Mechanics Activities

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Accelerating on a Ramp

Apparatus

wind up toy car, ramp

Action

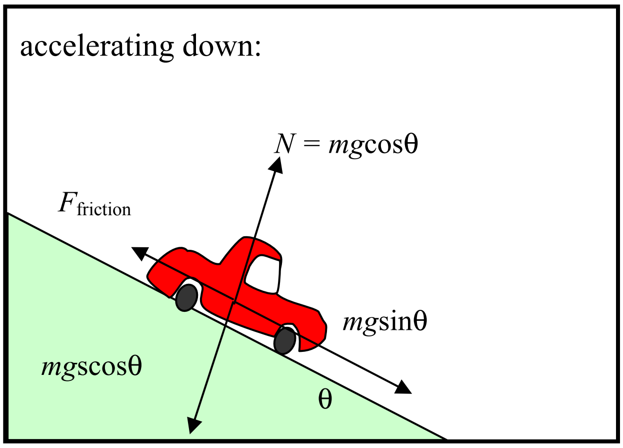
The students allow the car to roll down the ramp (without winding it up). They draw a free body diagram showing the forces acting on the trolley.

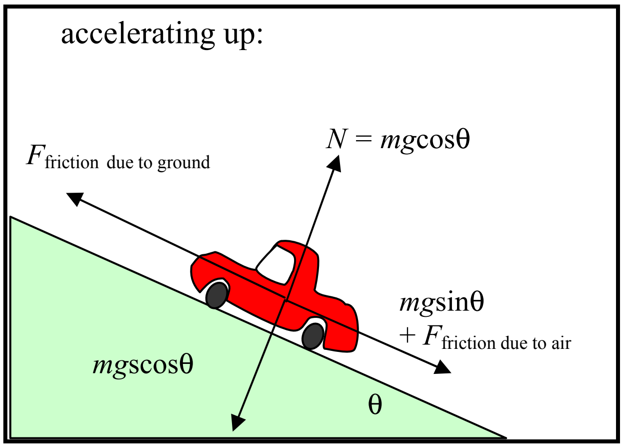
They then wind the car up so that it can accelerate up the ramp for at least a short distance. They should draw a free body diagram showing the forces on the car as it climbs the slope.

The Physics

The forces acting on the toy car as it rolls down are gravity, friction and the normal force. The component of gravity along the direction of the slope is greater than any frictional forces and gives an acceleration down the ramp.

When the toy car is wound up and set to climb the ramp its wheels exert a force on the ground. The ground exerts an equal and opposite force, due to friction, on the cars wheels which push the car. As long as the coefficient of friction is great enough that slipping does not occur, and the force on the wheels is greater than the component of gravity down the hill, the car will accelerate.





Accompanying sheet

Accelerating on a Ramp

Place the car at the top of the ramp and release it.
What happens? Why?
Draw a free body diagram of the car.

How does a car accelerate up a hill?
Draw a free body diagram showing the forces acting to accelerate a car up a hill.

A car with some initial speed reaches a downwards slope
and the driver allows the car to roll down the hill.
Will the car necessarily accelerate?

Acceleration due to Collision

Apparatus

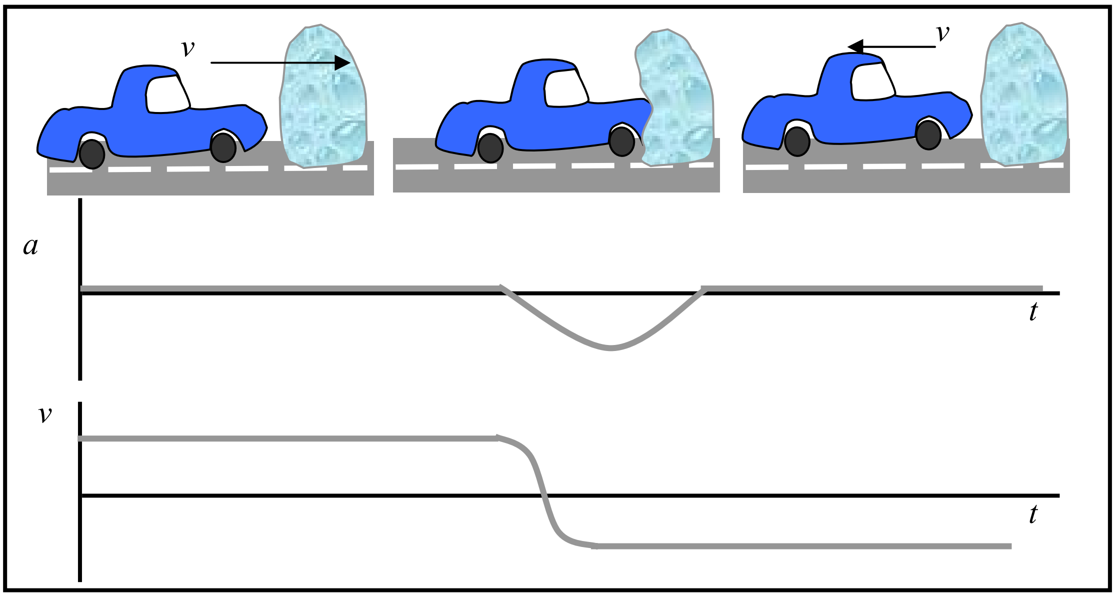
toy car, sponge

Action

The students roll the toy car at the sponge (not too quickly), and observe how it is slowed and then bounces back. They describe the collision in terms of velocity and acceleration and sketch the acceleration as a function of time. Note they should define a positive direction, for convenience this can be towards the sponge.

The Physics

The toy car initially has a positive velocity. It's velocity decreases as it is slowed down by the impact with the sponge. The velocity decreases to zero as the car comes to a halt. As the car begins to bounce back the velocity increases in magnitude, but is negative because the car is now moving in the negative direction. The change in velocity is always negative throughout the collision, hence the acceleration is always negative.



Accompanying sheet

Acceleration due to Collision

Define a positive direction.
Send the toy car into the sponge, so that it bounces back.

Describe what happens in terms of the velocity and acceleration of the car.

Sketch the acceleration of the car as a function of time.

Acceleration due to Gravity

Apparatus

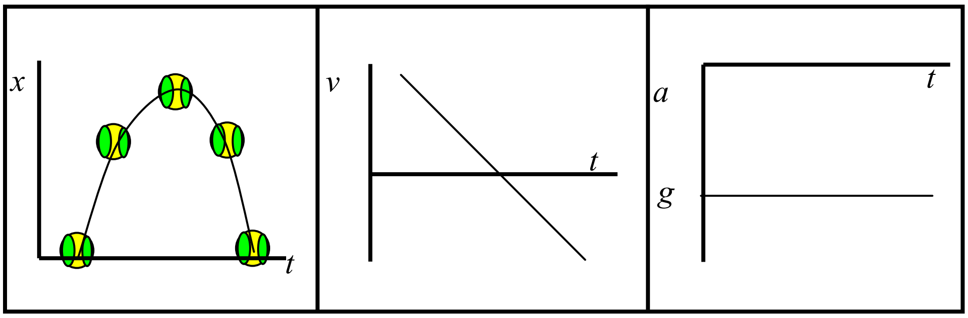
tennis ball

Action

The students throw the ball directly up into the air and catch it again. They should watch to see how the ball's velocity changes, and consider the direction of acceleration of the ball during its flight.

The Physics

Once the ball has left the student's hand there is only the force of gravity acting on it (neglecting air resistance). Hence the only acceleration is that due to gravity, and the acceleration is always downwards. The velocity of the ball decreases as it goes up, becomes zero, and then negative as it falls back down. Hence the speed (magnitude of velocity) decreases and then increases again, but the velocity only decreases. This exercise helps students recognise that acceleration is not always in the direction of velocity (or displacement). Many students find this a difficult concept.



Accompanying sheet

Acceleration due to Gravity

Throw the ball straight up into the air,
and catch it when it comes back down again.

Describe what happens to the velocity and acceleration of the ball.

Sketch the acceleration as a function of time.
Sketch the ball's velocity and displacement as a function of time.

Accelerometer

Apparatus

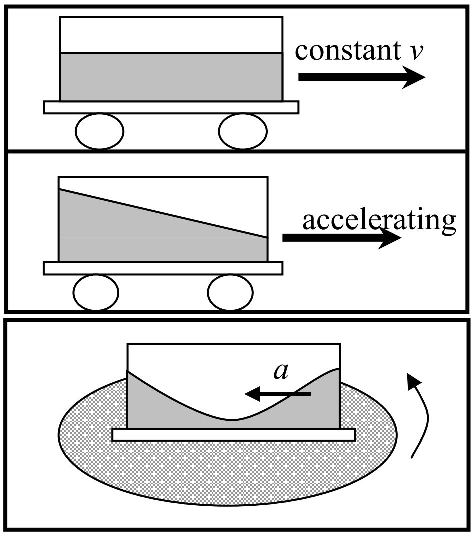
accelerometer on wheels, see diagram below

The accelerometer is a narrow Perspex tank partly filled with a coloured fluid, e.g. water with a little food colouring, with a string attached to one end so it can be pulled along. A good size is around 20 cm long by 15 cm high.

Action

The students pull the accelerometer at constant speed, and accelerate forwards and backwards.

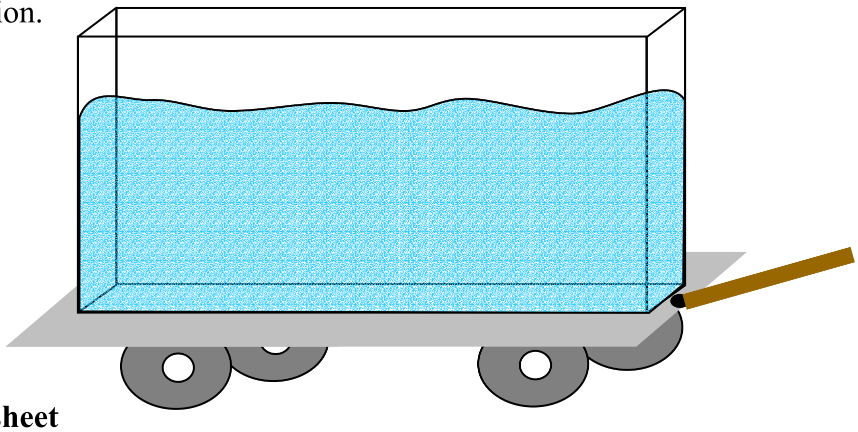
The Physics



The surface of the fluid in the accelerometer should be fairly flat and horizontal at constant speed, as there is no net force acting on the fluid, it looks just as it would if it were standing still.

When accelerated forwards, the fluid's surface will make an angle to the horizontal. The direction of the slope of the fluid shows you the direction of the acceleration. The fluid surface is at an angle because the net force on the fluid is no longer zero. The fluid collects at the back of the accelerometer when it accelerates. In general the fluid will "point" like an arrow in the direction of acceleration.

Note: this device is also handy for a relativity activity as it is impossible to tell whether you are moving at constant speed or standing still. It is also handy for circular motion – when placed on a spinning turntable the fluid collects at the two ends of the accelerometer, with the fluid pointing inwards, showing that the acceleration is towards the center of the motion.



Accompanying sheet

Accelerometer

Pull the accelerometer at a constant speed.
What does it show? Why?

Now accelerate it forwards. What do you observe?

Allow the accelerometer to roll freely on the carpet.
What does it show as it slows down?

Air Track

Apparatus

air track, several gliders (with springs, e.g metal loops, at the ends) of the same size plus a few of different sizes

Action

The students experiment with colliding moving and stationery objects of the same size, and of different size. The students should consider what happens when a moving object collides with a stationary one, what effect the relative masses have, and what role friction plays. They should consider the difference between elastic and inelastic collisions.

The Physics

The air track provides an almost frictionless surface, so any external horizontal forces acting on the gliders are very small. This means that the gliders can be considered as an isolated system. If the air track is turned off this is no longer the case. The springs on the gliders, e.g. metal loops, help to ensure the collisions are elastic and the gliders do not stick together. In elastic collisions kinetic energy is conserved, and in all collisions momentum is conserved.

A student at the University of Western Sydney experimenting with collisions on an air track.

Accompanying sheet

Air Track

What happens when a moving object collides with an identical stationary one?
What if they have different masses?

Send two identical objects, spaced a few centimetres apart,
with the same velocity towards a third.
What happens when they collide?
This is like a row of moving traffic hitting a stationary vehicle.

Put three identical objects in a row with equal spacing.
What happens when you collide a fourth object with them?

Balloons

Apparatus

packet of balloons, long ones work particularly well

Action

The students blow up a balloon and then let it go. They should watch the balloon and note the direction it moves in, and the position of the hole as it flies.

The Physics

When the balloon is released the air inside it rushes out because it is under pressure. The air comes out the neck of the balloon. For momentum to be conserved the balloon (and remaining air) must move in the opposite direction. This is what happens, and the balloon whizzes around the room, moving in the opposite direction to the airflow.

Students at the Australian Catholic University ready to launch a balloon.

Accompanying sheet

Balloons

Blow up a balloon, and do *not* tie off the neck.

Now let it go. What does the balloon do?

Explain what happens in terms of conservation of momentum.

Battleship Game

Apparatus

battleship game or other board game that uses a similar grid
(Cheap non-electronic "travel" versions of battleship are available)

Action

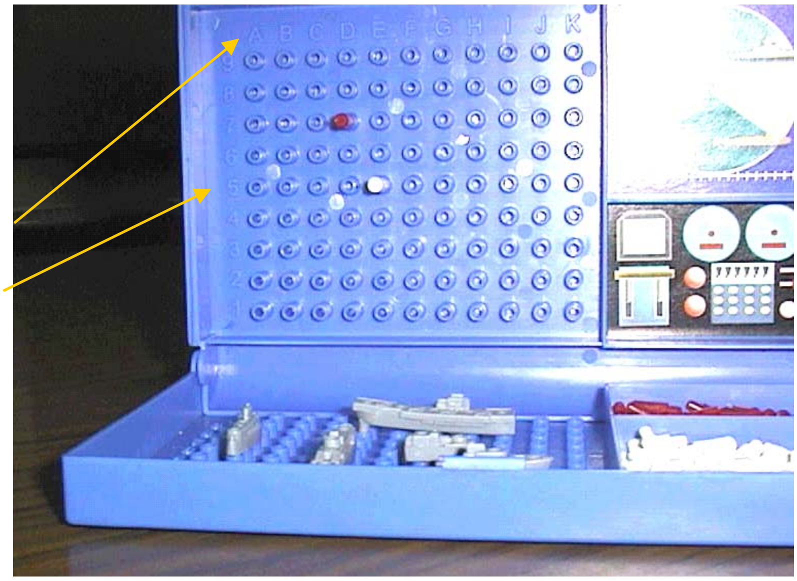
The students examine the board and note the use of vectors in the game play. Given the position of a pin they should describe its position using vectors in two different ways – letter and number; and angle with length.
(Note that they may need to be discouraged from settling down and having a game.)

The Physics

Battleship and similar games use vectors to determine the position of a ship. The vectors are usually written in terms of letter and number axes, rather than *x, y* axes, but are otherwise identical to vectors used in physics and mathematics. The origin is generally the bottom left hand corner. One way of describing the position of a pin is to give the lengths of perpendicular components, for example horizontal (numbers) and vertical (letters). Another way is to give the length of the vector and its angle to the horizontal. For example a pin at position C4 is also 5 units from the origin on a line 49^{o} above the horizontal. (In polar coordinates this would be written as (r,θ) = (5 spaces, 49^{o}).)

Note that some computer games such as "Cow Wars" use an angle input by the user to determine projectile range. This is another example of vector use, but using angle rather than *x, y* values.

"battleship" game showing letters along top and numbers down side for coordinates



Accompanying sheet

Battleship Game

Examine the game.
How are vectors used in this game?
Where is the origin?

Explain two ways you could use vectors to describe a position of a pin on the board.

Bicycle Wheel

Apparatus

smoothly rotating stool, bicycle wheel with handle through centre about which the wheel can spin (i.e. the handle should not spin with the wheel)

Note: a foot pedal operated motor with a belt attached to a pulley is useful to spin the wheel to large angular velocities, however this is not necessary. A good velocity can be obtained by hand, and this is safer with large classes.

Action

The students spin up the wheel and attempt to tilt it. The wheel should be carefully passed to a student sitting *at rest* on the rotating stool. This student slowly tilts the wheel to different angles. They can control the direction and speed at which the stool rotates by changing the angle of the spinning wheel.

The Physics

A large torque is needed to tilt the spinning wheel. Angular momentum must be conserved, and a rapidly spinning bicycle wheel has a large angular momentum. The wheel exerts a large reaction force upon the person attempting to change its angular momentum. When the person is on the rotating stool there is no strong frictional force holding the person still, and so they begin to rotate due to the large reaction force, and the total angular momentum is constant.

Note: the bicycle wheel should not be spun too fast as it can be dangerous if dropped or held too close to the body. The student on the stool should be cautioned to tilt the wheel very slowly. This activity needs close supervision.

Tilting the bicycle wheel causes the person to rotate on the stool.

Accompanying sheet

Bicycle Wheel

Spin up the bicycle wheel.
What do you feel when you try to tilt the wheel?

Carefully hand the wheel to someone sitting on the rotating stool.
What happens when they tilt the wheel? Why?

Caution: hold the spinning wheel carefully away from yourself.

Block on a Rough Variable Ramp

Apparatus

smooth variable ramp, one or more pieces of cloth with coarse surface to cover ramp, metal or wooden block

Action

The students experiment with changing the angle to find the angle at which slipping occurs. They should be able to estimate the coefficient of friction between the surface and the block for the smooth ramp and then the ramp with the rough (cloth covered) surface. They should draw a free body diagram showing the forces acting on the block.

The Physics

The forces acting on the block are the normal force, gravity and (static) friction. Decomposing these into components along the ramp and perpendicular to the ramp gives:

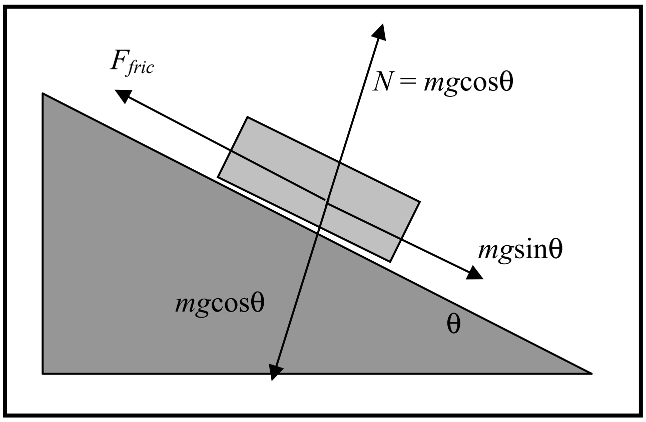
Forces perpendicular to ramp: N and $mg\cos\theta$, which are equal.

Forces along the ramp: $mg\sin\theta$ and F_{fric}, where $F_{fric} \leq \mu N = mg\sin\theta$.

Until the box begins to slide, $F_{fric} < \mu N$ and $F_{fric} = mg\sin\theta$.

At the point of sliding, $F_{fric} = \mu N = \mu mg\cos\theta = mg\sin\theta$.

The box starts to slide when $mg\sin\theta$ exceeds $\mu mg\cos\theta$, i.e. when $\mu < mg\sin\theta / mg\cos\theta = \tan\theta$. Hence the coefficient of static friction can be found by noting the angle at which slipping first occurs. This angle increases for rougher surfaces with larger μ.



Accompanying sheet

Block on a Rough Variable Ramp

Draw a free body diagram showing the forces acting on the block.

Adjust the angle of the ramp until the block just begins to slip.
Repeat using a different surface on the ramp.
What happens this time?

How can you estimate the coefficient of slipping from the angle?

Bouncing Balls I

Apparatus

selection of balls; for example super-balls, tennis balls, balls of blu-tac or play –dough

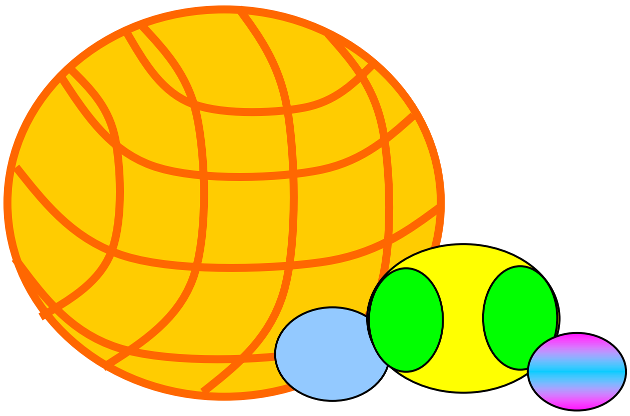
Action

The students experiment with dropping and throwing down the different balls. They should consider the energy changes as the balls fall, collide with the floor, and then bounce up again.

The Physics

Balls that lose less energy to non-mechanical forms on impact rise higher than balls that lose more energy. Balls of blu-tac or play-dough lose a lot of energy to internal frictional forces as they deform on impact. This energy is dissipated as thermal energy. Balls which undergo more elastic collisions bounce higher as they lose less kinetic energy.

No ball which is dropped (from rest) will bounce higher than the height it was dropped from. A ball can bounce higher than the original height if thrown down. These balls start off with kinetic energy and gravitational potential energy instead of just gravitational potential energy.



Accompanying sheet

Bouncing Balls I

Drop the balls from the same height.
Why do some balls bounce higher than others?

Can you make any of the balls bounce higher than the original height?
Does this contradict conservation laws?

Bouncing Balls II

Apparatus

two balls, one large and one small – for example a basketball and a tennis ball

Action

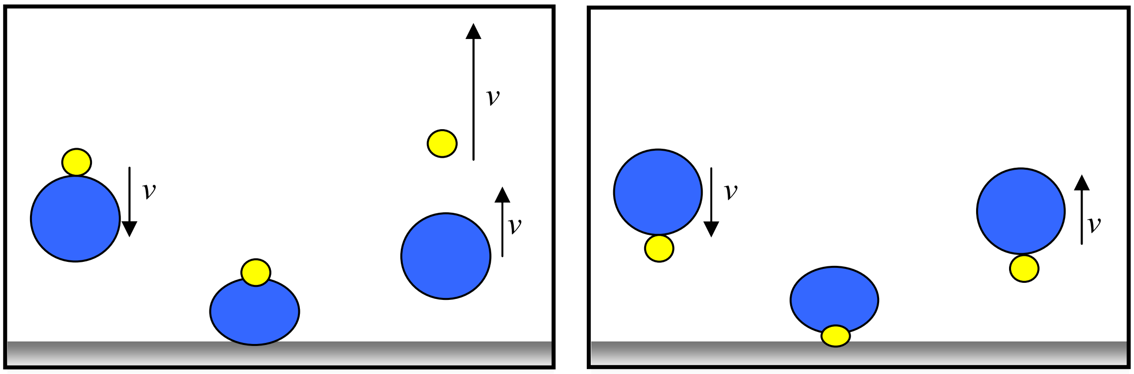
The students hold the small ball on top of the large ball and drop them together. They then repeat this with the large ball on top. They should try to explain their observations in terms of conservation of momentum.

The Physics

The small ball held over the big ball bounces off higher as some momentum is transferred from the big ball to the small ball, increasing its velocity. Momentum has been conserved during the collision and the change in momentum of the small ball is large. The results are most spectacular when the small ball is held exactly vertically above the large ball before they are released.

If the balls are switched around the momentum is still conserved, but the transfer of momentum from the small to the big ball makes little difference to the big ball's velocity due to its large mass.

Note: a reasonably clear space is needed for this activity as the small ball will gain a large amount of momentum and can fly off very fast and a long way.



Accompanying sheet

Bouncing Balls II

Hold the little ball on top of the big ball and drop them together.
What happens and why?

Does the same thing happen if you hold the big ball on top and drop them?

Boxes on a Trolley

Apparatus

three identical boxes filled to have different masses and sealed up, large trolley which will hold all three boxes in a row across the trolley with a regular surface

Action

The students examine the boxes to see which is heaviest and which is lightest. They then predict which will fall off the back of a trolley when it is accelerated. They should consider which direction the trolley accelerates, and predict which way the boxes will fall off. They then place the three boxes on the trolley and accelerate it to check their predictions. They should repeat the experiment a few times, changing the box positions, as small differences in surfaces will make one box or another fall off first.

The Physics

The boxes will all fall off together. Assuming the mass of the boxes is not so great as to squash the surface of the box or trolley, the acceleration due to friction will not depend on the mass of the box. The maximum possible acceleration due to friction (which is the net force holding the boxes to the trolley and hence accelerating it) is the maximum acceleration is $a_{\max} = \mu N / m = \mu mg / m = \mu g$. The acceleration does not depend on mass, only on μ, which should be the same for all boxes. Note that the net force acting is in the direction of movement, which is forwards, and this is the frictional force. Many students have difficulty with the idea that friction is causing the motion of the box.

Note that it may be easier to decelerate the trolley by stopping it suddenly with a foot rather than pulling on it. In this case the boxes slide the other way.

A student at the University of Sydney pulling the trolley with boxes.

Accompanying sheet

Boxes on a Trolley

Examine the three boxes.
Which will fall off the trolley first when you accelerate it? Why?

Place the boxes in a row across the back of the trolley.
What happens when you accelerate it?
What force is accelerating the boxes? In what direction is this force acting?

Which box falls off first?

Centre of Mass and Stability

Apparatus

a selection of items such as blocks stacked as a staircase, simple wooden wine bottle holder with (empty) bottle, baseball bat with stand which balances bat at centre of mass

Action

The students examine the items and determine when an object will be stable, and when not. An interesting extension is for them to stand with their backs against a wall and attempt to touch their toes.

The Physics

As long as the center of mass is over the base, an object will be stable. When you try to touch your toes you lean back and put your bottom out, so that your centre of mass stays over your feet. The wall behind you prevents this so you cannot touch your toes and maintain your balance.

Students at the University of Sydney experimenting with the stability of different objects

Accompanying sheet

Centre of Mass and Stability

Examine the objects on display.
Where is the centre of mass in each object? How can you tell?

Stand with your back against the wall and try to touch your toes.
What happens? Why?

Clocks

Apparatus

a clock with a "seconds" hand

Action

The students observe the clock and calculate the angular velocity of the three hands. They may also calculate the linear velocity of the hands if the radius is measurable (if the clock is not mounted high up on a wall).

The Physics

The angular velocity is independent of the clock size, however for larger clocks the linear velocity of the pointers at the end of the hands will be greater.

The second hand goes through 2π radians in 1 min, or 2π radian/60 seconds,
so $\omega = \pi/30$ rad.s^{-1} = 0.03 rad.s^{-1}.
The minute takes one hour = 60 s/min $\times$ 60 min = 3600 s to go around,
so $\omega = 2\pi$ / 3600 rad.s^{-1} = 1.7×10^{-3} rad.s^{-1}.
The hour hand takes 12 hours = 12 hours $\times$ 60 min/hour $\times$ 60 s/min = 43200 s to do 2π radians,
so $\omega = 2\pi$ rad/43200 s = 1.5×10^{-4} rad.s^{-1}.

Accompanying sheet

Clocks

What is the angular velocity of the second hand?

What are the angular velocities of the minute and hour hands?
Does it matter how big the clock is?

Does the length of the hands make a difference to their linear velocity?

Constant Acceleration

Apparatus

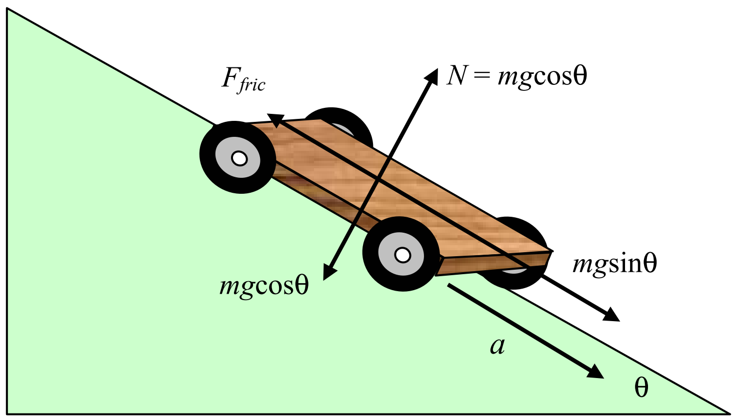
spring balance, smooth ramp, trolley

Action

The trolley is allowed to roll down the ramp unimpeded. The students should identify the component of force acting to accelerate the trolley, and estimate its magnitude. They should recognize that the acceleration is constant.

The Physics

When the trolley accelerates down the ramp it is not in equilibrium. The unbalanced forces are the component of gravity parallel to the ramp and the frictional force up the ramp.



Accompanying sheet

Constant Acceleration

Release the trolley at the top so it accelerates down the ramp.

Draw a free body diagram showing the forces acting on the trolley.

Identify the unbalanced forces (or components of forces)
which accelerate the trolley.

Constant Velocity

Apparatus

spring balance, smooth ramp, trolley

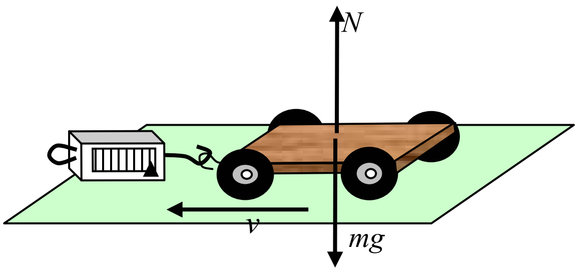
Action

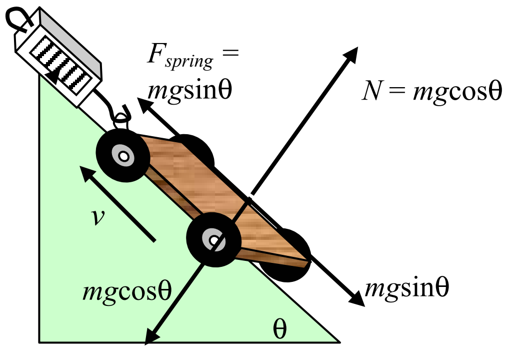
The students attempt to pull the trolley up the ramp with constant velocity. (This can be quite difficult and may take a few tries.) They should compare the reading on the balance when the trolley is on the ramp and still to when it is pulled at constant velocity.

They then pull the trolley with constant velocity along a flat table top. They should compare the readings on the spring balance when the trolley moves along the table at constant velocity and when it moves up the ramp at constant velocity.

The Physics

On a flat surface the net force acting to give a constant velocity is zero. Hence at constant velocity the spring balance will read close to zero. On a flat surface we need just enough force to oppose frictional forces To pull a trolley up a ramp at constant speed we need to apply a constant force of $mg\sin\theta$ so that the net force is zero. N balances the component of mg perpendicular to N, which is $mg\cos\theta$. The pull must be equal to the component of gravity $mg\sin\theta$.





Accompanying sheet

Constant Velocity

Pull the trolley along the table top with constant velocity.
What does the spring balance read? Why?

Pull the trolley up the ramp with constant velocity.
(This is not easy and may take several attempts.)
What does the spring balance show now?

Why are the readings different?
Is friction important here? How can you tell?

Drawing Orbits

Apparatus

board which pins can be pushed into, string, pencil, pins, table of planetary orbit data (see below)

Action

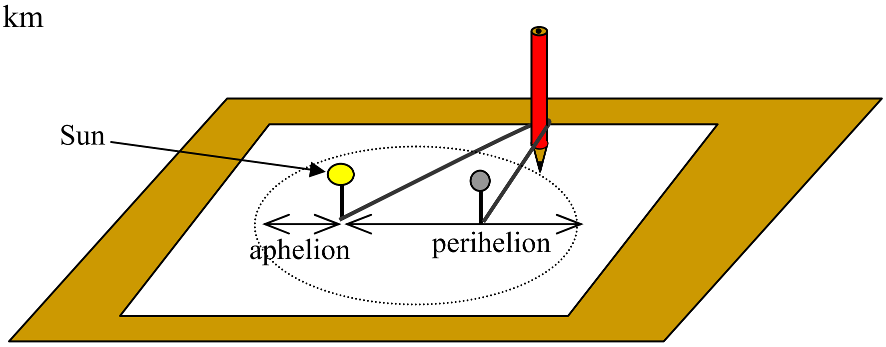
The students push one pin into the board to mark the position of the sun. Another pin is pushed in at the second focus of the orbit. The distance between the foci is equal to the difference in the aphelion and perihelion distances. The string is cut to the aphelion distance plus the perihelion distance, suitably scaled down, plus a little bit for tying. One end of the string is tied to each pin, and used to guide the pencil in drawing an elliptical orbit.
Alternatively, they cut a piece of string to a (scaled down) length equal to twice the sum of the aphelion and perihelion distances ($l = 2(a+p)$). They tie the string in a loop and put it around the pins and hold the pen in the loop so that it pulls the loop taut and use the string to guide the pen to draw the orbit.

The Physics

The planets move in elliptical orbits around the sun. The closest point to the sun is called the perihelion and the furthest point is called the aphelion. The sun is at one focus of the ellipse. The string should be a length equal to the sum of the aphelion and the perihelion, so that the pencil is at most the aphelion distance from the sun. The distance between the foci is equal to the difference between the aphelion and perihelion distances. The eccentricity of the orbit is the ratio of the distance between the foci to the length of the major axis, which is (aphelion – perihelion) / (aphelion + perihelion), which is equal to 0 for circle and is between 0 and 1 for an ellipse.

Planet	Mercury	Venus	Earth	Mars	Jupiter	Saturn	Uranus	Neptune	Pluto
Aphelion	70	109	152	249	817	1515	3004	4546	7304
Perihelion	46	108	147	206	741	1353	2741	4445	4435

Distances × 10^6 km



Accompanying sheet

> **Drawing Orbits**
>
> Place one pin at the sun position, and another at the other focus for one of the planets.
> How do you know where the other focus should be?
>
> Now cut a piece of string to a (scaled down) length equal to the sum of the aphelion and perihelion distances.
> Use the string to guide the pen to draw the orbit.
>
> Repeat for one or two other planets.
> Which planets have the most eccentric orbits? Which have the least eccentric?

Drop and Horizontal Throw

Apparatus

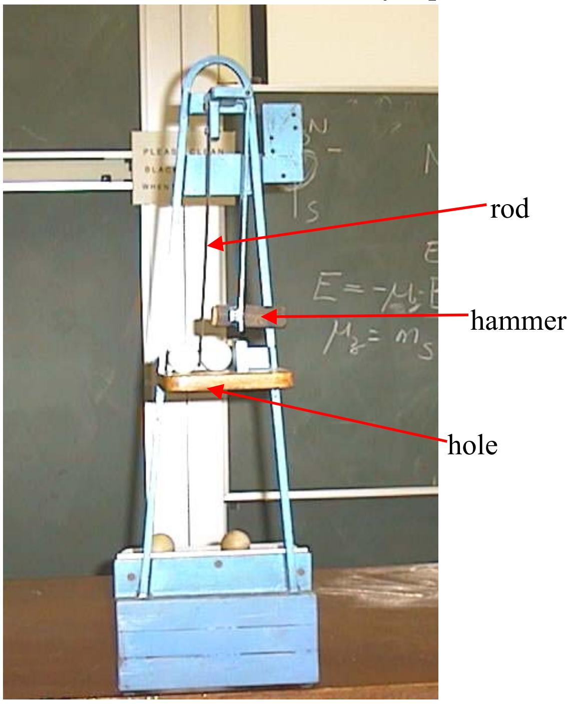
drop and throw apparatus (see below), two marbles or ping-pong balls

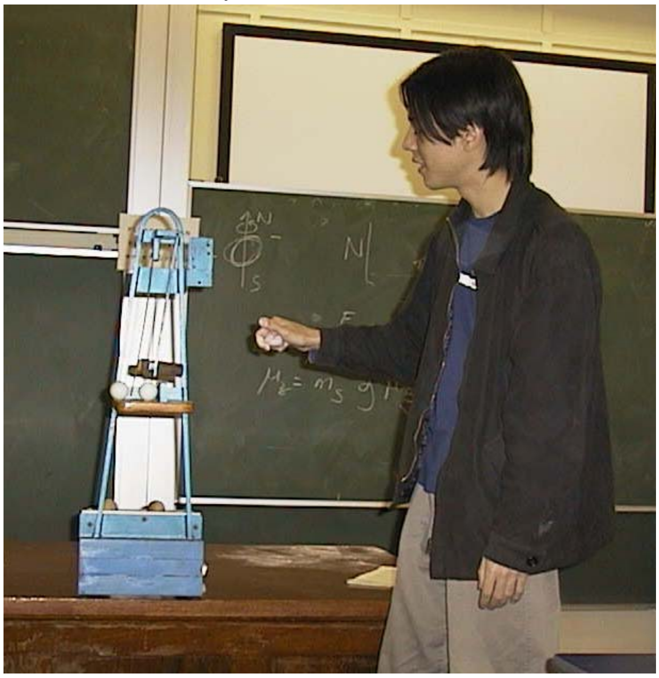
Action

The students observe what happens when the two marbles are released, and try to see which, if either, hits the ground first. They should try to predict what will happen *before* using the apparatus.

The Physics

The two marbles start with zero velocity in the vertical direction, and on release only one has a horizontal component to its velocity. The horizontal and vertical components of the velocity and displacement of the marbles are independent. In the vertical direction they both start with $v = 0$, and accelerate due to gravity, hence they both fall at the same rate and hit the ground together, although one will still have a horizontal velocity equal to its initial horizontal velocity.





When the student releases the hammer it will swing back, striking the rod which holds the first ball in place over the hole, and knocking it into the second ball. The first ball drops directly down, the second follows a parabola.

Accompanying sheet

Drop and Horizontal Throw

Set up the marbles ready to be released.

What will happen when they are released?
What are the initial velocities of the two marbles on release?

Which, if either, will hit the ground first? Why?

Release the marbles and check your predictions.

Falling

Apparatus

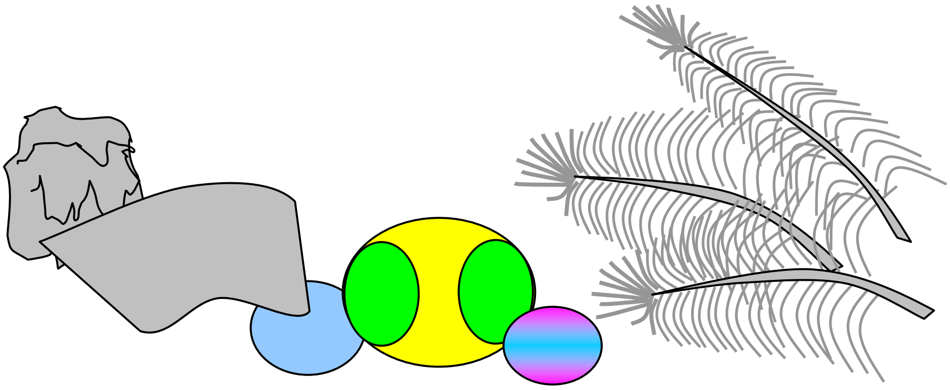
objects, such as marbles, bits of paper, balls, which can be dropped

Action

The students drop the objects and consider what forces are acting, and what work is done on the objects as they fall.

The Physics

As the objects fall they gain kinetic energy and lose potential energy. Work is done on the objects by gravity. Objects which experience a large drag, such as feathers and pieces of paper, fall more slowly. These objects have a large frictional force (air resistance) acting on them, which also does work on the objects, but does negative work – it decreases their kinetic energy. The objects are doing work on the air. The net work done is the sum of the work done by the frictional forces and gravity.



Accompanying sheet

Falling

What energy changes occur when you drop an object?

What work is being done, and on what?

What force or forces are doing the work?

Falling Cats

Apparatus

a stool which rotates smoothly,
enough floor space for other students to stand well back.

Action

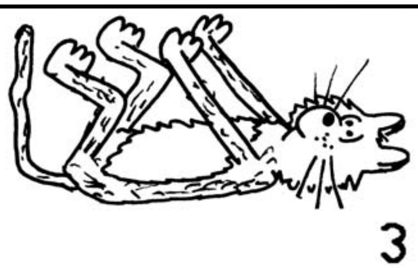
The students look at the diagram showing how a cat falls, and attempt to rotate themselves 180^{o} on the stool, without assistance and without touching anything else. Note that this is quite difficult and may take some practice.

The Physics

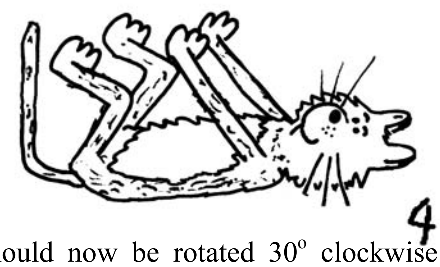
Angular momentum is conserved throughout the maneouvre, see diagrams below. This demonstration is adapted from Dr Karl Kruszelnicki's book "Fidgeting Fat, Exploding Meat and Gobbling Whirly Birds and Other Delicious Science Moments"

Falling with all four limbs sticking straight out.

Pull in front legs (arms) and rotate them 60^{o} clockwise. Outstretched rear legs have to rotate 30^{0} anti-clockwise.



Extend front legs (arms) and rotate them 30^{o}anti-clockwise, and pull in back legs which have to rotate 60^{o} clockwise.



You should now be rotated 30^{o} clockwise. Repeat this 5 times and you'll be facing the right way and ready to land!

Accompanying sheet

Falling Cats

Sit on the stool.

Look at the diagram showing how a cat turns itself around in mid air.
Can you turn yourself through 180^{o} in the same way?

Is conservation of angular momentum being violated here?

Falling Objects and Terminal Velocity

Apparatus

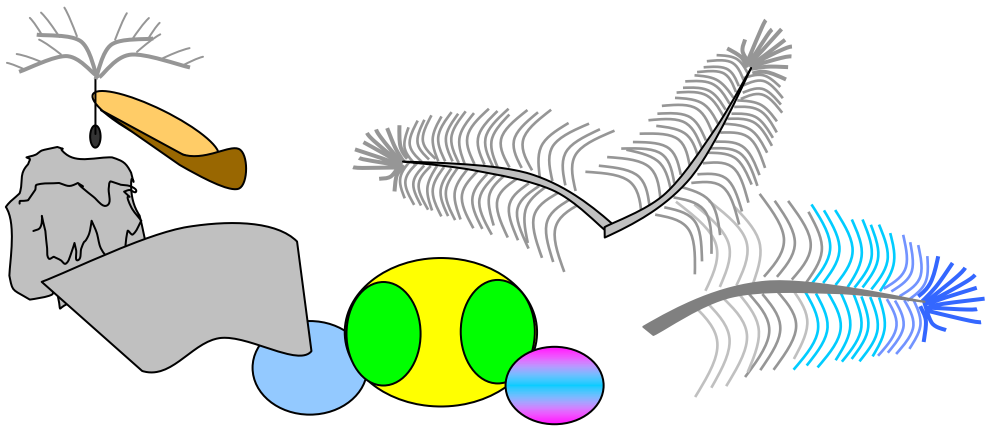
sheets of paper, flat and crumpled into balls, marbles, feathers, interesting seeds, some balls of the same size and surface texture but different masses, e.g. hollow ping pong ball and one filled with sand

Action

The students examine the objects and predict which will fall fastest. They then drop the objects and check their predictions.

The Physics

The greater the drag on the object the sooner it will reach terminal velocity. Greater surface areas give greater drag, for example a piece of paper held flat and dropped will fall more slowly than one held vertically and dropped. The two similar balls with different masses should fall at the same rate, as they have the same surface characteristics and hence should experience a similar air resistance.



Accompanying sheet

Falling Objects and Terminal Velocity

Examine the different objects on display.

Which ones will reach terminal velocity soonest? Why?

Drop the various objects and see what happens.

Finding Your Own Centre of Mass

Apparatus

two bathroom scales, long plank (approx 1.8 m – 2 m long) with line halfway along plank.

Action

The plank is laid with a scale beneath each end such that the readings are still visible. Before starting the students should check that the reading is the same on each scale, or the scales can be adjusted to ensure this is the case. A student lies on the plank while two others observe the readings on the scales. They direct the student to edge towards or away from them until the readings on the two scales are identical. When this is done the student notes where the mid line of the plank crosses their body.

The Physics

When the readings are identical the force on each scale is the same. This means that the centre of mass of the person is midway between the scales, i.e. where the mid line of the plank is. This is usually around hip height for females and a little higher than this for males.

It is also interesting to experiment with curving the body such that the centre of mass is over the plank, but not within the body. They will need to lie on their sides to do this. This is what high jumpers do to send their centre of mass below the bar while the body goes above it.

A University of Western Sydney student finding his centre of mass.

Accompanying sheet

Finding Your Own Centre of Mass

Use the bathroom scales and the plank to find your own centre of mass.

When your center of mass is halfway between the scales, they will have the same reading. Why is this?

Is it where you expect it to be?
Is it different for other people in your group?

Gaining Weight

Apparatus

two bathroom scales

Action

A student stands on one of the scales. They then see if they can change the reading without touching anything else. They should try to hold the new reading. They then try to change the reading while holding on to a friend. They should note the direction of the force that they exert on their friend, and the direction of the reaction force exerted on them. They should also note the direction of change of the reading on the scale.

With one foot on each scale the students can experiment with shifting their weight distribution. They should attempt to draw free body diagrams showing the forces acting on themselves and on the scales.

The Physics

When the student is not touching anything else the only external forces acting on them are gravity and the normal force. They can change the reading on the scale momentarily by bouncing up and down, but they cannot change and hold the reading. When the students can experience an additional external force, by pushing up or down on a friends arm, they can change and hold the reading.

If they push down on the other student they experience a reaction force upwards, which decreases the force acting on the scales and it reads a lower weight. The forces acting on the student are now gravity, the normal force due to the scales, and the external force due to the other student. By pushing upwards against the other student they can increase the weight shown on the scale.

With one foot on each scale they can vary the proportion of their weight on each scale, but the sum of the two readings should be constant.

The student decreases his weight (apparently) by pushing down on the table.

Accompanying sheet

Gaining Weight

Stand on a scale.
Can you change the reading without touching anything else?
Can you hold the new reading?

Can you change and hold the new reading while hanging onto a friend?
What direction do you apply the force in to increase the reading?
What about to decrease it?

Draw a free body diagram showing the forces acting on you and on the scale.

Gravitational Well

Apparatus

plastic or foam parabolic well, marbles

A parabolic well can be simply made using a swimming cap stretched over the opening of a suitable container, such as a plant pot, and weighed down in the middle with a heavy weight.

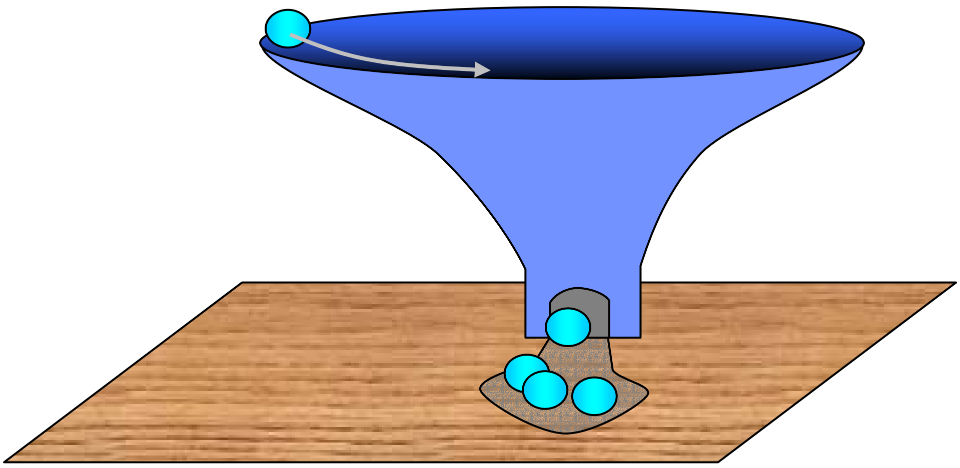
Action

The students roll the marbles around the well, observing how the velocity increases as they spiral inwards and downwards.

The Physics

The force acting to keep any object in a circular path is $F = mv^2/r$ where r is the radius of curvature, m is the mass of the object and v is its velocity. For a satellite this force is the gravitational force, $F = GMm/r^2$, where G is the gravitational constant, M is the mass of one body (e.g. the Earth) and m is the mass of the other (e.g. the satellite). These forces must be equal, $F = mv^2/r = GMm/r^2$, so $v^2 = GM/r$. As G and M are fixed, the velocity varies inversely with the square root of the radius, so the greater the radius the smaller the velocity.

(The model is slightly more complicated in that the marble has a vertical and horizontal component to its motion, however it does show this effect.)



Accompanying sheet

Gravitational Well

Drop a marble into the well.

What happens to the "orbital distance" of the marble as it sinks in the well?
What happens to the velocity of the marble?

How does the velocity of a satellite vary with orbit radius? Why?

The Human Body

Apparatus

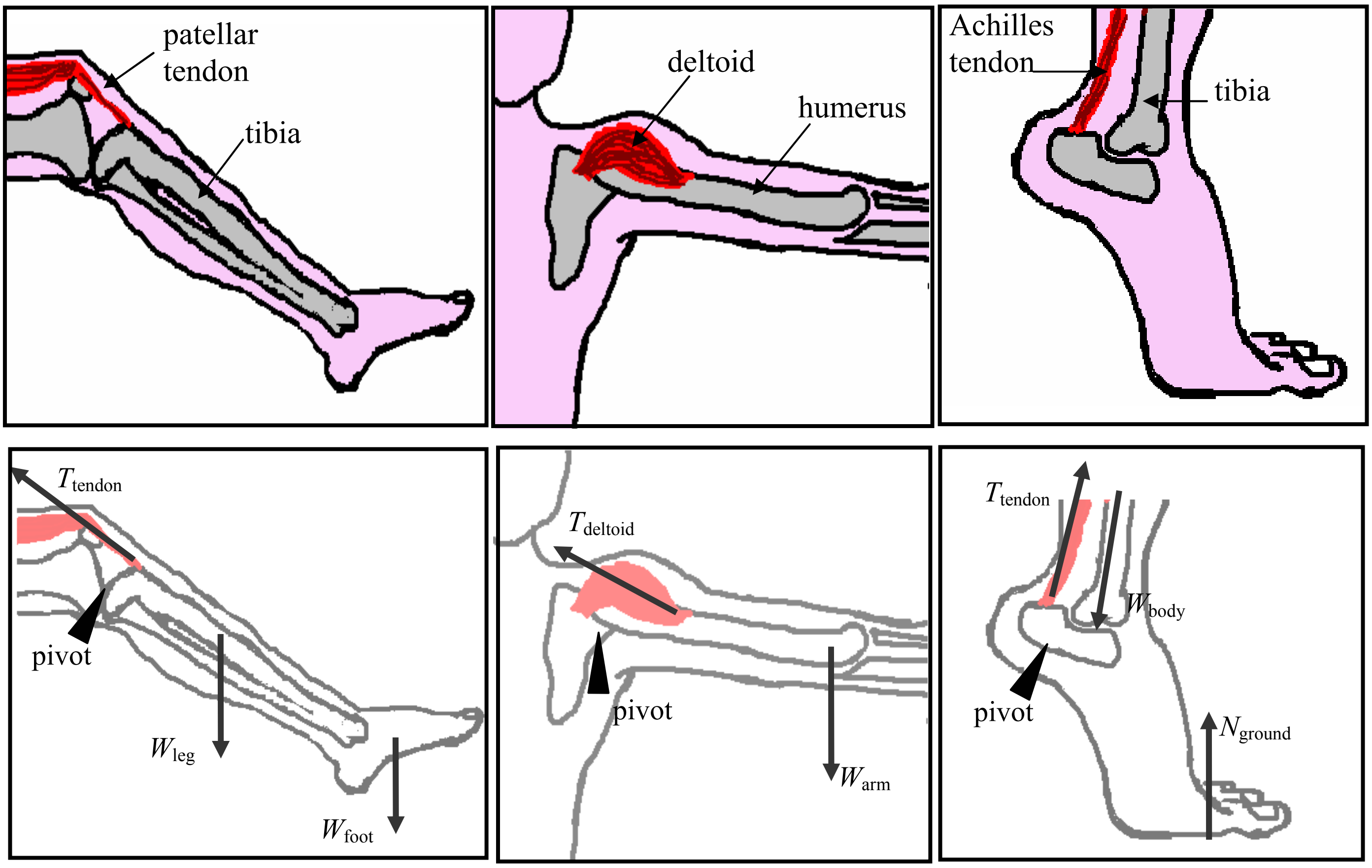
set of diagrams showing some of the pivots (joints) in the human body and the muscles which exert torques around them, see below for examples

Action

The students examine the diagrams, and their own joints. They should identify the pivots, forces and directions of forces acting at the joints.

The Physics

Several joints and the muscles/tendons which exert torques on them are shown.



Accompanying sheet

The Human Body

Identify the pivots in the diagrams.
What muscles act to produce a torque around these joints?
Where do the forces act, and in what direction?

You may want to compare with your own joints.

Kepler’s Second Law

Apparatus

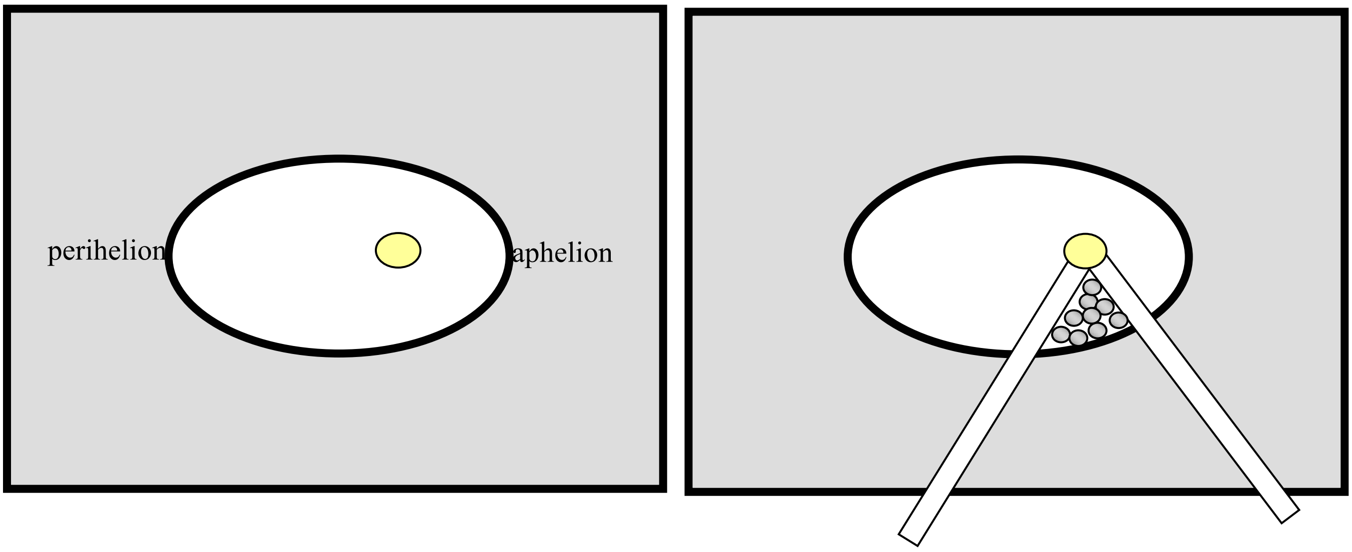
two perspex plates sitting one atop the other, with an ellipse cut out of the top one, with two movable arms attached to one focal point, some ball bearings - see diagram below
The arms should be long enough that they slide around along the upper perspex sheet, the ball bearings should be large enough that they can sit between the two arms without sliding beneath them.

Action

The students move the long arm around, which pushes the ball bearings and other arm along. They should note the relationship between distance from sun, area swept out, and velocity. The area covered by the ball bearings is constant, which can be seen by the lack of gaps between them. The greater the angle between the arms, the greater the angular velocity required to sweep out that area in a given time.

The Physics

The area swept out per unit time by the line joining the planet and the sun is constant. The distance between the sun and planet varies, because the orbit is elliptical, hence the length of this line varies in time. For the area swept out per unit time to be constant the velocity must vary, decreasing as the planet moves further from the sun (towards aphelion) and increasing as it moves closer (towards perihelion). Note that Kepler’s second law is identical to conservation of angular momentum, $L = I\omega =$ constant. This can be seen as the angle increases between the arms to give the same area swept out when the planet is near aphelion. The angle, and hence angular velocity, decreases near perihelion.



Accompanying sheet

Kepler’s Second Law

Move the “planet” around the sun.
Note the line joining the planet to the sun and observe the area that it sweeps out.

What happens to the velocity of the planet as it moves
further away from the sun (towards aphelion)?

What happens as it moves closer to the sun (towards perihelion)?

A Loaded Race

Apparatus

ramp, several balls of different sizes and masses, several cylinders (for example large and small cans of different masses)

Action

The students try to predict which can or ball will win a given race. They then allow the objects to roll down the ramp and check their predictions.

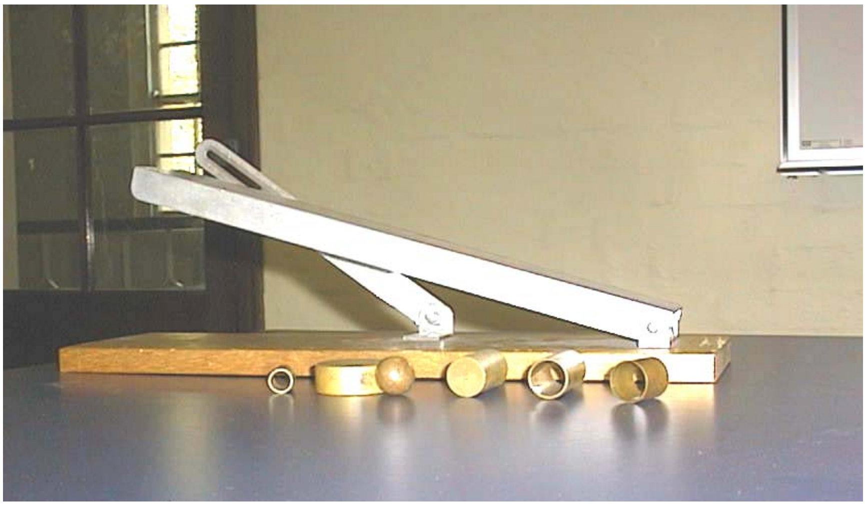
Note that a full "chunky soup" can is interesting because it can not be considered a solid mass, the contents move about changing the behaviour of the can.

The Physics

Neglecting air resistance, all the solid spheres will hit the bottom at the same time. From energy conservation equations we have $mgh = \frac{1}{2} mv^2 + \frac{1}{2} I\omega^2$ rearranging for v gives $v = \sqrt{10/7\, gh} \sim 1.19\, gh$ for solid spheres. Thus the velocity at the bottom of the ramp is independent of M and R so all the balls should reach the bottom at the same time.

For a solid cylinder $v = \sqrt{4/3\, gh} \sim 1.15\, gh$, so generally spheres have a higher speed than a cylinder and will win the race.

A soup can with contents that slosh about will also take longer than one with more solid contents.



Accompanying sheet

A Loaded Race

What determines how fast a sphere or cylinder rolls down a hill?

Examine the various objects.
Which will roll fastest?

Experiment with rolling them down the hill.
Why do some roll faster than others?

Maps

Apparatus

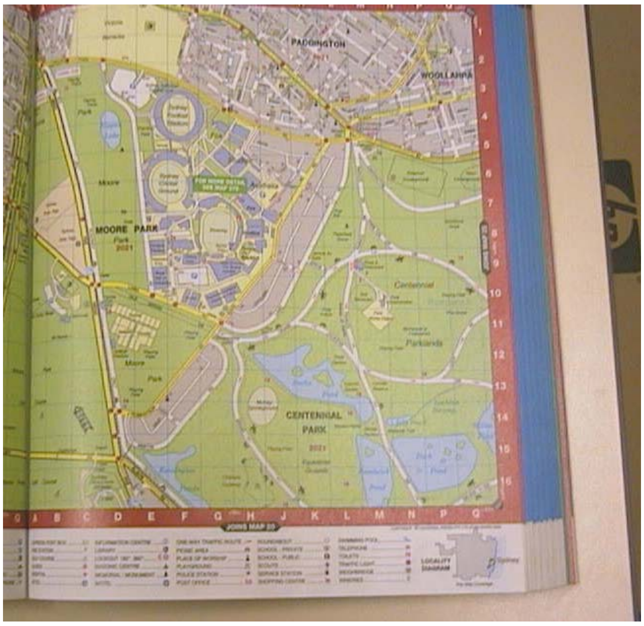
street directory, other maps, e.g. campus maps

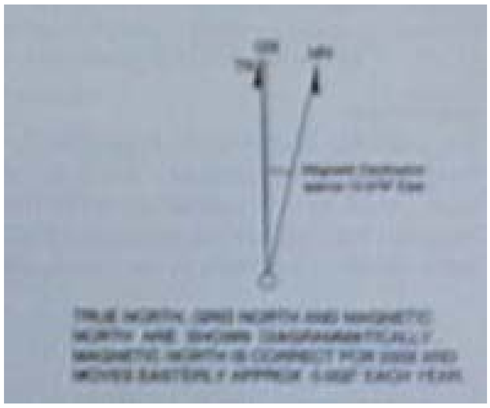
Action

The students examine the maps and look for examples of the use of vectors. They choose a starting and finishing point on a map, for example the university and the local shops, and find a vector which represents the displacement when travelling from one to the other.

The Physics

Vectors are used to define positions on the maps via a letter/number grid. Most maps will also show a vector pointing north to define compass directions on the map, and sometimes vectors showing both true north and magnetic north. The vector representing displacement can be written as x North + y West, or in terms of the angle.





Accompanying sheet

Maps

Examine the maps.

How many examples of the use of vectors can you find?
(There are at least two.)

Choose a starting point and an end point.
Write down the vector that describes the displacement
from the starting point to the end point.

Marble Ejecting Trolley

Apparatus

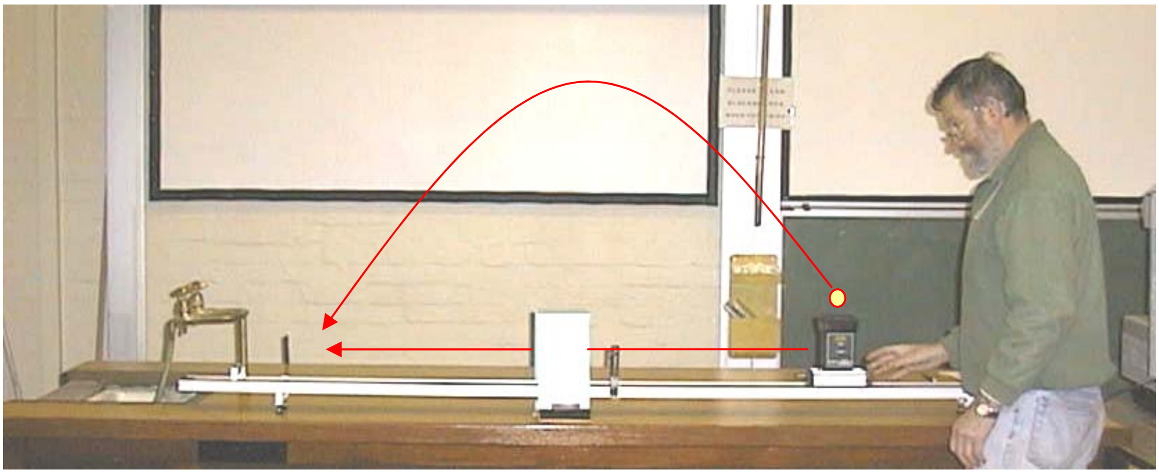
projectile launcher with wide barrel pointing directly upwards, mounted on trolley, marbles or other small projectiles

Action

The students launch a marble from the launcher while it is stationary. They then predict what will happen if the trolley is moving while a marble is ejected. They roll the trolley forwards, and eject a marble to test their predictions. Note that this should be done by giving the trolley a gentle push and then launching so that its velocity is as close to constant as possible. Alternatively, a motorized trolley, such as the base of a battery powered toy car or train, can be used.

The Physics

The marble will have a constant horizontal velocity (neglecting air resistance) equal to that at which it was launched, i.e. the horizontal velocity of the trolley. Its vertical velocity will be $v_{initial} - gt$. These components are independent. Hence in the horizontal direction the trolley and marble have the same displacement and the marble falls back into the barrel of the launcher. This is also a good activity to introduce reference frames. In the trolley's frame the marble has zero horizontal velocity, in the frame of the student observers it has some velocity, $v > 0$.



Lecture demonstration coordinator (University of Sydney)
demonstrates the marble ejecting trolley.

Accompanying sheet

Marble Ejecting Trolley

With the trolley stationary, eject the marble.

What will happen if it is moving and a marble is ejected?
Check your prediction.

Warning:
Do NOT stand in front of the trolley. Do not look into the barrel!

Minkowski Diagrams

Apparatus

large Minkowski diagram, contacted or laminated, markers for drawing on it

Action

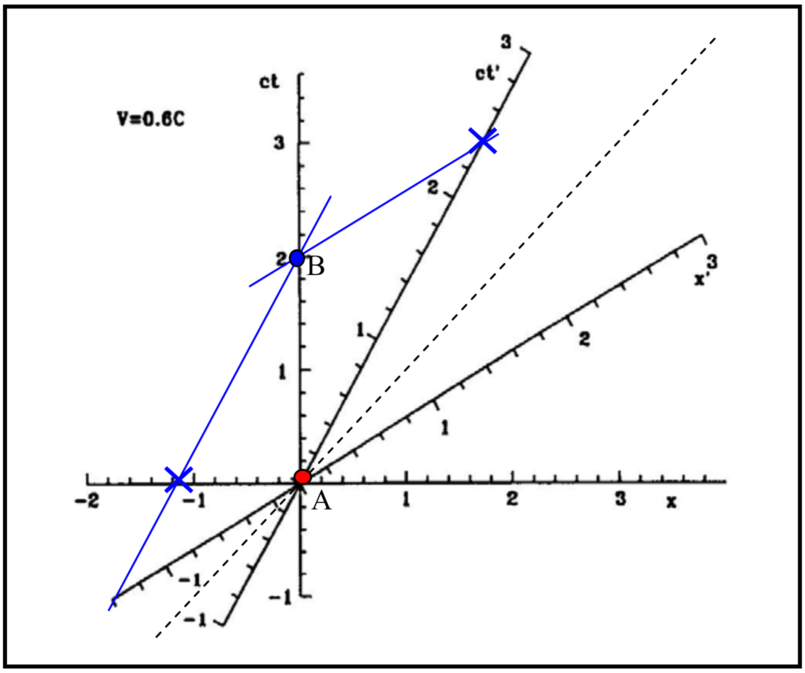
The students should begin by identifying the two sets of axes as belonging to two different reference frames, *S* and *S*'.
The question contains the following information:
Frame *S* is stationary relative to the ground, and frame *S*' is a frame moving relative to the ground along with an alien spacecraft at velocity $v = 0.6c$. At time $t = t' = 0$ the spacecraft passes FBI agent Fox Mulder. Fox is at the origin of the *x* and *x*' axes. 6 nanoseconds later he turns on his mobile phone to make a call to his partner.

The students mark the coordinates for each of these two events on the Minkowski diagram. They then draw lines back to the axes to find the *x, t* and *x', t'*, coordinates for each event.

The Physics

The axes of frame *S* are the *x* and *ct* axes. Event A on the diagram is the spacecraft passing Fox Mulder, and occurs $x = 0$, $t = 0$ in *S*, and $x' = 0$, $t' = 0$ in *S'*.
Event B is Fox turning his phone on.
This happens at $x = 0$, $t = 6$ ns $= 2$ *ct* in the *S* frame.

In the *S'* frame this happens at $x' = -1.4$, $t' = 7.5$ ns. These coordinates are found by drawing lines through the point (point B in this case) parallel to the *S'* axes and finding the intersections with the *x'* and *ct'* axes.
Note that the time axis is *ct* not *t*, so that in finding the time we need to divide by *c*.



Accompanying sheet

Minkowski Diagrams

The diagram has two sets of axis, one for each of two reference frames.

Frame *S* is stationary relative to the ground, frame *S*' is a frame moving relative to the ground along with an alien spacecraft at velocity $v = 0.6c$.
At time $t = t' = 0$ the spacecraft passes FBI agent Fox Mulder.
Fox is at the origin of the *x* and *x*' axes.
6 nanoseconds later he turns on his mobile phone to make a call to his partner.

Mark the coordinates for each of these two events on the Minkowski diagram.
Write down the x, t and x', t', coordinates for each event.

Mirrors and Reflections -Coordinate Systems

Apparatus

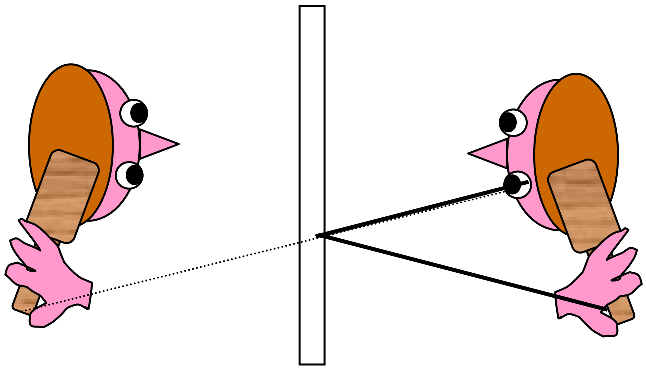
large mirror

Action

The students look at their own reflection in the mirror. They should try moving a hand left and right and up and down. They should recognize that left and right are reversed, but not up and down.

The Physics

In a reflection left and right seem to be reversed, but not up and down. This is because we define left and right as relative to ourselves, not our surroundings. It is important to know how you are defining your coordinate system. For example, "towards the wall" and "away from the wall" are not reversed, just as up and down are not reversed. Up and down directions in an externally defined coordinate system, as well as in your internally defined system of coordinates. They are defined externally, usually relative to the ground, hence are not reversed.



Accompanying sheet

Mirrors and Reflections - Coordinate Systems

Look at your reflection in the mirror.

Move your right hand to the right.

What does your reflection do?
Which way does the reflected hand move?

Why are left and right reversed in the mirror but not up and down?

Models of the Solar System

Apparatus

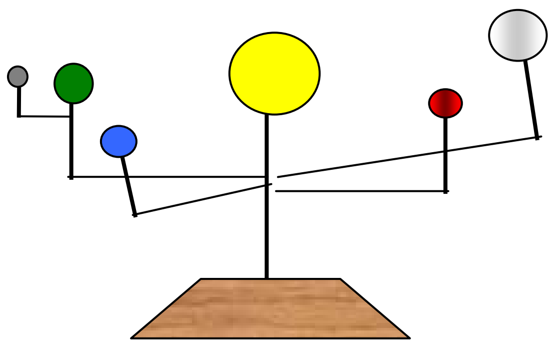
different models of the solar system, ideally including a pre-Copernican model with the Earth at the centre of the planet's and sun's orbits
Note that these are simple to make using wire and polystyrene balls.

Action

The students examine the models and note differences and similarities between them.

The Physics

Our understanding of the motion of the planets has changed greatly over the last few hundred years. We no longer believe that the Earth is at the centre of the solar system with everything else orbiting around it. (It is interesting to note that while this is generally taken for granted these days, in 1981 Pope John Paul II set up a commission to "coordinate the research of theologians, scientists and historians which would help to further clarify the events which occurred between Galileo and the Church and, more generally, the Ptolemaic - Copernican controversy of the 16th and 17th centuries in which the Galileo affair is situated". Galileo seems to have been officially forgiven in 1992.)
We also know that the planets travel in elliptic orbits described by Kepler's laws, rather than in circular orbits. This has implications such as the varying velocity of the planets in their orbits.



Accompanying sheet

Models of the Solar System

Examine the different models,

How are they similar?
How are they different?

Describe how our knowledge of the orbits of the planets has evolved in time.

Newton's Cradle – Two Steel Balls

Apparatus

Newton's cradle with only two steel balls

Action

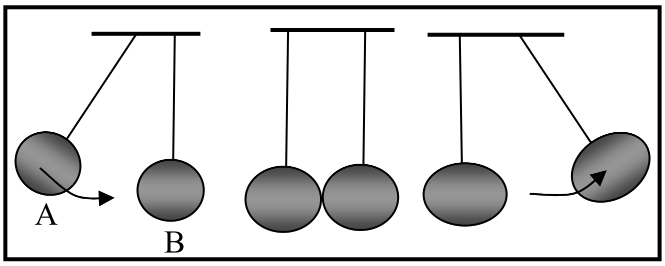
The students swing one of the balls out and observe what happens when it is released and collides with the other ball. They should try to identify the forces acting on the balls and identify an action-reaction force pair. This demonstration is used to demonstrate Newton's third law on the Newton's laws sheets, and conservation of momentum of the Momentum Conservation sheets.

The Physics

When the swung ball collides with the stationary ball is exerts a force on it which accelerates it and causes it to swing outwards. The stationary ball exerts an equal and opposite force on the initially moving ball, which decelerates it, causing it to stop. The action-reaction force pair is the force due to ball A on ball B and the force due to ball B on ball A. Note these forces have opposite directions, equal magnitudes and act on different objects. At all times gravity and tension due to the strings act on the balls, but these are *not* an action-reaction pair.

When the first ball (ball A) swings back and hits the second ball (B) it stops. The second ball swings out. Momentum is conserved, so the change in momentum of ball A must be equal in magnitude and opposite in direction to the change in momentum of ball B. We can write this as $\Delta p_A = - \Delta p_B$.

We also know that $\vec{\mathbf{F}} = \frac{d\vec{p}}{dt}$, which is Newton's second law. Since the momentum changes of the two balls are equal in magnitude and opposite in sign, the forces acting on them must also be equal in magnitude and opposite in sign. This is equivalent to Newton's third law which states that the force exerted by ball A on ball B must be equal and opposite to the force exerted by ball B on ball A, $F_{AB} = -F_{AB}$.



Accompanying sheet

Newton's Cradle – Two Steel Balls

Swing one of the balls out and release it.

What happens?
Is there an action-reaction pair here?
If so, what is it?

Newton's Cradle – Different Balls

Apparatus

two sets of Newton's cradle with different types of balls, one with lead balls and one with steel balls

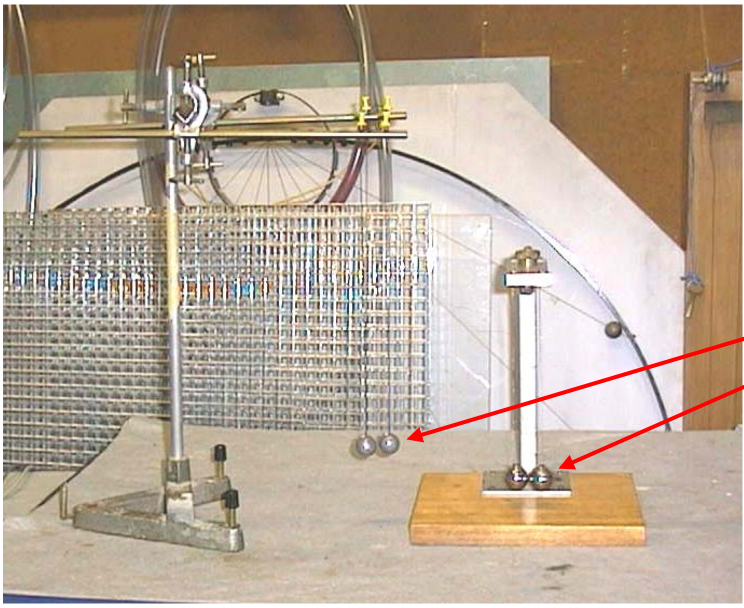
Action

The students swing one of the balls out and observe what happens when it is released and collides with the next ball along. They should compare the behaviour of the two sets.

The Physics

Steel balls have almost elastic collisions, in which both kinetic energy and momentum are conserved. When the ball is released and swings back it stops, and the ball at the far end swings out to almost the same height as the first ball was lifted to. This is due to a series of very rapid collisions between the balls.

The lead balls have inelastic collisions in which only momentum is conserved, so the ball at the far end swings out very little as not much energy is transferred. This is because lead is softer and deforms on impact, absorbing the kinetic energy and dissipating it as thermal energy.



Newton's cradle with lead balls and steel balls.

Accompanying sheet

Newton's Cradle – Different Balls

Experiment with the two sets of Newton's cradle.
Why do they behave differently?

Is energy being conserved?
What about momentum?
In which set is the collision an elastic one? Explain your answer.

Pendulum

Apparatus

simple pendulum, such as a ball on a string suspended from a retort stand

Action

The students swing the pendulum and determine how the kinetic and gravitational potential energy of the bob vary in time. They identify the positions at which kinetic energy is a maximum and minimum, and where gravitational potential energy is maximum and minimum. For the "motion" worksheets the students determine where the velocity and acceleration are a minimum and maximum.

For the Work, Power and Energy worksheets the students look at energy changes and determine which forces are doing work.

The Physics

At the lowest point of its motion, kinetic energy is maximum and potential energy is minimum. This is where the velocity is a maximum. At the highest point of its motion, kinetic energy is minimum (i.e. zero) and potential energy is maximum. The acceleration is a maximum at the end points of the swing, and a minimum (zero) in the middle, at the lowest point.

The forces acting are gravity, tension and friction. Tension does no work because it is always at right angles to the direction of motion. Both gravity and friction do work, although the only *net* work done on the pendulum in a complete swing is done by friction slowing the pendulum down.

Students at the Australian Catholic University observing energy changes in a pendulum.

Accompanying sheets

Pendulum	**Pendulum**
At what position is the kinetic energy maximum? Where is it minimum? At what position is the potential energy maximum? Where is it minimum? Draw energy bar graphs for the pendulum at different points in its swing.	What forces are acting on the pendulum? What work is being done on the pendulum? What forces are doing the work?.

Pendulum on Trolley

Apparatus

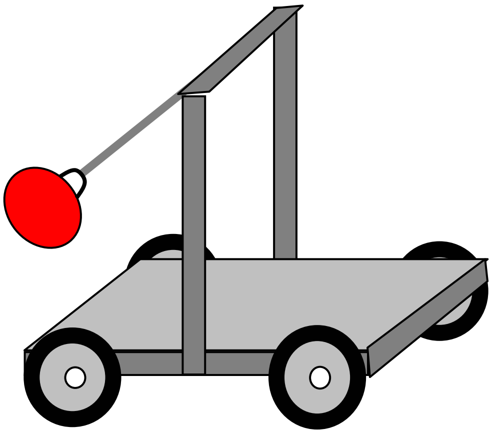
simple pendulum (not too big) mounted on a trolley

Action

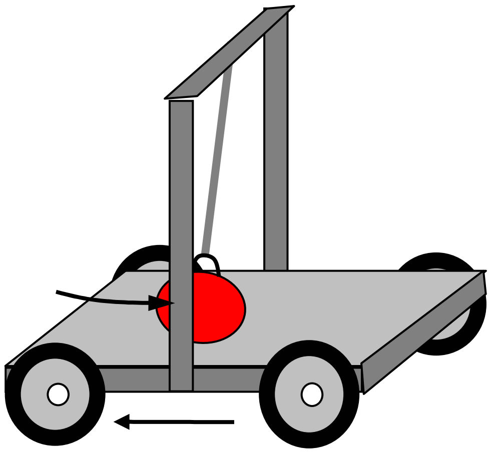
The students swing the pendulum bob out while holding the base still. They then let go of the base and release the bob. They should observe the motion of the pendulum and the trolley.

The Physics

When the bob is raised and the base held still the total momentum of the pendulum-trolley system is zero. When you release the bob it swings down, gaining momentum. In order for momentum to be conserved the trolley must move the opposite way, which it does. As the pendulum swings back and forth the trolley will roll back and forth in the opposite direction, until friction eventually stops it.



release bob



bob and pendulum move
in opposite directions

Accompanying sheet

Pendulum on Trolley

Hold the trolley still and swing the pendulum bob out.

Now let go of the trolley and release the bob.

What happens to the trolley?
Why does it behave like this?

Power

Apparatus

various small appliances with power ratings shown, for example hair dryer, jug, heater, toaster etc

Action

The students examine the various appliances and determine how much power they use. They should try to describe the energy conversions which take place when the devices are operating.

The Physics

The power listed on the device is the rate at which it converts electrical potential energy into other forms of energy. A hairdryer converts electrical potential energy into heat and kinetic energy. Most appliances convert a lot of electrical potential energy into unwanted heat. In general devices which use motors, such as hairdryers, use more power than those that simply heat, such as toasters or jugs.

Selection of appliances and detail from fan heater showing power rating.

Accompanying sheet

Power

Examine the various appliances on display.
Which uses the most power?
Which uses the least?

At what rate do they turn electrical energy into other forms of energy?

What energy conversions are taking place when these appliances are working?

Projectile Launcher

Apparatus

projectile launcher which can be angled, soft projectiles

A simple launcher can be made using a piece of pipe and spring with trigger to release the spring. Alternatively a toy gun with spring which can be mounted on a retort stand and angled can be used.

Action

The students experiment with firing the projectiles with different launch angles, and see what angle gives them the maximum range.

Note: Students should be cautioned to keep clear of the projectile launcher when firing, and never look down the launcher.

The Physics

Provided initial speeds are the same, the launch angle for maximum range is 45^o. To achieve maximum height the projectile should be launched directly upwards so that its initial vertical velocity is a maximum.

Accompanying sheet

Projectile Launcher

What is the angle of launch corresponding to maximum range?

What is the angle of launch corresponding to maximum vertical height?

.

Warning:
DO NOT stand in front of the launcher!!!!!!!!

Relativity and Electromagnetism

Apparatus

coil connected to ammeter, bar magnet

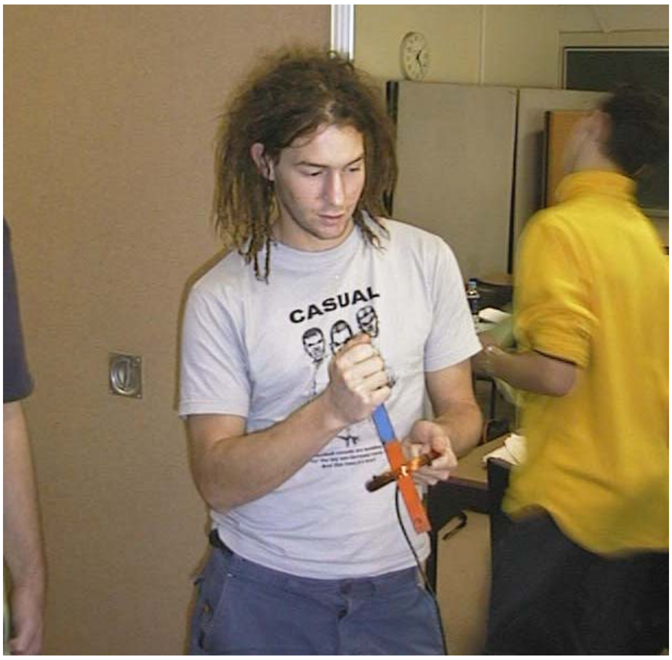
Action

The students experiment with moving the magnet in and out of the coil in different directions. They should then investigate the effect of moving the coil rather than the magnet.

The Physics

The direction of the current depends on the motion of the magnet relative to the loop and changes when the magnet is reversed. It doesn't matter whether the coil or the magnet is moved, only the relative motion of the two is important. It was this observation that led Einstein to his theory of relativity.

Whether you consider a reference frame attached to the magnet or the coil makes no difference, the physical result, a current, is the same.



Student at the University of Sydney experimenting with a magnet and a coil.

Accompanying sheet

Relativity and Electromagnetism

Move the magnet in and out of the loop of wire with the ammeter.

What happens if the loop is moved and the magnet is stationary?

What does this tell you about the frame of reference of the magnet and the coil?

Rolling Down a Ramp

Apparatus

ramp with one section polished very smooth or very lightly oiled, two identical smooth balls

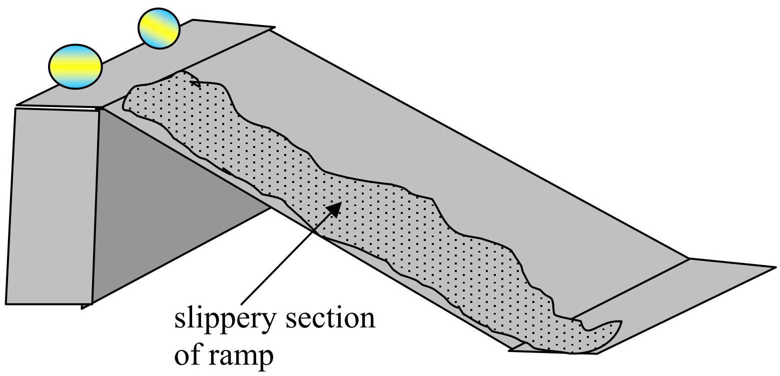
The ramp should be angled such that on one side a ball will slide down without rolling, and on the other a ball will roll down.

Action

The students predict on which side (approximately frictionless, or with friction) the ball will reach the bottom first. They then test their prediction. They should consider the forces acting on the balls in both cases, and the work done by these forces.

The Physics

A ball will get to the bottom of a frictionless ramp faster than one with friction. On the frictionless ramp the ball slides down, and does not roll, all the balls potential energy is converted to translational kinetic energy. When the ball rolls, some of the potential energy is converted to translational kinetic energy and some to rotational kinetic energy, hence it will have a smaller translational velocity and take longer to reach the bottom. The frictional force acts to counteract the sliding that would otherwise occur. The torque means that rotational motion (rolling) occurs.



Accompanying sheet

Rolling Down a Ramp

One side of the ramp is very slippery, the other is not.
On which side will a ball reach the bottom first?

Place the balls at the top of the ramp.

On which side does the ball reach the bottom first?
Why does this ball win the race?

Why is friction necessary for rolling?

Rotating Stool

Apparatus

a stool which rotates smoothly,
small hand held weights,
enough floor space for other students to stand well back.

Action

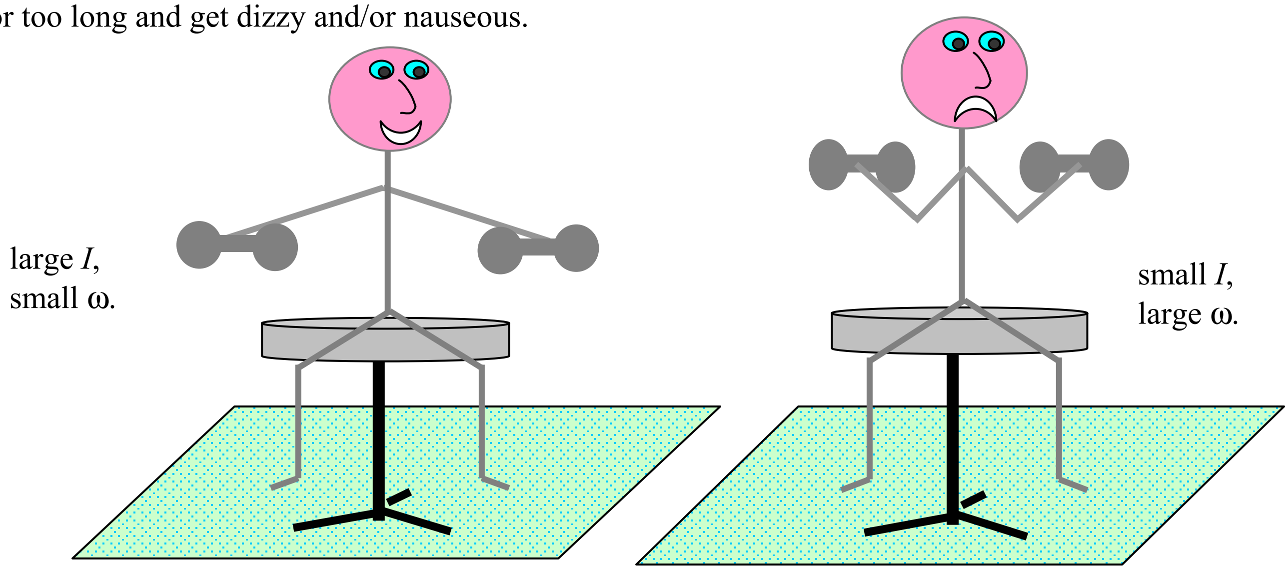
The students take turns sitting on the stool and being spun SLOWLY by each other. They should start off with their arms drawn in, so that they can brake by extending their arms. If they start with arms out they can spin very quickly and fall off when they draw their arms in.

The Physics

When the hands are stretched the system has a larger rotational inertia and a smaller angular velocity. When the hands are pulled inward towards the body the rotational inertia decreases and hence the angular velocity increases. Angular momentum of the system (person and weights) is conserved.

Notes:

It is important that other students stay well clear of the chair to avoid mishaps, and students do not rotate for too long and get dizzy and/or nauseous.



Accompanying sheet

Rotating Stool

Sit on the stool with equal weights in your hands.

Start rotating with the hands stretched out
and slowly bring your hands towards your chest.
What happens? Why?

What happens when you stretch your arms out again?

Warning: Stand well back from the chair when it is in use!!
Do Not Rotate Too Quickly!!!

Rotation Platform

Apparatus

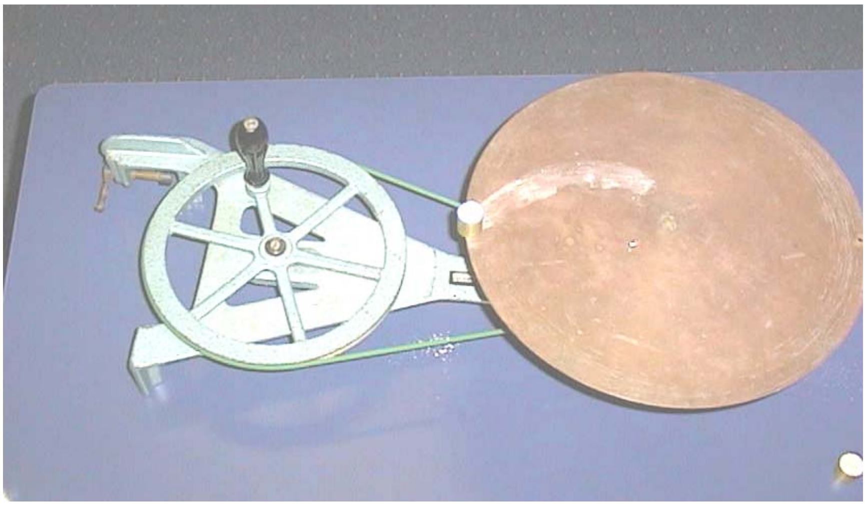
rotation platform, such as a small turntable from a record player, with some way of turning it steadily, small objects, chalk dust

Action

The students dip the base of the objects in chalk dust, and place them on the rotation platform. They then turn the platform steadily, gradually increasing speed, and observe when and how the objects slide off.

The Physics

The speed of rotation, distance from the centre and coefficient of friction, μ, affect slipping, but not the mass. The objects will slide off at a tangent to the curve, in the direction of their velocity vector. At the edges of the platform the linear acceleration is greatest, hence objects are most likely to slip off when close to the edge.



Rotation platform showing chalk mark
of object about to slip off.

Accompanying sheet

Rotation Platform

Put some chalk dust on an object and place it on the turntable.

Turn the handle at a steady rate, then gradually increase the angular velocity.
What happens to the object on the turntable?
Describe the path that it follows?

Try placing the object in different positions on the turntable.
What happens?

Shoes

Apparatus

selection of shoes for different purposes, for example golf or soccer shoes with spikes for grip, walking shoes, dress shoes with slippery soles, dancing shoes, etc

Action

The students examine the soles of the shoes and consider why different shoes have different soles.

The Physics

Some activities, such as soccer, require a lot of grip as they are played on slippery surfaces. Normal shoes will not provide enough grip as the coefficient of friction between shoe and muddy ground will be too low. This is less important in walking as the accelerations are usually not as great, hence the coefficient of friction does not need to be so large. Dancing shoes need to be able to slide, but not too much. Hence they usually have smooth soles, to which talc is applied to increase the coefficient of friction between shoe and floor.

Accompanying sheet

Shoes

Why do some of the shoes have spikes?
If spikes give you more grip, why don’t hiking or running shoes have spikes?

Why do some of the shoes have smooth soles?
How can the coefficient of friction between
these shoes and the floor be increased?

Smooth Variable Ramp

Apparatus

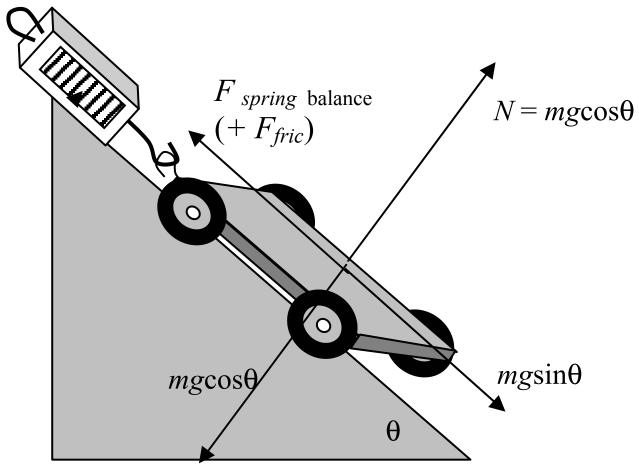
smooth variable ramp, small trolley or toy car, spring balance, protractor

Action

The students attach the trolley to the spring balance and place the trolley on the ramp. They then adjust the angle of the ramp and observe how the reading on the balance changes. They should draw a free body diagram showing the forces parallel and perpendicular to the ramp, and comment on the relative sizes of these forces.

The Physics

The forces acting on the trolley are the normal force, gravity, the force due to the spring balance and friction. Decomposing these into components along the ramp and perpendicular to the ramp gives:
Forces perpendicular to ramp: N and $mg\cos\theta$, which are equal.
Forces along the ramp: $mg\sin\theta$, the force due to the spring balance and friction.
The force due to the spring balance plus friction will be equal to $mg\sin\theta$, the friction should be very small so the spring balance should read (approximately) $mg\sin\theta$. This will increase as the angle increases, and will be equal to mg when the ramp is vertical.



Accompanying sheet

Smooth Variable Ramp

Draw a free body diagram showing the forces acting on the trolley.
What are the components of the forces
acting parallel and perpendicular to the ramp?

Is the force on the trolley from the spring balance equal to $mg\sin\theta$?
What happens to the force needed to keep the trolley stationary on the ramp
as the inclination of the ramp is increased?

Solar Panel and Electric Circuit

Apparatus

small solar panel connected to small motor or light, desk lamp

Action

The students hold the solar panel beneath the desk light and observe the light or motor. They track the energy changes from the desk light through the circuit. It is helpful to draw a flow chart showing the energy conversions taking place.

The Physics

Energy as light is converted to electrical energy by the solar cell which is then converted to kinetic energy by the motor or back to light by the globe. Some energy is also converted to thermal energy at each step.

A student at the Australian Catholic University using the light energy from a desk lamp to run a small fan to cool himself.

Accompanying sheet

Solar Panel and Electric Circuit

Trace the energy conversions and identify
which ones are "not useful" and which are.

Think of a case where this "not useful" energy may be useful.

Trace energy transformations that occur as water stored in a dam,
supplies energy to a hydro-electric power station,
which supplies energy to turn on an appliance at home.

Space - Time Diagram

Apparatus

large space - time diagram (for example that shown below), covered in contact or laminated, with markers to draw on it

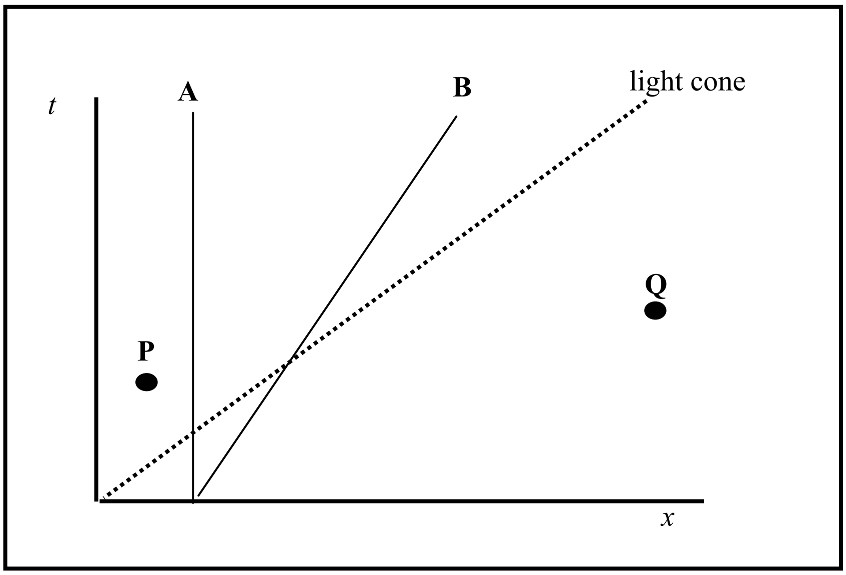
Action

The students identify the paths shown as belonging to moving or stationary objects and identify the light cone. They should recognize that it is not possible to travel faster than the speed of light, hence no path steeper than the light cone is possible.

The Physics

Line A represents an object at rest (relative to the reference frame). Its position is not changing in time. Line B representing an object whose position is changing in time, hence this is a moving object.

It is not possible for any object to move from point P in space-time to point Q, as to do so it would have to travel faster than the speed of light. No path steeper than the light cone is permitted, and it is impossible to move from the left side of the light cone to the right.



Accompanying sheet

Space-Time Diagram

A space-time diagram is useful for showing how things move in time.

How is this diagram different to the displacement diagrams you usually draw?

What does path A represent?
What does path B represent?

Is it possible for an object to go from point P to point Q? Explain your answer.

Tennis Racquet

Apparatus

tennis (or squash) racquet, tennis balls

Action

The students hold the tennis racquet in one hand and drop a ball onto it, observing how high the ball bounces from the racquet. They then hold the racquet with the handle firmly pressed against a horizontal surface (such as the floor or desktop). This is quite difficult, and works best when the handle is stood or sat on. They then drop the ball onto the racquet from the same height above the racquet as previously, and observe how high it bounces this time.

The Physics

Kinetic energy from the ball is transferred to the racquet strings and through the handle to the wrist or hand of the person holding the racquet. When the racquet is held loosely it vibrates, dissipating energy. When it is held firmly so that it cannot vibrate there is less energy lost from the strings to the handle. Hence more energy is stored in the strings and returned to the ball, allowing it to bounce higher than when the handle is loosely held.

Students at the University of Sydney experimenting with the tennis racquet.

Accompanying sheet

Tennis Racquet

Hold the racquet out horizontally and drop a ball onto it.
How high does the ball bounce?

Hold the handle still by stepping on it.
Drop a ball onto it from the same height as before.
How high does the ball bounce now? Why?

Tools

Apparatus

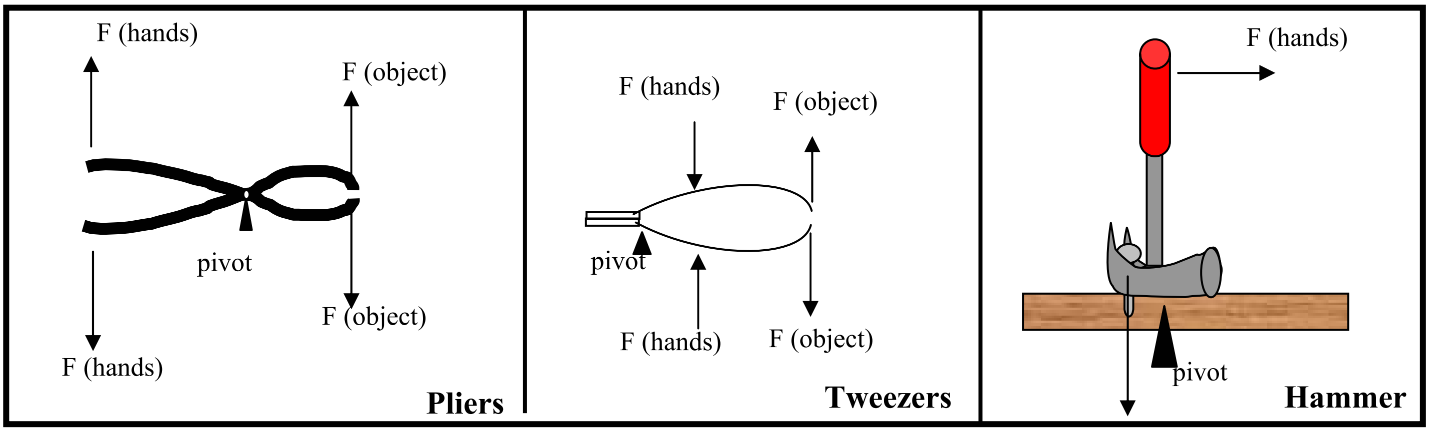
a range of tools which torques; for example pliers, screw drivers, a hammer with claw for removing nails and nail in block of wood, tweezers, spanners etc

Action

The students examine and experiment with using the tools. They attempt to identify the pivot and direction of torque for each tool.

The Physics

Many tools use torques, three examples are shown in the diagrams below. The forces shown are those applied by the hands of the person applying the tool, and those applied by the object to which the tool is being applied.



Accompanying sheet

Tools

On display are tools that use 'torque' in their design and application.
Examine the tools. How are they used?

Identify their pivots, axes of rotation and the direction of the forces on the tools.

Train Set

Apparatus

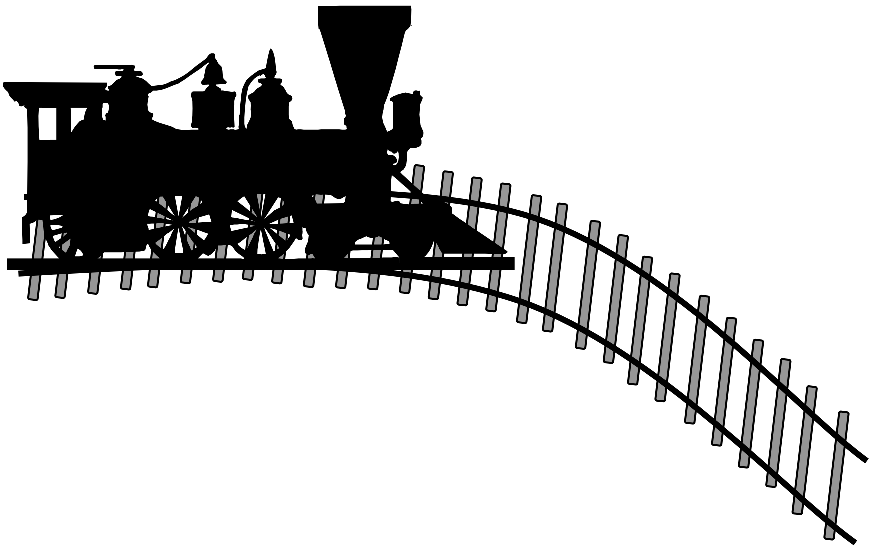
toy train set with variable speed controller and track laid out straight

Action

The students choose a positive and negative direction along the track. They then use the speed controller to move the train along the track with positive and negative velocities, and positive and negative accelerations.

The Physics

To move with a positive velocity the train must be moving in the positive direction. To move with a positive acceleration the velocity of the train must be increasing. This will be the case if it is getting faster while moving in the positive direction, or slowing down while moving in the negative direction. To have a negative velocity and a positive acceleration is the second case; slowing down while moving in the negative direction.



Accompanying sheet

Train Set

The train can only move in one dimension.
Choose a convention to label the positive and negative directions.

Use the controller to vary the velocity and acceleration of the train.

Can you move the train from one point to another point
such that it has a negative velocity and a positive acceleration?

Vector Game

Apparatus

large clear floor area marked with grid, set of cards showing vectors

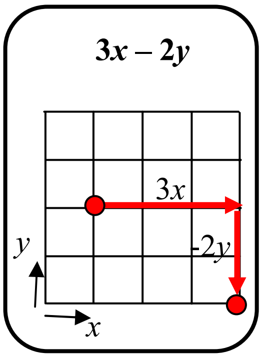
The grid can be marked on using masking tape. The squares should be big enough to stand in, and an *x* and *y* direction should also be clearly marked. The cards should have a vector written on them, and a diagram showing the vector.

Action

One student acts as caller, and also as referee. The other students choose a starting position and walk the vectors called by the caller. The caller should call one vector, and then watch that everyone walks it correctly. The diagram on the card allows the caller to double-check the vectors as walked.

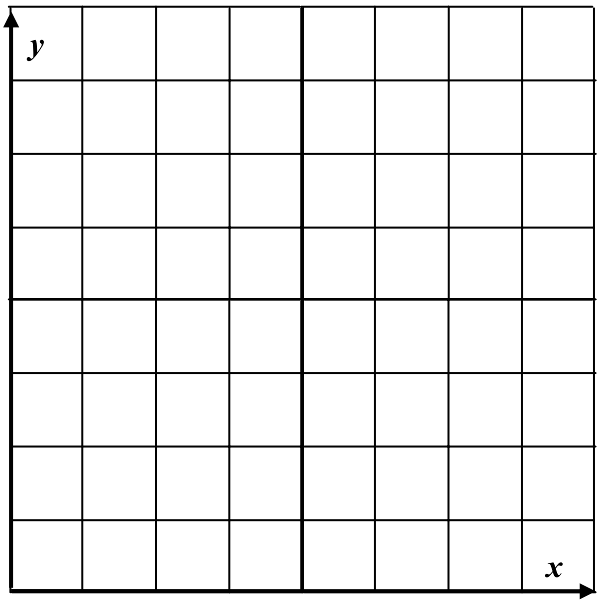
The Physics

The axes are chosen in advance and marked, so you know which direction is +x and which direction is +y. For example, forward may be +y and right may be +x. If the caller says "5x + 3y" you take 5 steps to the right and three steps forward. If the caller says "-5x - 3y" you take five steps left and three steps back.



sample card

grid on floor



Accompanying sheet

Vector Game

One group member is the caller and judge.
They take the cards and call out the vectors, and see who walks them correctly.

Everyone else chooses a starting point near the middle.
Walk the vector as called.
When you get it wrong, you're out!

Velocities

Apparatus

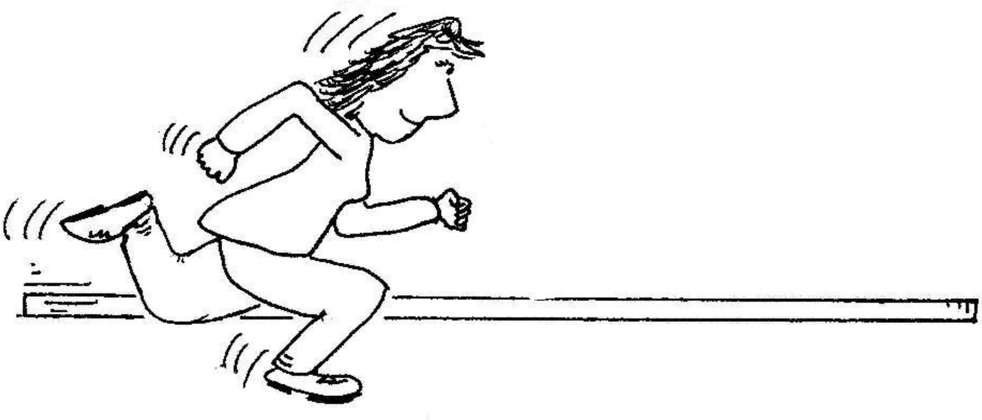
tape measure, stop watches, masking tape

Action

The students use the tape measure and masking tape to place two lines of tape on the floor some set distance (e.g. 10 metres) apart. They then take turns trying to walk from one line to the other with positive and negative velocities, and at a given magnitude of velocity. They will need to define in advance which direction is positive and which negative. They should consider how they define positive, whether with reference to the room (e.g. towards the door/window/blackboard/etc is positive) or with reference to themselves (the way I face is positive). They should recognise that defining direction relative to the room is more useful than defining in terms of self, as they turn around frequently.

The Physics

Velocity is displacement per unit time. Most people have a step length a bit less than 1 m, usually around 70 to 80 cm, so 1 $m.s^{-1}$ is equivalent to a little more than one step per second. To move with a negative velocity they must walk in the negative direction, which is *not* equivalent to walking backwards in the positive direction (unless they have defined positive as the way they are facing).
It is interesting to also get them to consider their acceleration, and how they can have a positive velocity but a negative acceleration etc.



Accompanying sheet

Velocities

Try to walk from one marker to the other at 1 $m.s^{-1}$.
Get someone to time you so that you can check how fast you are going.

Now try to go at 0.5 $m.s^{-1}$ and 3 $m.s^{-1}$.

What do you need to do to move at –1 $m.s^{-1}$?

Yo-yo

Apparatus

one or more yo-yos

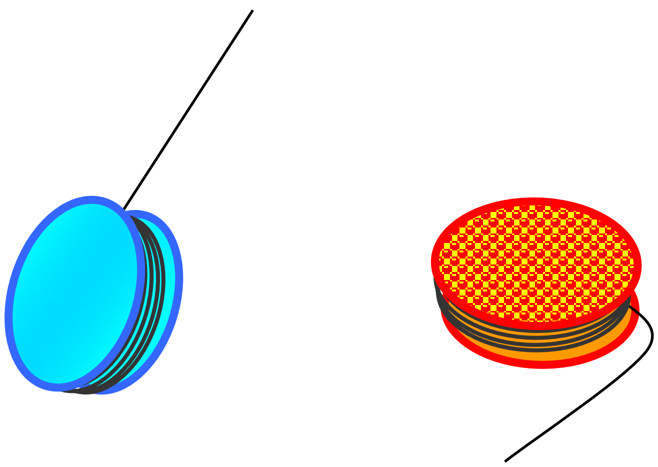
Action

The students experiment with making the yo-yos go up and down. They should examine the yo-yos carefully and try to explain why they go up again, and what force is responsible for accelerating them upwards against gravity.

The Physics

As it falls, the yo-yo loses gravitational potential energy and gains both translational kinetic and rotational kinetic energy. At the end of the fall the yo-yo continues to spin as it has angular momentum. If the string is looped loosely around the central axis then the yo-yo will stay spinning at the bottom of its fall for a reasonably long time.

The yo-yo comes up again if the yo-yoist tugs on the string. The friction between the string and the yo-yo provides an upward force on the yo-yo. Since the yo-yo is spinning, it will continue to rotate as it moves upwards again.



Accompanying sheet

Yo-yo

Experiment with the yo-yo.

Describe the energy conversions that occur as a yoyo falls.

Why does a yo-yo come up again?
What provides the force to accelerate it back up?