations such as diagrams
* qualitative explanations may include the use of force arrows
* quantitative explanations may involve the use of formulas and/or force arrows that show relative magnitudes of forces
* both qualitative and quantitative predictions should be included in assessment tasks and may be assessed separately in relation to different scenarios and/or in a single task where students are required to provide both qualitative and quantitative responses to a single scenario.

Some of the learning activities in this resource may be used/adapted as summative assessment tasks.

A sample summative assessment in which students investigate the dependence of acceleration on applied force is given in [Appendix 7: Modified Atwood’s machine (sample assessment task)](#App7).

A second sample summative assessment, in which students design a food aid delivery system in the context of an air drop, is given in [Appendix 8: Food aid drop scenario (sample assessment task)](#App8). This assessment allows students to demonstrate their ability to measure and analyse energy transformations and the effect of forces on food aid parcel.

Other resources

* Tytler, R & Hubber, P 2005, ‘Force and motion’, Ideas for Teaching Science: Years P–8, Resources for Teaching Science, Deakin University, https://blogs.deakin.edu.au/sci-enviro-ed/early-years/force-and-motion
* The Australian Academy of Science has produced freely available online resources aligned to the Australian Curriculum on their Primary Connections website, <https://primaryconnections.org.au>. It is the responsibility of teachers to check that these activities are aligned to the Victorian Curriculum F–10.

Appendices

Appendix 1: Tracking motion (template)

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Appendix 2: Video analysis of motion of a car being pulled at a constant velocity.

The data in the table below have been captured from a video of someone pulling a car at a constant velocity. Every fifth frame has been saved as a still image. Frame 0, 5 and 10 are shown below. The position of the car at the time of each of the still images is recorded in the table below. The graphed data points fit well to a linear trendline. The position of the car changes by a similar amount every five frames; that is, the car is moving at a constant velocity.

The calculated average velocity is the change in position divided by the time taken, which is equivalent to finding the gradient of the trendline, which in this case is 57 cm/s. The position of the car changes by an average of 57 cm every second; that is, the average velocity of the car is 57 cm per second towards the person pulling.



|  |  |  |
| --- | --- | --- |
| **Frame number** | **Time taken (s)** | **Position (cm)** |
| 0 | 0.00 | 0 |
| 5 | 0.17 | 9 |
| 10 | 0.33 | 18 |
| 15 | 0.50 | 29 |
| 20 | 0.67 | 37 |
| 25 | 0.83 | 45 |
| 30 | 1.00 | 53 |
| 35 | 1.17 | 64 |
| 40 | 1.33 | 75 |
| 45 | 1.50 | 86 |
| 50 | 1.67 | 97 |

Appendix 3: How average is average velocity?

In the table below, the average speed during each individual time interval has been calculated. The average speed for each time interval is also shown in the column graph below. The orange line is the average speed for the data over the whole time period. You can see that there are small variations in the speed as the car moves along, maintaining the same direction.

Note: The smaller the time interval compared to the total time of the motion, the more information there is about the variation of the speed during the motion.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Frame number** | **Change in time (s)** | **Position (cm)** | **Change in position (cm)** | **Average speed (cm/s)** |
| 0 |  | 0 |  |  |
| 5 | 0.17 | 9 | 9 | 54 |
| 10 | 0.17 | 18 | 9 | 54 |
| 15 | 0.17 | 29 | 11 | 66 |
| 20 | 0.17 | 37 | 8 | 48 |
| 25 | 0.17 | 45 | 8 | 48 |
| 30 | 0.17 | 53 | 8 | 48 |
| 35 | 0.17 | 64 | 11 | 66 |
| 40 | 0.17 | 75 | 11 | 66 |
| 45 | 0.17 | 86 | 11 | 66 |
| 50 | 0.17 | 97 | 11 | 66 |

Appendix 4: Interactions and forces (example diagram and notes)

Pulling force on the car by person

Forces on car from the ground opposing sideways motion of the car. There will also be a small contribution from air resistance. The relative sizes will be affected by the speed of the car

Gravitational force on car by Earth’s mass

Upwards force on car from ground opposing downwards compression of ground by the car

|  |  |  |
| --- | --- | --- |
|  | **Interaction type** | **Force on car by …** (naming the partner in the force and the direction of the force) |
| Car mass is attracted to mass of Earth (gravity) | gravity (non-contact) | Downwards force on car by Earth’s gravitational attraction |
| Car pushes air out of the way as it moves | air resistance (contact) | Force on car by the air, opposite to direction of motion |
| Car wheels roll along the ground, pushing down into the ground and slipping along the ground in the direction of motion | compressing (contact)  friction (contact) | Force on car wheels upwards by ground (opposing the compression of the ground by the car)  Force on car wheels by ground opposite to the direction of motion (opposing the forward push of the wheels on the ground as they are dragged forward, resulting in the wheels rolling) |
| Car is pulled by a string | pull (contact) | Force on car by string (equal to force on string by person pulling) |

Appendix 5: Representing energy transfer

Energy transfers can be represented using different types of diagrams. Here we take two examples involving energy transfer – (A) an example of a ball hitting a glass window and (B) the example in Learning activity 1 of an object moving with a constant velocity – and illustrate the use of four particular diagrams.

Example A: Ball hitting a glass window

Energy transfer diagram

Each block is a component of the system. Arrows indicate energy flow from one block to another from before the ball hits the window to afterwards. The word or words in brackets specify the change in energy of the block.

Kinetic energy from the ball is transferred to the glass. Some is retained by the glass due to the change in shape of the glass and vibrations in the glass. Some is transferred from the glass into the environment (dissipated) as sound and heat.

ball  
(kinetic)

glass  
(internal)

environment  
(sound, heat)

Sankey diagram

A Sankey diagram illustrates energy flow from one component of a system to another over time using an arrow, where the width of the arrow indicates the amount of energy transferred into each system component.

This diagram shows that the ball still has some kinetic energy after impact but that most is transferred into the glass as a change in the spacing between the glass particles and increased motion of the glass particles. The glass then transfers some energy as heat and sound, which dissipates into the environment.

kinetic

sound,   
heat

internal

Ball hits glass

The Sankey diagram also captures a key physics principle. Energy is a property of a system or object. The energy of a component of the system can change, but any change has to be accounted for. Any change in energy of an object or system is matched by a change in energy in another object or part of the system. This is the principle of conservation of energy.

Energy bar chart

The circle lists the components of the system. The bar graph on the left shows the contributions to the energy of the system before the ball hits the window and the bar graph on the right shows the contributions to the energy of the system afterwards. Sometimes, the amount of energy associated with a particular component – for example, in this case, the internal energy of the window before and after – is not known exactly. In this case the diagram just indicates the change in energy of that component but is not to scale. If the energies can be quantified, then a scale is added to the vertical axis.

Energy

Energy

**Key:** kinetic internal sound, heat

Energy transfer bar chart

The circle contains the components of the system. Each bar shows a change in energy in the system, with bars below the horizontal axis being a reduction and bars above being a gain. The actual values are not known, so the bars are not to scale.

The ball’s kinetic energy decreases and the internal energy of the glass increases. Some energy is also dissipated into the environment as heat and sound.

+

-

Energy change

**Key:** kinetic internal sound, heat

Example B: A car moves at constant velocity, pulled by a person across the ground

Energy transfer diagram

Each block is a component of the system. Arrows indicate energy flow from one block to another from before the ball hits the window to afterwards. The word or words in brackets specify the change in energy of the block.

The person pulls the car so that it maintains a constant speed and unchanging direction. This means:

* there is no change in the kinetic energy of the car
* the internal energy of the person decreases as they supply energy to maintain the contraction of their muscle and their motion
* heat due to friction between the car and ground and sound due to the rubbing of the car and ground are produced.

If the car is particularly heavy, there could be some permanent deformation of the ground, raising its internal energy.

person  
(internal)

environment (sound, heat)

(sound, heat)

car (kinetic, sound, heat)

The longer the car is pulled, the more energy is transferred to the environment. If the speed stays the same, then the amount of energy transferred into kinetic energy does not increase.

Sankey diagram

A Sankey diagram illustrates energy flow from one component of a system to another over time using an arrow, where the width of the arrow indicates the amount of energy transferred into each system component.

This diagram shows that due to the motion of the car, internal energy from the person decreases and becomes heat and sound that spreads through the environment. In this case, the initial time is taken to be when the person starts to pull the car, so there is also some energy transferred to the kinetic energy of the car.

sound, heat

internal

car moving at constant speed

kinetic

kinetickinetic

As time passes, the consumption of the initial reserve of internal energy of the person will increase and the amount contributed to the environment will increase. The kinetic energy of the car will stay the same until the person ceases to pull.

Energy bar chart

The circle contains the components of the system. The bar graph on the left shows the contributions to the energy of the system at a starting time – in this case, sometime after the person has begun to pull and the car is moving with a constant speed. The bar graph on the right shows the contributions to the energy of the system at a later time – in this case, when the car is still being pulled with the same speed. The internal energy of the person pulling has reduced by an amount corresponding to the energy dissipated due to friction such as that between the wheels and the surface and the accompanying production of heat and sound.

Energy

Energy

**Key:** kinetic internal sound, heat

Energy transfer bar chart

The circle contains the components of the system. Each bar shows a change in energy in the system, with bars below the horizontal axis being a reduction and bars above being a gain. The actual values are not known, so the bars are not to scale.

**Energy change**

**increase +**

**no change 0**

**decrease −**

**Energy forms**

**Key:** internal energy of person pulling kinetic energy of car   
gravitational potential energy dissipated

Note:

* The car keeps moving at a constant speed, so there is no change in its kinetic energy.
* The separation of the car from Earth does not change, so the gravitational potential energy is constant and there is no change in the gravitational potential energy between the car and Earth.
* Energy is being dissipated mainly due to the frictional interaction with the ground. This energy is being transferred from the person pulling the car.[[7]](#footnote-7) The person draws upon the energy stored in their body to pull on the car. Their energy reserves are decreased by the same amount as the energy dissipated in frictional interactions and production of heat and sound as the car moves.

Appendix 6: Energy transfer bar charts – charting energy transfer over time (examples)

A student videos the motion of a car being pulled in a straight line along level ground by their friend. The car starts from rest, reaches a steady speed after 2.0 seconds, and continues on at a steady speed for another 4.0 seconds. The person then stops pulling and the car slows to rest by 8.0 seconds.

After looking at the video, the students suggest the following set of charts to describe the energy transfer occurring during the motion of the car.

They decide that the kinetic energy of the car changes during the motion, as does the chemical potential energy of the person pulling the car, and there is energy dissipated in the form of heat and sound due to friction and air resistance.

**Key to energy forms:**  chemical potential of person pulling car kinetic energy of car sound, heat

**Energy transferred between forms from 0 to 2 seconds**

**Energy transferred between forms from 2 seconds to 4 seconds**

**Energy change**

**increase +**

**no change 0**

**decrease −**

**Energy forms**

**Energy change**

**increase +**

**no change 0**

**decrease −**

**Energy forms**

**Energy change**

**increase +**

**no change 0**

**decrease −**

**Energy forms**

**Energy change**

**increase +**

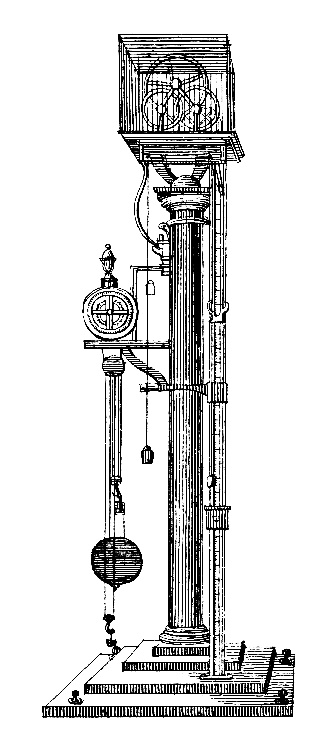
**no change 0**

**decrease −**

**Energy forms**

**Energy transferred between forms from 6 seconds to 8 seconds**

**Energy transferred between forms from 4 seconds to 6 seconds**

Appendix 7: Modified Atwood’s machine (sample assessment task)

George Atwood was a mathematician who invented an experiment for testing Newton’s second law around 250 years ago. The apparatus he used is shown in the illustration on the right.

The following can act as a basis for an assessment task involving reporting on and analysing experimental data. The task can be scaffolded, as appropriate.

**Aim:** To investigate the relationship between applied force and acceleration

**Background:** In the set-up shown below, the cart and the hanging mass accelerate together when the cart and mass are released. This is because there is an overall force on the cart-mass system equal to the difference between the gravitational force on the hanging mass and the friction on the cart. By changing the value of the hanging mass, students can change the overall force on the cart-mass system and observe the effect on the acceleration of the cart-mass system. According to Newton’s second law, as the overall force increases, the acceleration should also increase.

Overall force = *mg – F*friction *= Ma*

*a = mg/M – F*friction*/M*

**Variables:**

Independent: hanging mass, *m* (kg)

Dependent: acceleration of cart and hanging mass, *a* (m/s2)

Controlled: total mass of cart and hanging mass system, *M* (750 g)

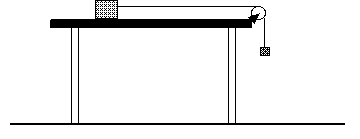
**Apparatus:**

Pulley attached to end of tabletop

String

Cart (low friction if possible)

Mass hanger and masses



**Method:**

1. Hang set mass from mass hanger. Make sure that total mass of cart and hanging mass is about 750 g.[[8]](#footnote-8)
2. Release the cart and film its motion.
3. Using the method outlined in Learning activity 2 for finding the acceleration of a dropping ball,[[9]](#footnote-9) find the acceleration of the cart.
4. Repeat a total of three times.

**Results:**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Mass hanging**  **(kg)** | **Trial 1 *a***  **(m/s2)** | **Trial 2 *a***  **(m/s2)** | **Trial 3 *a***  **(m/s2)** | **Average *a* (m/s2)** | ***F*applied by hanging mass** |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |

**Analysis:**

Graph the class data, with acceleration on the horizontal axis and applied force from the hanging mass on the vertical axis.

1. What does your graph tell you about the relationship between applied force and acceleration?

Would expect to see the data fit a linear trendline, so the graph would be expected to indicate that if the applied (overall) force was doubled, the acceleration would also double. It is possible that the graph will have a non-zero vertical intercept, indicating that the applied force from the hanging is slightly larger than overall force due to friction between the cart and the surface.

2. What does the gradient of your graph tell you about the equipment in your experiment?

The gradient of the graph is related to the total mass, *M*, of the cart and hanging mass. If the students plot *F*applied byhanging mass on the vertical axis and acceleration on the horizontal axis, then the gradient equals the total mass, *M*. If the students plot acceleration on the vertical axis, then the gradient equals 1/*M*.

3. Is the force applied by the hanging mass the net, or overall, force acting on the cart and hanging mass? Explain your answer.

The overall force on the cart and hanging mass is the difference between the force applied by the hanging mass and the friction experienced by the cart.

4. Is this experiment consistent with what you would expect from Newton’s second law? Explain your answer.

Newton’s second law states that acceleration is equal to the net or overall force divided by the total mass of the cart and hanging mass, so the acceleration is directly proportional to the overall force on an object. This should be consistent with the results obtained in this experiment. Differences could occur if the set-up results in significant friction.

5. Provide an alternative explanation for your results in terms of energy transfer.

The hanging mass loses gravitational potential energy, which corresponds to the gain in kinetic energy of the cart and hanging mass and energy dissipated by the cart and string passing over the pulley due to friction.

**Conclusion:**

Example: Our results show that there is a linear relationship between acceleration, *a*, of a system and the overall force *F* applied to the system. The constant of proportionality was found to be 1/*M*, where *M* is the mass of the system. These results are consistent with Newton’s second law.

Students should comment on the difference between what they might have expected by applying Newton’s second law in an idealised, frictionless case and what they found. For example: We also found that while our data was linear, due to friction, the trendline did not pass through the origin, corresponding to a consistently lower value of the acceleration than would have been expected if there were no friction.

Students should also comment on the variation between the data from each trial. How precise was the value they obtained for the acceleration? How repeatable is their data? What could be the cause of variation between trials?

Students should also compare data obtained from different groups of students. How reproducible do the results from this experiment seem to be? What could be the causes of variation between groups?

Appendix 8: Food aid drop scenario (sample assessment task)

Delivering food aid from the air – a case study of energy transformation and the effect of forces.

In many areas of the world, delivering [food aid by air](https://www.wfp.org/stories/how-do-you-drop-food-17000-feet-conflict-zone-watch-our-video) is an essential humanitarian relief mission.

Your task is to report on your proposed aerial delivery of much needed fresh water to a remote secret location with a hard landing surface. You will build a prototype for proof of concept for the delivery of a 50–100 mL volume of water. You will work in a group of no more than three students and conduct a minimum of three trials of your system. You will be provided with a garbage bag, duct tape, string and several water balloons, which will enable you to construct a parachute that attaches to a water balloon carrying 80–100 mL of water and to carry out multiple test deliveries. You will be dropping your prototype from a height of approximately 4 metres. You will video your prototype as it descends to the ground and collect evidence of the transformation of energy and types of forces acting from your motion data.

Your aim is to achieve safe delivery of the maximum possible volume of water, with a minimum trial volume of 50 mL.

Your report on your prototype needs to include the following:

* **An introduction** to your work. To safely deliver the water, what are the key considerations? What energy transformations will occur during the descent and landing of your prototype? What forces will be acting on your prototype during the descent and landing?
* **A list of variables** describing the conditions under which you are testing your prototype. What will you be measuring? Which variables are controlled or the same for each of your trials? How will you keep them the same? Which variables would you ideally be able to control, but may not be able to?
* **A description of your method and materials** for constructing and testing your prototype. You will be supplied with a garbage bag, duct tape, string and several water balloons, and you can supplement these items with additional resources if you wish. Assess any potential risks and mention relevant steps undertaken to keep procedure safe.
* **A diagram and photo** of your prototype.
* **Observations** of what happened during descent and landing.
* **A table of data**, giving the position and time information for each trial for your prototype.
* **A table of calculated results**, including calculation of the velocity, acceleration, kinetic energy and gravitational potential energy of your prototype.
* **Graphs** of the position, velocity, kinetic energy, gravitational potential energy and the sum of the kinetic and gravitational potential energy during the descent and landing of each trial of your prototype. The energy data can all be displayed on the one graph.
* **Discussion of your results:**
  1. **Summarise** the features of the velocity of the prototype. Does it speed up, stay the same speed or slow down? If so, at which point in the descent and landing do you observe these behaviours?
  2. **Explain what the velocity information tells you about the forces** on the prototype. Is there air resistance? How do you know? What happens upon landing? Are there times when the forces appear to be unbalanced? Are there times when the forces appear to be balanced? Give an explanation for what you observe.
  3. **Explain what the velocity and position information tell you about the energy transformations** experienced by the prototype. What happens to the initial gravitational potential energy of the prototype? Is it all converted into kinetic energy? What happens when the prototype lands?
  4. **Describe the quality of your data**. How repeatable is your data? What was similar about your trials? What was different? Is it likely that your data is reproducible? How accurately were you able to measure the position of your prototype from your video? What were the limitations? How precise was your data?
* **A proposal for future improvements:** What issues do you see with scaling up your design to delivery of more significant volumes from greater heights? What problems would need to be solved?
* **A conclusion** as to whether the aim of your prototype was achieved.
* **A brief reflection** on insights that your work has given you into the challenges of delivering food aid effectively to regions inaccessible by land-based transport.

Appendix 9: Assessing Science Understanding

The rubric below shows examples of how students may demonstrate progression of conceptual understanding as they work towards and beyond the achievement standard for elements of the Science Understanding strand at Levels 9 and 10.

Cross-references to relevant learning activities (LA) are included in the rubric.

Sample rubric for assessing concepts of motion, forces and energy change

| **Curriculum links** | | |  | **Assessment rubric** | | | | | |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Science sub-strand** | **Levels 9 and 10 content description** | **Levels 9 and 10 achievement standard extract** |  | **Working towards Level 10** | | | **At Level 10** | | **Working beyond Level 10** |
| Physical sciences | The description and explanation of the motion of objects involves the interaction of forces and the exchange of energy and can be described and predicted using the laws of physics ([VCSSU133](https://victoriancurriculum.vcaa.vic.edu.au/Curriculum/ContentDescription/VCSSU133)) | … explain the concept of energy conservation and model energy transfer and transformation within systems … give both qualitative and quantitative explanations of the relationships between distance, speed, acceleration, mass and force to predict and explain motion. | Motion | Relate distance travelled to a change in position LA1 | Calculate distance and know that position is measured with respect to a reference point LA1, LA2 | Distinguish between displacement and distance LA1 | | Interpret a displacement and/or position-time graph to describe the path taken by an object  LA1 | Use displacement and/or position-time graphs to predict possible collision points between different objects LA1 |
| Identify distance travelled and time taken by a moving object LA1, LA2 | Qualitatively compare fast and slow objects and define average speed as the distance travelled over time taken LA1, LA2 | Calculate the average speed of an object using distance and time information and convert between measurement in different units  Use graphed position-time data to find the average speed of an object with a constant velocity LA1, LA2 | | Distinguish between average speed and average velocity and between positive and negative velocity LA1, LA2 | Distinguish between instantaneous and average velocity  Sketch a graph of velocity versus time of an object based on the displacement versus time graph of an object LA2 |
| Identify that objects can speed up or slow down and that starting to move and coming to a stop are examples of changing speed LA2 | Define average acceleration as the change in speed divided by the time taken LA2 | For an object moving in a straight line with a constant acceleration, find average acceleration from graphed speed versus time data and/or calculate the average acceleration from the change in speed divided by time taken  LA2 | | Identify whether an object is experiencing positive or negative acceleration LA2 | Find the acceleration versus time from graphed velocity versus time data for an object experiencing a non-constant acceleration LA5 |
| Forces and Newton’s laws | Identify contact and non-contact forces and know that all objects experience a gravitational force LA2 | Describe each force experienced by an object in terms of the force on the object by another object LA1, LA2 | Represent the forces on an object using a force diagram, with forces appropriately labelled  Know that the size of the force of the mass of Earth on the mass of an object close to the surface of Earth is *mg*, where *m* is the mass of the object and *g* equals 9.8 N/kg LA2 | | Draw a force diagram consistent with the motion of the object in cases where the object is moving horizontally or vertically LA1, LA2 | Draw a force diagram consistent with the motion of the object in cases where the object is moving both vertically and horizontally LA2 |
| Know that the motion of an object is affected by whether or not the forces on the object balanced each other out LA1, LA2 | Know that Newton’s second law says that an overall force on an object will cause the object to speed up, slow down or change direction, with the amount of change depending upon the mass of the object  LA2 | Apply Newton's second law to calculate the acceleration of an object of a given mass and/or use Newton's first law to explain that if the forces on an object balance each other out, so that there is no overall force, the object will maintain the same velocity  LA2 | | Use Newton’s third law to explain how self-powered bodies, such as humans, cars and rockets move | Apply Newton’s second law quantitatively to connected bodies, such as an Attwood machine |
| Energy transfer and conservation | Identify different forms of energy LA3 | Identify different forms of mechanical energy including kinetic and gravitational potential energy LA3, LA4 | Describe kinetic energy and gravitational potential energy LA3, LA4 | | Explain the concept of dissipated energy LA3, LA4 | Describe the energy transfer in cases involving springs LA5 |
| Know that energy can be transferred from one object to another and/or from one place to another LA3, LA4 | Know that an increase in one form of energy must be balanced by a decrease in another form of energy LA3, LA4, LA5 | Demonstrate conservation of energy as an object moves from one position to another using diagrams, such as energy transfer bar charts  LA4, LA5 | | Quantitatively calculate the energy transferred when an object is moved from one place to another LA4, LA5 | Quantitatively account for energy transfers in situations involving springs LA5 |

1. Pulling is recommended rather than pushing because it is easier to achieve an approximately constant speed. A teacher or student can walk at a steady pace pulling the object along behind them. [↑](#footnote-ref-1)
2. This is an opportunity to discuss measurement uncertainty, accuracy and precision. [↑](#footnote-ref-2)
3. Frame rates may vary from the value given in the device specifications, which can introduce a small inaccuracy in your data analysis. [↑](#footnote-ref-3)
4. Make sure that your set of hanging masses is compatible with the spring balance range. For example, the force on a set of 10 × 50 gram slotted masses would be suitable for measuring with a 0–10 N Newton meter. If you have only a 0–2 N Newton meter, you could suspend a paper cup containing varying numbers of marbles or plasticine balls. [↑](#footnote-ref-4)
5. Newton’s third law states that the force on the mass by Earth must be the same size as the force on Earth by the mass. If the force on the mass by Earth is dependent on the value of the mass, it follows that the force on Earth by the mass is dependent on the value of Earth’s mass. [↑](#footnote-ref-5)
6. The kinetic energy of a body, *EK* , with a mass *m* moving in a straight line with speed *v* can be quantified using the mathematical formula . [↑](#footnote-ref-6)
7. The scientific term for the energy transfer when a force is applied to an object along the direction of its change in position is ‘work’. The person does work on the car. [↑](#footnote-ref-7)
8. Students will find it easier to measure if the acceleration is not too large; however, the greater the mass of the cart, the greater the friction, so a compromise needs to be chosen. [↑](#footnote-ref-8)
9. Alternatively, use the free software package [Tracker](https://physlets.org/tracker/), which has been specifically designed to enable analysis of videos of motion by high school physics students. [↑](#footnote-ref-9)