FORCED TO GO

Educator's Guide

SCIENCE TRAVELS

Presented By

SCIENCE CENTRE singapore

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The Guide to the “Forced to Go” Exhibition

What to expect in this Exhibition?

“Forced to Go”, an exhibition on the properties of forces, is developed by Science Centre Singapore to allow you to explore the different types of forces and their curious effects on the objects affected by them.

Objective of the Exhibition

Invoke your sense of wonder and curiosity by introducing exhibits that show physical movement in surprising, unexpected, and engaging ways.

What to expect from this guide?

The travelling exhibition features a total of 15 interactive exhibits.

You may refer to the guide for the following:

- Background understanding of the physics that the exhibits generally involve
- Contents of the exhibit, including:
  - An overview of what the exhibit is about
  - Safety or use precautions regarding the exhibit
  - Questions to think about as you use the exhibit
  - How the exhibit works
  - How the phenomena may be observed in daily life, or fun science DIYs to try.
- Additional books/audiobooks to sustain learning of the topic, for students of different ages, educators and general public

Safety or Use Precautions

The Forced to Go exhibition set is intended to require no supervision to use, and design precautions have been made to allow safe use as far as reasonably possible. Exhibit parts are also designed to allow freedom of movement in hopes that users can explore the physics of the components without feeling encumbered or limited.

Each interactive involves loose or moving parts that can pose possible danger to the users or cause damage to the exhibits through misuse. The exhibits are public property and damages or loss of exhibit components significantly impact the experience of other users.

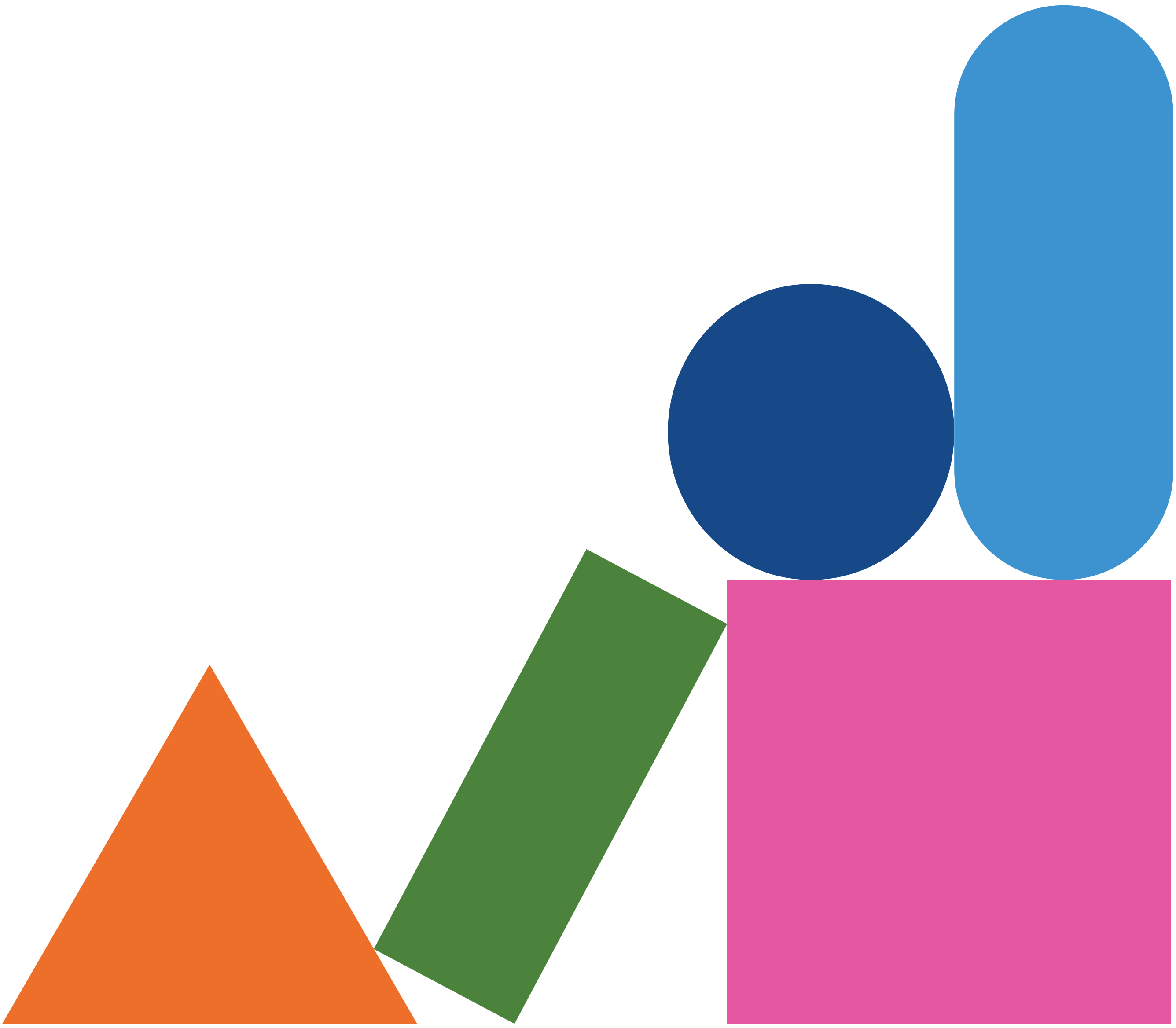
The Science Centre Board entrusts users to act in good faith and treat exhibit components appropriately with considerations for others and future users’ needs.

Contents

Background Understanding

Forces are a fundamental part of our lives. Our heart pumps, exerting a force on our blood to push it through our arteries. Our fingers manoeuvre a pair of chopsticks, clamping onto a piece of food. The ebb and rise of the tides are caused by gravitational force. Inescapable as forces are, the effects they create on objects have long since been quantified.

The first section introduces basic theories and laws in classical physics relevant to the individual exhibits.



What is a Force?

We know from personal experience and in the syllabus that a 'force' is expressed as either a push or a pull. A push would be a force away from the observer and a pull would be a force towards the observer. A force has a component of directionality and is described as a **vector**.

Motion produced by force can express a whole range of interesting effects. When an object moves in a curved path, we get centrifugal force e.g. with passengers in a car when it swerves past a corner. When something moves while in contact with a surface, it creates frictional forces that slows down the motion, as with scraping your shoes against concrete. Pressure is constant force acting on the surface on an object, such as squeezing a toothpaste tube. And these are just physical forces! There are also magnetic, electric and gravitational forces.

Isaac Newton's Laws of Motion
These are a set of principles that Isaac Newton developed to explain the relationship between physical objects, the forces acting upon them and their motion through space.

Newton's 1st Law of Motion: An object in motion tends to stay in motion at a constant speed and in a straight line (constant velocity). An object at rest tends to stay at rest, unless an external force acts on it.

Newton's 2nd Law of Motion: The acceleration of an object depends on the mass of the object and the force acting on the object. This can be simplified by the equation as follows: *Force = Mass x Acceleration.*

Newton's 3rd Law of Motion: Whenever one object exerts a force on another object, the second object exerts an equal and opposite force on the first object.

What is Gravity?

Isaac Newton also studied gravity and understood it as a type of force. Gravity is a force that acts between any two objects with mass. We can find out how strong the attractive force is using this equation:

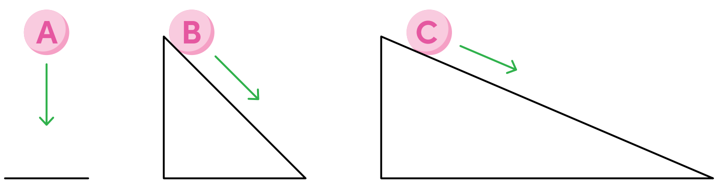
$$F = G\frac{m_1 m_2}{r^2}$$

The two objects attract each other by the same amount of force, the value **F**. **m_1** and **m_2** refer to the mass of the two objects. **G** is the gravitational constant with the approximate value of **6.6743×10^{-11} $N \cdot m^2/kg^2$**, a fixed value that is determined by testing, and r (radial distance) is the distance between the two objects.

The greater the distance between the two objects is, the weaker the gravitational force is between them. Unlike the other forces, the force of gravity only “attracts”. Why do objects not clump together over time if they all attract one another? It is because gravity is extremely weak. On a daily basis, only celestial objects like the moon or the Earth are large enough for us to observe their effects.

The satellite actually attracts the Earth by the same amount of force as the Earth to the satellite! They revolve around one another. But the Earth’s mass is huge and it is also extremely large. As a result, the effect of the satellite’s attraction is not noticeable.

All objects on the Earth are subject to the forces of gravitational attraction of the Earth. The act of speeding up is called acceleration and objects speeding up as they fall to the ground is called gravitational acceleration. It is an increasing speed of 9.8 metres per second for every additional second, or $9.8 m/s^2$.



Ball A accelerates downwards due to gravity at $9.8 m/s^2$. B and C are travelling on a slope. Although all 3 balls travel the same distance vertically, the slopes that ball B and C are travelling on will slow down their acceleration. The gentler the slope, the slower the acceleration of the ball. Nevertheless, they will reach the bottom with the same final speed.

Questions that students may ask:

Q. Is there such a thing as anti-gravity or gravitational repulsion?

Gravitational force is present in all objects and is an attractive force. So far, we have no way of creating gravitational force or fields that repels objects.

Q. Why doesn't Earth or planets fall into the sun from gravity?

The Earth orbits around the sun, at an angle perpendicular to the gravitation attraction to the sun. It is this motion that keeps the Earth (as well as the other planets) from falling into the sun.

Q. Is there gravity in space?

Yes, there is gravity in space. Gravity acts through matter and does not require "air molecules" to transmit force. The Earth exerts a gravitational force on the Moon, while the Sun pulls all the planets in the solar system to orbit around it.

What is Pressure?

There is a consequence of force called **pressure**, which is obtained by:

$$Pressure = \frac{Force}{Area}$$

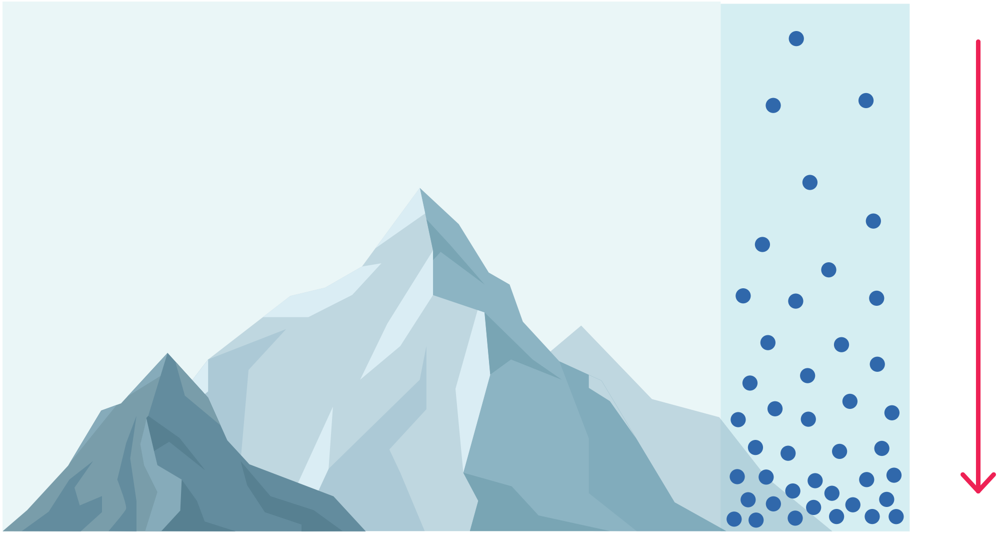
Pressure can be described as a *constant exertion of a force over an area.* The unit for pressure is **pascal**.

In records as early as ancient Greek times, Philo of Byzantium, an engineer, experimented with inventions that made use of suction effects and gas expansion. Such inventions made use of the properties of pressure.

Atmospheric Pressure

Everything on the Earth is subjected to pressure. An average human body with surface area of 1.7 m^2 is pressed by about 17,600 kg of air all around the body! Our body has tissue that can't be easily compressed, and resists the pressure from outside. Otherwise, we would be crushed. We call this outside pressure, **atmospheric pressure**.

Why does air produce such an immense force? It is because of gravity! Air has weight, and as it stacks above the Earth, the air closest to the Earth is denser (greater mass in a given volume), pressed by the weight above it.



The more the amount of air above, the greater the atmospheric pressure pressing down. The further away from the Earth, the lower the atmospheric pressure. When far enough in a region we designate as space, there is no air, and the pressure is reduced to zero.

It is not only air that is subjected by gravity. The water on the Earth – seas, lakes, rivers, etc. also experience gravity and has higher pressure at depth. Furthermore, water is denser than air, and thus produces greater pressure.

Questions that students may ask:

Q. What happens to a human body subjected to the vacuum of space (no atmospheric pressure)?

The human body is adapted to the atmospheric pressure on the Earth. Our bodies usually have dissolved air in the blood and body cells. In space, the dissolved air will escape through boiling (without heat) from loss of pressure. Death will happen within minutes.

Q. Do different fluids produce different amounts of pressure?

Yes, with the understanding that both air and liquids are considered "fluids". Pressure is applied from the weight of a fluid pressing down. A denser, heavier fluid will exert a greater pressure on an object that has sunk in it. Imagine diving down by 1 metre in a swimming pool compared with walking down 1 metre down a flight of stairs (where atmospheric air pushes down on you). Which environment exerts a greater pressure on your body? Can you feel the water pressing down on your body as you dive lower in water?

Q. How do fish living deep beneath the ocean withstand the immense water pressure?
Similar to how humans adapted to air pressure on the Earth's surface, fish that live deep beneath the ocean have an internal pressure sufficient to withstand their surrounding waters.

Their swim bladders may use other chemicals or biological structures like soft tissue and cartilage instead of gas to stay buoyant and accommodate the pressure, as air pockets and rigid structures may collapse under the weight of the water.

If they are brought to the surface, their soft structures, built to work in high water pressure, may collapse without the pressure to maintain their shape.

Buoyant Force

Do you feel lighter in the swimming pool than your usual weight? The water helps to lift your body up. A balloon filled with helium gas floats in air. Those are the results of **buoyant force**.

The deeper the water, the stronger the water pressure below has to be to support the weight of the water above. This forms the basis of the "upward" force of water on the bottom side of the object, which is always greater than the "downward" force of the water on the top side of the object.

The buoyant force is that upward force. The more water that is displaced when the object is placed in water, the greater this total upward force.

However, this alone does not determine whether the object sinks or floats. The object is also pulled down by gravity. Only if the object itself is less dense than water, does this buoyant force exceed the gravitational pull, allowing the object to float.

Questions that students may ask:

Q. Why is buoyant force always upwards? Why can't it push the object downwards?
Water pressure is applied in all directions. The source of the buoyant force lies in that the water pressing from the bottom of an object is greater than from the top, because the water pressure always increases as the depth increases.

Q. If metal sinks in water, why do metal ships still float?
The body of the ship contains air. By taking the average density of the metal and the air in the hull, we find that it is still overall lower than the density of water. However, when the ship takes in water due to hull damage, the average density of the ship slowly increases with the incoming water.

What is Electromagnetism?

Electromagnetism is a combination of 2 seemingly separate ways of interacting with objects, **Electrostatic force** and **Magnetic force**.

Magnetic Force

The most common type of magnetism is ferromagnetism. The atoms' magnetic properties align in the same direction, creating a permanent magnet. This creates the normal interactions where 'like' magnetic poles **repel**, 'unlike' magnetic poles **attract**. A magnet attracts "ferromagnetic materials", like iron, cobalt, nickel, etc.

A magnetic field can be produced by electricity. Electric current flowing through a wire will produce a magnetic field concentric to the flow of electricity. If you take a wire and coil it up, each additional coil will add to the magnetic field and make it stronger.

Questions that students may ask:

Q. What is considered a magnet and not just a metal?

When a material (iron, steel, cobalt, etc) is able to produce a magnetic field that causes attraction or repulsion on another magnetic material, it is considered a magnet.

Q. What is a magnetic field?

A magnetic field is the region around the magnet where magnetic materials experience a force. It weakens with further distance from the magnet.

Q. If I break a magnet in half, will I get 2 magnets each having a single pole?

No, a magnet will always have 2 poles. You will get 2 magnets each with a North and South pole.

Q. It is said that our blood contains iron, does it mean that it can be affected by magnets?

The iron in our blood is in a form that does not allow it to be strongly attracted to magnets, even in a strong magnetic field.

Electrostatic Force

Electrostatic force is caused by the interactions of the two types of electric charges, **positive (+) charges** and **negative (-) charges**. Like charges will repel, unlike charges will attract. You might notice this similarity between the electric and magnetic force. However, an object can be simply negatively charged instead of always having two magnetic poles. The most fundamental unit for charges are:

- Electrons that provide negative charge

- Protons that provide positive charge

These are the subatomic particles that make up the atoms of everything in our Universe. Electrons can jump away from an object to make it negatively charged or positively charged as they are very mobile.

Questions that students may ask:

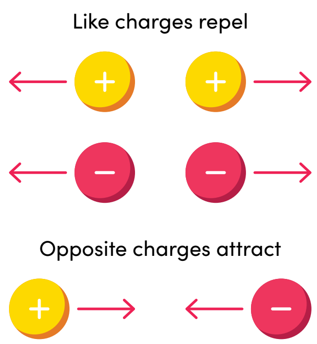
Q. Is electrostatic force the same as electricity?

Electrostatic force refers to the attraction between charged objects. The charged objects are separated by an insulator, something that prevents electricity conduction.
The electrons do not move between objects to create the attractive force.

Electricity refers to the broader idea of movement of electric charges and can refer to static electricity or current electricity.

Q. Why are there only two types of charges?

We use the words “positive” and negative” to describe the charges, but they can take on any name (A and B, Yin and Yang, for example). However, based on experiments that showed how the charged objects interacted, we can conclude that there are only two types of charges. If there were more than 2 types of charges, there would be more combinations of different outcomes.



An experimenter in the past rubbed materials against each other and determined that electrified materials could be categorised into two types, with 3 possible outcomes. Scientists would later realise it could be possible to measure “how much” the material is charged.

Q. Is lightning the same as electricity?

Lightning is one form of electricity- there is a build-up of electric charges in the sky, then the discharge to the ground. It carries a lot of energy. Electricity refers to the general movement of electric charges with varying strength (voltage and current).

Q. If I zap an object with electricity, does that make it charged?

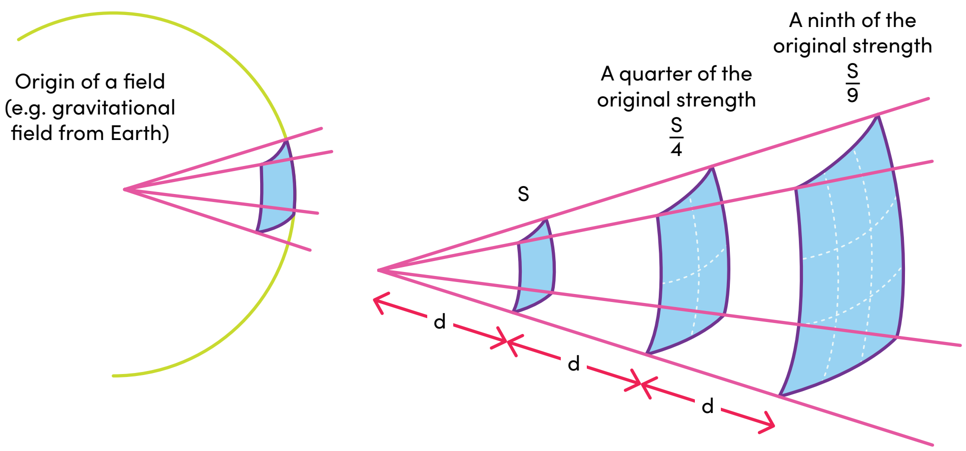
Materials can be divided into insulators and conductors. If “zapping” refers to supplying a conductor with electricity continuously, then yes, the object will have a supply of charges that “discharge” when moving into contact with another conductor. Insulators do not carry electric currents if connected to a power supply, but they can be made charged through losing or gaining electrons from scrubbing against another material.

What is a field in the study of Forces?

A field can be imagined as a constant area that pushes or pull things without touching it.

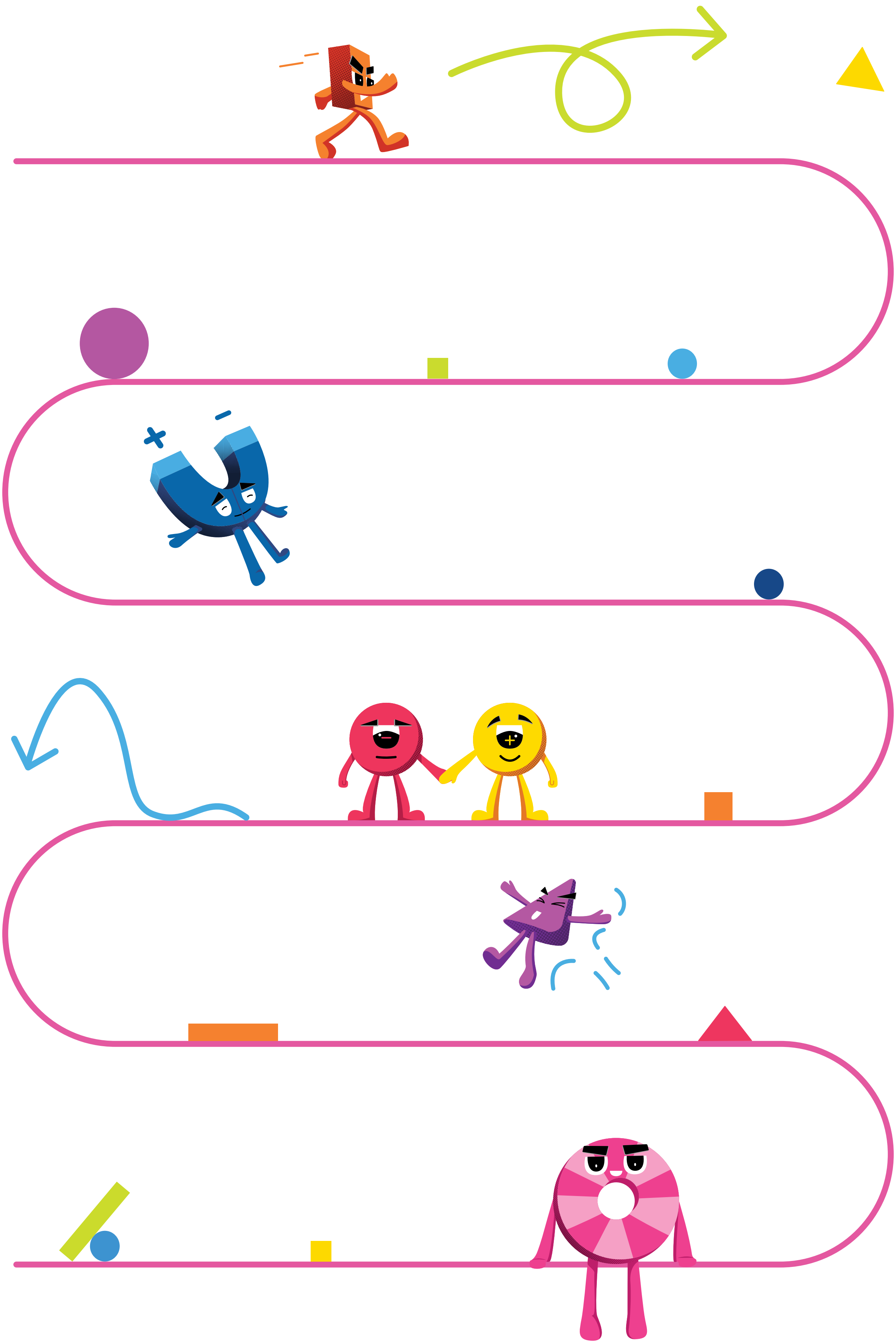
With regards to electromagnetism, a magnet will exert a magnetic field that interacts with metal, creating the effects of an attractive magnetic force. It can also interact with another magnetic field creating either an attractive or repulsive force. A magnetic force/ field will not interact with a non-magnetic material at all.

Forces from radial fields follow the **inverse square law**, where the strength of the force weakens by a square power of the distance rather than linearly. This can apply to the field from a charged object, or gravitational field from the Earth, for example.

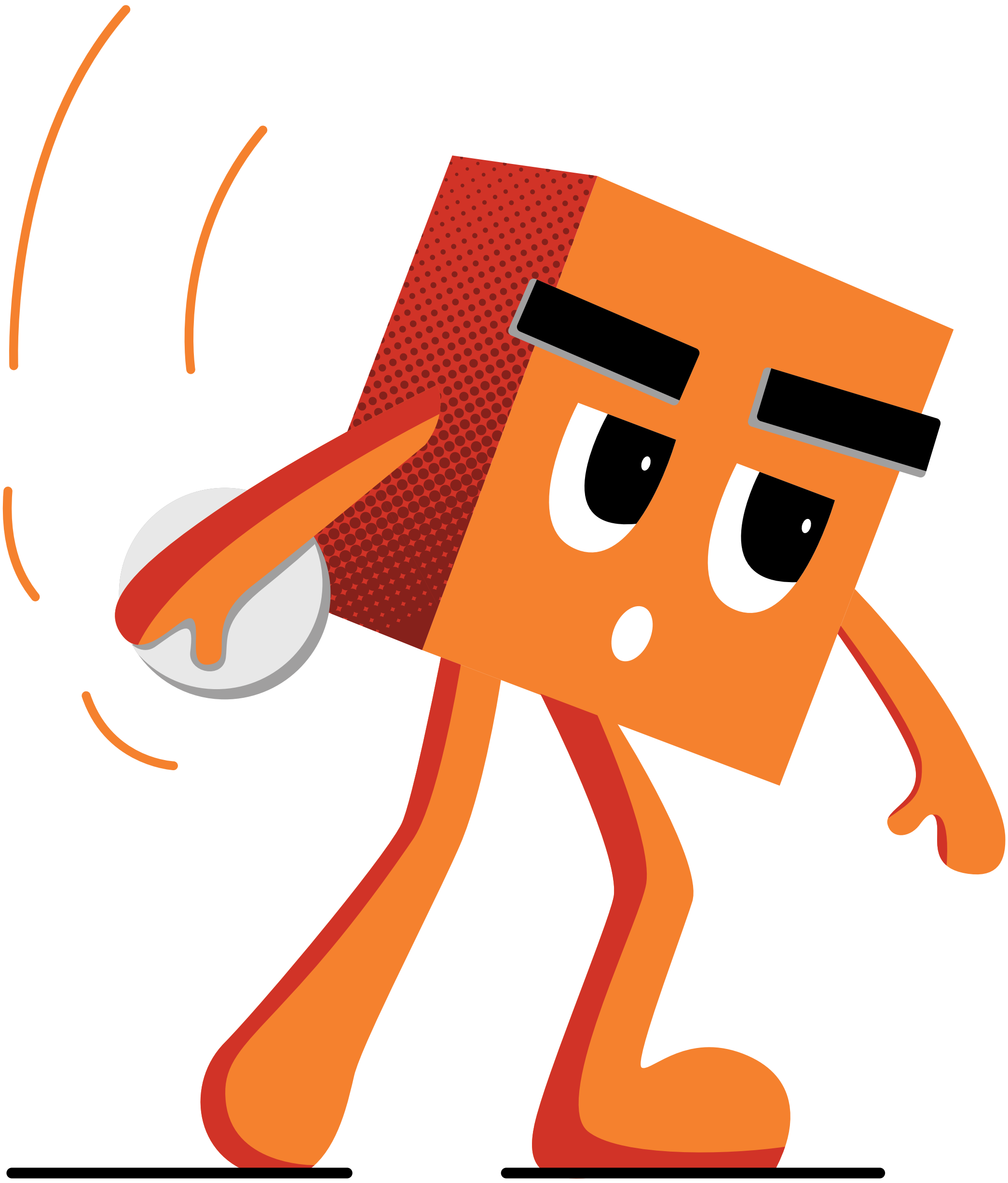


If the distance is tripled, the force is 1/9th its original strength, rather than 1/3th. S here refers to the strength, and d here refers to the distance from the origin.

Exhibits



1. Basics of Forces and Motion



1.1 Hanging By a Thread

On The Exhibit

Tensegrity combines the word "tension" with "integrity". This exhibit is a self-supporting structure that is balanced with cords under tension. It is the equilibrium between compression and tension that keeps the structure upright.

Safety Precautions

Hanging by a Thread has cords that are pre-tensioned in order to provide stability. Snapping the cords can cause a strong and dangerous recoil, and can cause the top structure to crash down from its weight. Under supervision of an adult, users can be invited to touch or strum the cords to feel the tension and rigidity of the cords, but they should not attempt to dislodge the top part by toppling, shearing, or swivelling the structure, pull the cords like bowstrings, nor apply their body weight to bend the cords.

Exploratory Questions

Q. Why doesn't the tensegrity structure collapse if it is only supported by cords under tension?

Do you notice the four cords with tension at the corners? They help to keep the structure in balance. The central cord suspends the upper part, bearing a significant weight, while the corner cords stabilise it. Otherwise, it will twist on its sides and the whole structure will collapse.

Q. Most of the force that a free-standing structure experiences is from gravity. If the tensegrity structure is in space, how would it behave?

A well-built tensegrity structure, where all of its cables are kept under tension, should maintain its form even when it is not under the pull of gravitational force.

Q. If you cut one of the cords in the structure, would it still work?

No, it will very likely become lopsided and the top part may topple. If you cut the central cord, the whole structure will collapse.

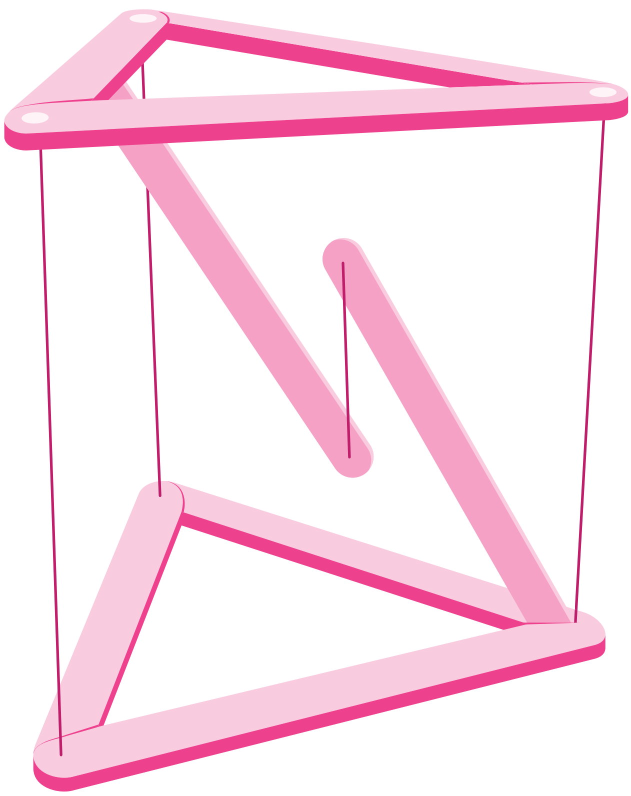
Exhibit Interactions

Examine the structure closely and consider which direction the force from the tension of the cord is pointing towards. The charm of a tensegrity structure lies in its perceived improbability, using limp, flexible cords to make a structure stand upright.

Extended Thinking

An object that is moving at constant speed, or is stationary, has no net force. Having no net force is the result of either no force acting on the object, or all the forces balancing out in opposite directions. Everything in our daily lives is subject to gravity, and it is the reaction force from the objects directly underneath them that supports them from falling.

One way for you to explore the concept of compression, tension and gravity is for you to build your own tensegrity structure using ice cream sticks, tape or glue, and strings. To balance the structure effectively, you will have to experiment with tensioning each string before knotting.



1.2 On Track to Finishing First

On The Exhibit

3 tracks start from the same height and end at the same height. By releasing the balls down the track, it is observed that the balls complete at different times, with the steepest track allowing the ball to finish first.

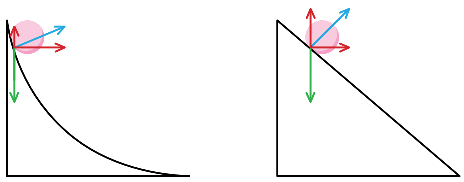
Safety and Use Precautions

On Track to Finishing First houses loose balls of a certain weight. The unimpeded acceleration of the balls forms an integral part of showing the phenomena. The Science Centre Board does not condone the theft of the balls, and implores that users refrain from misuse of the balls by dropping them or throwing them. Users should also refrain from leaving trash on or inside the exhibit.

Exploratory Questions

Q. What makes the steep curved track allow for faster acceleration than a straight track?

Any object touching another object results in a reaction force – for each falling (rolling) ball, the angle of the reaction force is different. The reaction force can be broken down into its vertical and horizontal component- and the steeper the track, the less the component that is counteracting the force of gravity, resulting in a smaller force against gravitational force and a larger net force that moves the ball.



The green and blue arrow involve the same amount of force – the green arrow is the force from gravity, and the blue arrow is the reaction force (normal force) perpendicular to the contact surface. By subtracting the vertical force component of the normal force from the force of gravity acting on the ball, we obtain the net force acting on the ball, which determines its acceleration. Note that all 3 balls from each track will end up with the same speed at the end!

Q. Is it possible to accelerate an object faster than the speed that an object free falls?

By gravitational acceleration on the Earth alone, the acceleration of a free falling object is $9.8m/s^2$. Nevertheless, we can accelerate an object downward faster than $9.8m/s^2$ by applying extra force as we throw or propel the object, or if we were on another larger planet instead of the Earth with greater gravitational force.

Q. Do heavier or larger objects accelerate faster than $9.8m/s^2$ compared to lighter ones?

The mass of an object does affect the strength of gravitational force. However, most objects are tiny and light compared to the size of the Earth. Remember the equation $F = G\frac{m_1 m_2}{r^2}$? With m_1 being the mass of the Earth, and m_2 being objects we see in our daily lives, the difference in sizes of most objects is negligible, and *F* ends up roughly as the same value.

Thus, for our daily use, it is simpler to treat all objects as falling at the same acceleration and speed, and it is air resistance that determines how much slower they fall.

Exhibit Interactions

Release the 3 balls on the track and observe their progress. The ball on the curved track with the greatest initial drop will travel fastest and reach the bottom of the track first, followed by the straight track, despite needing a shorter distance to travel. The curved track with the gentle initial slope takes the longest to complete.

Extended Thinking

A slope is an example of a 'simple machine'. It allows you to use a smaller amount of force to raise an object to a higher position. The final amount of energy used is the same, as the smaller amount of force must be exerted over a longer distance. Archaeologists believe that it was the invention and use of ramps that allowed the ancient Egyptians to carry heavy blocks for the Pyramids. Conversely, gentler slopes allow hikers to walk much easier downward due to the slower acceleration and less chance of slippage.

1.3 Going Nowhere Fast

On The Exhibit

There is an upward-rolling treadmill with adjustable speed. Turn it on and place the slinky in the middle, pulling it quickly downwards in an arc shape to initiate tumbling. By adjusting to an appropriate speed, the slinky will continuously walk in place against the upward rolling belt of the treadmill.

Safety and Use Precautions

Going Nowhere Fast uses a slinky. The free movement forms an integral part of showing the phenomena. The Science Centre Board does not condone the theft of the slinky, and implores that users refrain from misuse of the slinky. Users should be gentle as not to entangle or bend the coils.

The rotary knob is made loose for turning to allow easy adjustment of the speed. Users should refrain from rapid spinning of the knob unnecessarily.

The treadmill belt loops around rollers. No attempts should be made to slot any object into the gaps where the belt meets the edge guard along the side, the top, or the bottom.

Users should also refrain from leaving trash on or inside the exhibits.

Exploratory Questions

Q. Can a slinky walk/tumble upwards?

Unlike springs which can hold great elastic potential energy due to their material, slinkies are rather soft and limp, and usually only fall downwards from higher places, converting potential energy to kinetic energy as they move. A slinky's ability to walk down a slope or a flight of stairs is a combination of gravity and the initial momentum of the slinky 'pulling' the rest of its body down the stairs/slope.

Q. Can a slinky walk downhill permanently?

In an ideal scenario, yes! A very long and steep hill path would normally let it continue downhill all the way. In reality, minor imperfections in the ground or the belt causes not just downward motion, but also motion to the left or right, making movement of the slinky erratic over time, where it will then bump into an obstacle or fall off the track. Some of the energy is also lost to friction, and the slinky will eventually lose enough energy to become unable to tip over again.

Exhibit Interactions

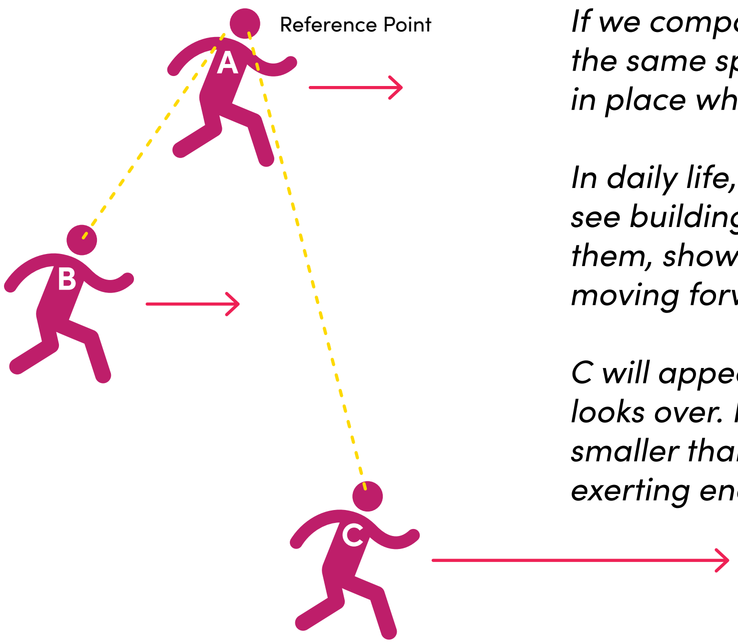
Use the button to start the exhibit and adjust the speed. The slinky has to be pulled in a downward arc for a consistent tumbling motion instead of rolling on its sides. It cannot "walk" until you provide it with the initial impetus to start the continuous motion.

Extended Thinking

We can use the walking slinky to help us understand *absolute* and *relative* speed.

The idea of absolute speed uses a reference point that is assumed not to move and comparing the speed of two other moving objects to it.

With relative speed, the reference point is one of the moving objects, and the speed of the other object (towards or away from it) is calculated by pretending that moving object is static and any change of distance is the result of the movement of the other object.



If we compare A and B, if they are running at the same speed, B will appear to be running in place when A looks toward them.

In daily life, this perception is rare, as A can see buildings and road obstacles rushing past them, showing that both A and B are moving forward.

C will appear to run forward, faster than A when A looks over. However, the relative speed of C to A is smaller than the absolute speed that C is actually exerting energy to travel at.

Imagine you are on a river stream flowing the same direction you want to go. You will end up at your destination faster than the speed shown on your boat's meter (which is calibrated based off how fast the boat goes due to the turning of the turbine blades) as the river's speed should be taken into consideration as well. Your absolute speed is greater than what is powering the boat alone.

Sometimes when two trains are side-by-side heading in the same direction at the same speed, without the cues from nearby landmarks around to help you perceive that you are moving forward, and you are inside with no feeling of rushing wind to give you a sense of forward movement, there may be a short period where looking at the other train makes you feel as if both trains are stationary. Even though both trains are speeding forward, the distance between them does not increase or decrease. The relative speed of one train to the other is zero.

1.4 Worth the Weight

On The Exhibit

Weights hang along the arms of the frame. You can adjust the position of the weights to shift the centre of gravity so that the frame may balance properly.

Use Precautions

Worth the Weight has a flexible tether attached to the pillar and the frame to allow for free movement in a controlled range. The tether should not be tampered with, and the weights should not be damaged or removed from the frame.

The stainless-steel frame should not be abused to damage or scratch the exhibit housing.

Exploratory Questions

Q. If the tail arm is so long and heavy, how does the object balance properly?

The centre of gravity is a specific point on an object where the weight is evenly distributed and that the object can be balanced. On a simple 1-metre ruler, that point would be at the 50cm mark. However, distance of how far the weighty parts of the material is from the balancing point also come into play.

By making the closer parts heavier, the weights can add together to match the weight of the long and heavy tail.

Q. Can an object have more than one centre of gravity?

An object can only have one centre of gravity. If its shape is changed, causing the mass to be distributed differently, the centre of gravity will also change to a different position. An object where the mass inside shifts around, such as soup in a bowl, may have a constantly shifting centre of gravity when rattled, making it harder to balance.

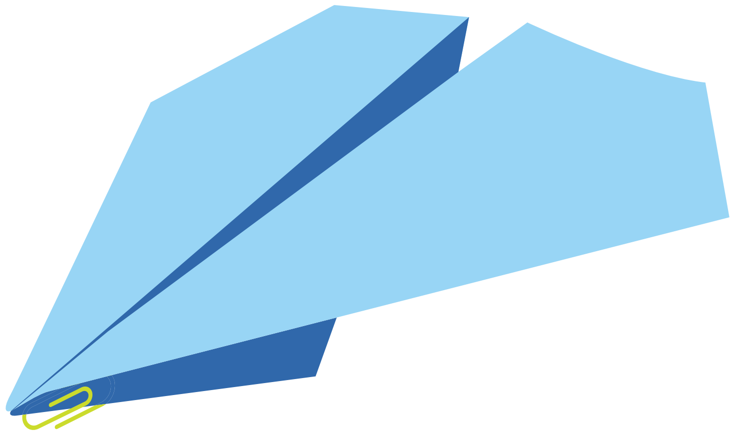
Exhibit Interactions

Shift the weights along the nodes in order to balance the object. Examine if the weights are symmetrically positioned, and what it means if they are not.

Extended Thinking

The closer something you hold is to your centre of gravity, the less strain it puts on your back. As you extend it away from your body, your spine takes on significant stress to keep itself from bending, possibly causing injuries to the overloaded muscles.

Other than the distance from the centre, how high the centre of gravity is from the ground also has relevance to safety. Flat cars with a low centre of gravity are less likely to flip as they turn bends. When we climb uphill or downhill, it feels less exhausting if we lean towards the ground to lower our centre of gravity, such that we do not have to counteract our weight to stay upright. Furniture, decorations and ladders with a higher centre of gravity are at greater risk to topple and fall.



The centre of gravity also affects the performance of moving objects. Build a paper aeroplane and attach paperclips at different regions. Throw it and observe how the performance of the plane differs. Where would you attach the paperclips to maximise distance travelled?

1.5 Turn of the Sentry

On The Exhibit

A flywheel that can be made to turn is fixed on top of a turning platform. As the flywheel spins, any attempt to tilt the flywheel seemingly produces another rotating force, causing the whole contraption to turn.

Safety Precautions

Turn of the Century involves a rotating platform and a swivelling flywheel made of metal. Measures have been taken to indicate the zone where flywheel sweeps but ***the platform is NOT intended to be sped up by peddling against the ground.*** Instead, users should spin the flywheel and turn the handle as the only mean of accelerating the platform.

Only one user should be on the rotating platform to use the exhibit. Other users are prohibited from speeding up the exhibit by propelling the user on the platform. They are also prohibited from interfering to cause a suddenly stop that may propel the user from their own inertia.

Users who get dizzy easily due to their constitution should be mindful of their tolerance for the rotation of the platform. Tripping and stumbling may occur when stepping off. By powering the flywheel and turning the handle, the platform usually does not spin at untenable speeds.

Do not attempt to grip the flywheel hard while it is spinning quickly.
The hand may be dragged forward or backward causing friction burns or toward the axis guard and be pinched.

Exploratory Questions

Q. What does the flywheel do?

The flywheel introduces the starting angular momentum used to create the surprising motion of the standing platform.

Momentum is the product of a mass and velocity of an object. Angular momentum is the momentum of an object travelling about an axis. It also considers what distance most of the weight is from the axis of rotation, which is why the flywheel has a wider, weightier rim than the main body of the wheel, to increase the momentum.

Q. Why does tilting the spinning flywheel cause the entire platform to turn?

Just like how a bicycle wheel tends to keep balance on the ground if spun quickly, the flywheel will resist a change in its direction of rotation due to its angular momentum. When you move it, it produces a reaction force in the opposite direction – however, as the flywheel is connected to the platform, it turns the platform instead.

We understand this as the conservation of angular momentum, where all the components within the same system, without introduction of external forces, add together to the same total amount of angular momentum, assuming no energy lost to friction.

The heavy platform spinning slowly in one direction and the light flywheel spinning quickly in the other direction add up to the initial momentum before the flywheel was turned.

Exhibit Interactions

Spin up the flywheel with the platform remaining stationary. Stand on the platform and grab the handle on both sides. Tilt the wheel to one side. You may feel a very small resistance as you turn the wheel and feel the platform turning in the reverse direction of the flywheel. Test the other side as well.

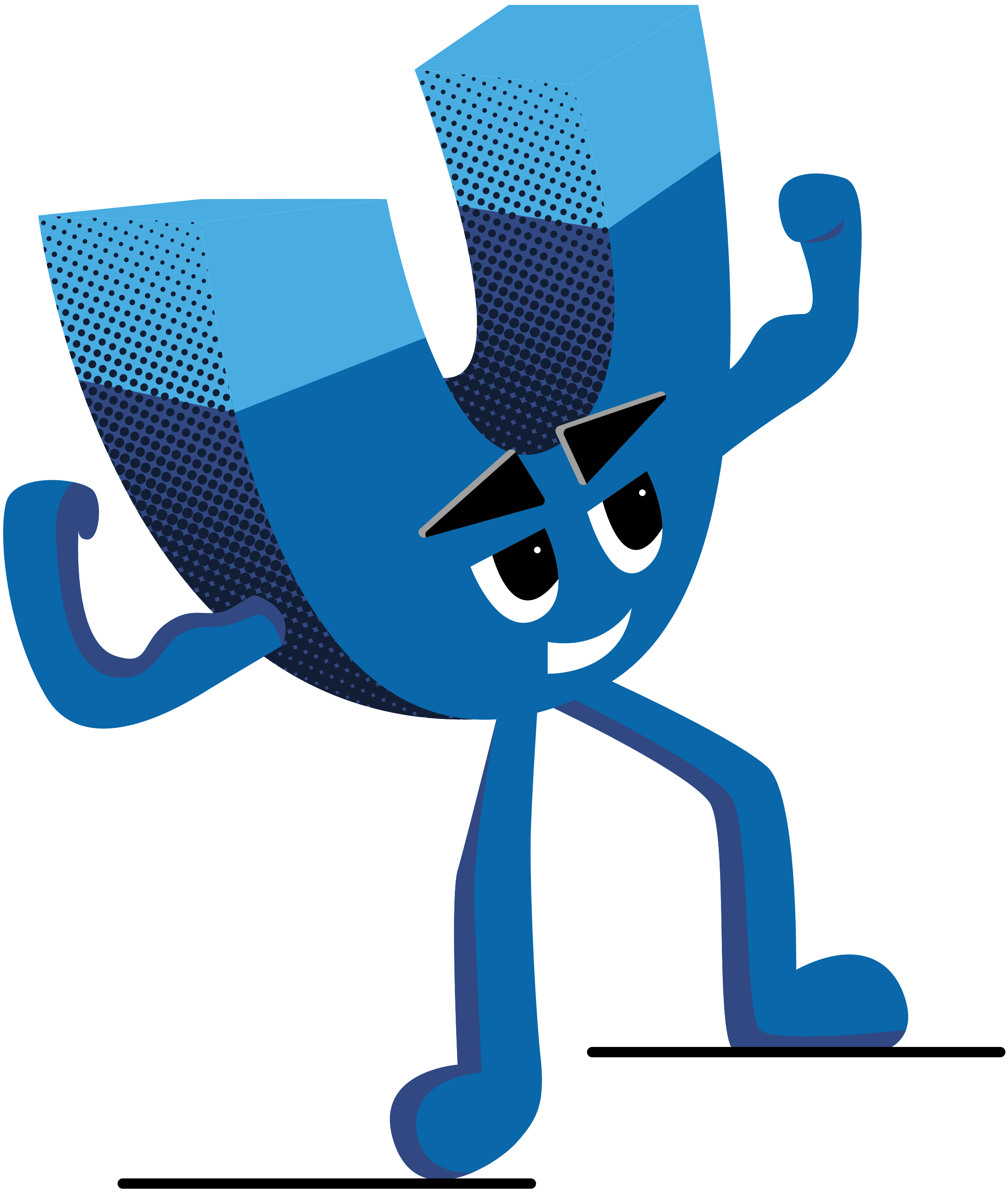
Extended Thinking

The spinning top is an ideal object to demonstrate what a gyroscope is. It spins parallel to the ground, perpendicular to the downward pull exerted by the force of gravity. The top is only able to maintain this orientation when spinning. As it slows down, it falls on its side.

A moving bicycle with turning wheels will also stay upright if the wheels are spinning quickly. The faster the wheels spin, the more stable the bicycle is against falling. You could also replicate this with a coin, where as long as it is rolling or spinning, the coin is better at staying on its side without falling over.

So far, we have discussed examples of objects spinning on the Earth. What would an object be like if it was spinning in outer space, in the absence of gravity? Consider the rotation of planets such as Jupiter or Uranus. All the planets in our solar system spins on their axes. What happens to a planet that doesn't spin? The two ends of the axis of rotation are called the 'poles' and circumference of the planet at the midpoint of the poles is called the equator. Planets that spin will have a bulge on their equator, making them slightly oblate (flat oval). A planet that doesn't spin would be more spherical in shape.

2. Magnetic Force



2.1 Mass Attraction

On The Exhibit

On a table full of compass needles, a large magnet may be brought close, causing all the magnets to align to the magnetic fields of the larger magnet.

Safety Precautions

Mass Attraction has flexible tethers attached to magnets to allow free movement in a controlled range. The tether should not be tampered with, snapped or cut, and the magnets should not be damaged, or otherwise removed from their casing.

The Science Centre does not condone any attempt to break the casing by use of force and shall treat the act as vandalism.

Users are prohibited from swinging the magnets to damage or scratch the exhibit housing. Allow the tether to retract slowly instead of dropping them against the table Users should also refrain from scraping the magnet against the display surface.

Exploratory Questions

Q. Why do the compass needles change their orientation with respect to the permanent magnet when you bring it close?

Magnetic forces are greatly weakened by distance. When compass needles, being weak magnets themselves, are left suspended, they align to the geomagnetic poles of the Earth. The magnetic field of the permanent magnet exerts a much stronger force due to its close distance to the compass needles, and they align to the field of the permanent magnet instead.

Q. If a North-South pole pair attract, and the North-North pole pair repel, why does the North pole of the compass points towards the North pole?

When we speak of the North Pole on the Earth, we are usually referring to the Arctics where the *geographical* North pole resides. However, this side of the Earth is where the *geomagnetic* South pole is, not the North one. These two poles curiously are not in the same position. The geomagnetic poles also shift positions slightly over time.

Exhibit Interactions

Place the bar or horseshoe magnet around the needles and observe the changes in orientation of the needles. What sort of pattern do they form? The pattern demonstrates influence of the Earth's magnetic field on compasses all around the Earth and why compasses can be used to tell the direction of North and South.

Extended Thinking

How does the Earth generate such a large magnetic field that can influence compasses all around the globe? The Earth doesn't have a giant, solid, permanent magnet embedded in its centre. The magnetic field is generated by the movement of molten iron in its outer core. This movement of charges produces a magnetic field.

2.2 Dramatic Iron-y

On The Exhibit

There is a small microphone that takes in sound. Depending on the pitch, different electromagnets activate and attract black shiny fluids in containers, causing the fluids to move and pulse.

Use Precautions

Dramatic Iron-y uses a microphone that allows detection of sound even at a comfortable height for adults without needing to bend down.

Users should not attempt to insert any material through the slits of the microphone cover.

Exploratory Questions

Q. What is the black liquid, and how does it response to the pulsing of the electromagnet?

The black liquid is ferrofluid. It is a suspension of nano-size magnetic particles — tiny particles of iron floating in a liquid. These iron particles will align themselves to the magnetic field generated by the electromagnet.

Q. How does an electromagnet work?

An electromagnet works by running an electric current through a coiled wire, allowing it to generate a magnetic field. Usually, the amount of magnetism generated by the wire carrying a current is small. However, if you wind the wire many times around an iron core, the strength is increased. Every extra coil adds to the strength of the magnetic field.

Exhibit Interactions

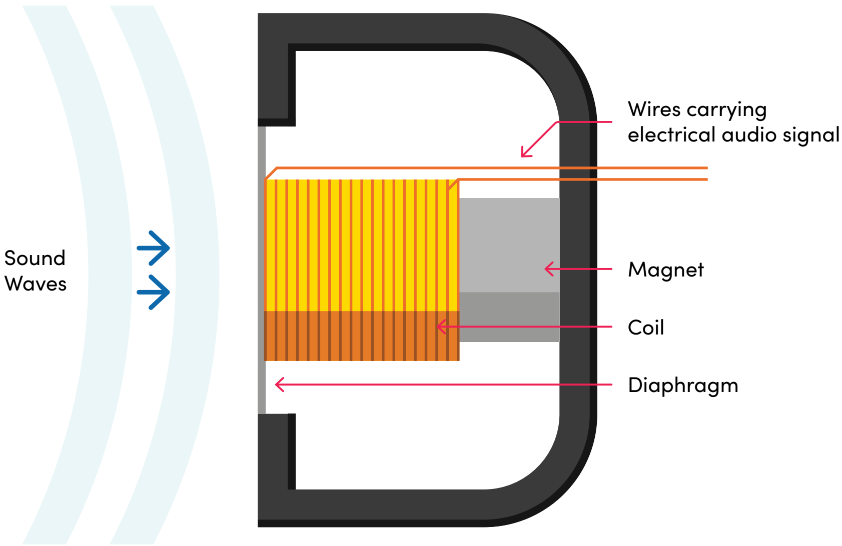
Press and hold the button to turn on the microphone. The sound waves that are picked up are converted into electrical signals that activate electromagnets paired with containers that have ferrofluid. Varying the pitch of the sound activates different electromagnets, where the lower ones detect lower pitch and vice versa.

Extended Thinking

How is sound converted into an electrical signal by the microphone and sent to the electromagnet? Sound is a series of longitudinal waves produced in the air, usually imagined as vibrations.

A microphone works to capture these waves using a diaphragm (membrane) that vibrates back and forth with the produced sound. The diaphragm itself is connected to a copper coil which moves within a magnetic field, creating electric currents within the wire.
On a phone, the pattern of the currents are replicated on the speaker side to recreate the sounds.

Cross-Section of Dynamic Microphone



2.3 Off With Their Hands!

On The Exhibit

This "guillotine" is designed with a copper blade. When the plate is pressed, the lifter releases the blade. The blade falls and passes through the magnetic field along its falling path and slows down, touching the bottom gently.

Use Precautions

Users should not attempt to circumvent the guard behind the plate to interfere with exhibit components or throw trash inside.

Do not extend the fingers into the gap between the plate and the guard. When the plate is pressed, the fingers can become trapped.

Exploratory Questions

Q. Does the magnetic field induced by the eddy current always oppose the original magnetic field that created the current? Is there a direction of movement that induces a field that augments the original magnetic field instead?

Yes, the induced field always opposes the original, and no, there is no orientation that a field can be induced to augment the original. No matter if it is a push or a pull, the produced effect always resists the movement.

The motion induces eddy currents within the copper blade, which are circular flows of electrons within the metal itself. These eddy current in turn forms a localised magnetic field that is in opposition to the magnetic field of the magnets, slowing down the blade.

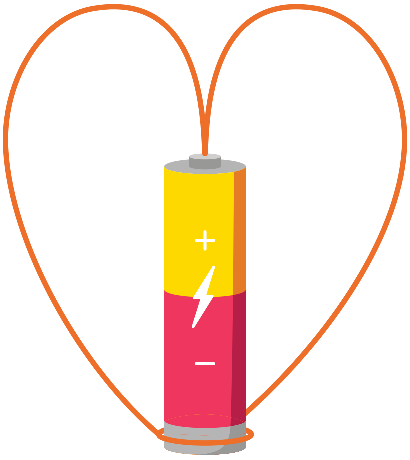
Exhibit Interactions

Use the roller to draw the blade up. Press down on the plate and challenge yourself to keep your hand there without withdrawing! You will discover that the blade slows down as it falls, enough that it drops on your hand lightly.

Extended Thinking

An eddy current can be made by the conductor moving around a magnet, or vice versa. We can even create an eddy current using an electromagnet with a source of alternating current!

Using our understanding of eddy currents, we can use a combination of permanent magnets and electricity to produce motion. This is the basis of the electric motor!
You can use an AAA battery, a coil of copper wires and a small, powerful coin-shaped magnet and build themselves an electric motor. For details, you may look up on 'homopolar motors". **Do note that these motors tend to heat up quickly as they are essentially short circuiting the battery. If children are attempting to make their own, please have an adult supervise them.**



2.4 Egging It On

On The Exhibit

Press the button and witness the metal egg spinning! Underneath the platform the egg sits on, there are 3 iron core each coiled with copper wires, creating magnetic fields in a sequential fashion.

Use Precautions

No trash should be left on or inside the exhibit.

Exploratory Questions

Q. What is happening when the egg stands on its narrow end as it spins faster?

As the egg starts spinning, the egg also precesses, reducing its moment of inertia and contact with the surface. At a high speed, the egg spins on the narrower sides with the smaller radius of rotation.

Q. What causes the egg to spin? Why can the egg spin in the opposite direction?

An alternating current is sent through the copper wires inducing a "changing magnetic field". This "changing field" if visualised, appears to rotate. The changing magnetic field induces an eddy current in the metal egg to form its own magnetic field, causing the 2 magnetic fields to interact. This produces a physical motion as the magnetic poles of the egg tries to align with the magnetic poles of the coils, causing the egg to spin.

The sequence of activation of the electromagnets determines the direction of the magnetic field generated. By reversing the sequence, the rotating magnetic field generated changes direction accordingly, clock-wise or anti-clockwise.

Exhibit Interactions

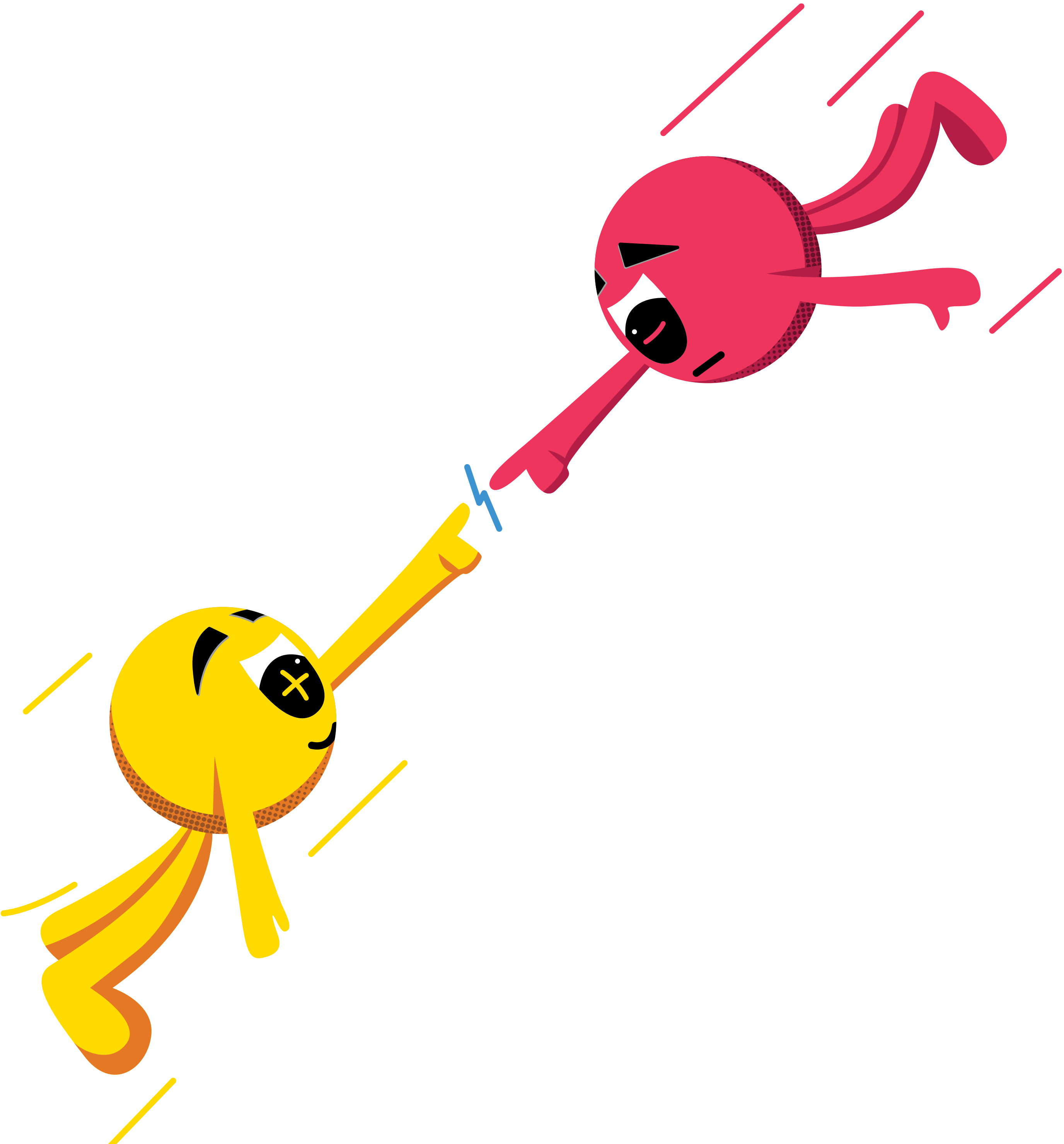
Press either button and observe the metal egg as it builds up speed. The two buttons cause the electromagnets to activate in sequence such that the egg turns clockwise or anticlockwise. Adjusting the knob allows the egg to spin faster or slower.

Extended Thinking

Unlike direct current produced from an electric battery, which flows from one end of the terminal to the other, alternating current flows both ways. The polarity of one terminal will switch from (+)positive to (-)negative and vice versa very rapidly. In fact, alternating current is the more widely used source of electricity. The electrical outlets in our house supply AC rather than DC.

As for the way that the egg spins, you may observe something similar by spinning a hard-boiled egg. As you spin it faster, it will precess to spin on its narrower end. This is the secret to check between boiled and raw eggs without cracking them open! The egg white and yolk in a raw egg is much more fluid, causing the centre of gravity to constantly shift as it sloshes inside. The raw egg would not spin stably.

3. Electrostatic Force



3.1 Electropop-corn

On The Exhibit

When you rub a scrubber across the plastic window, you charge it with static electricity and 'influence' the styrofoam beads, causing them to be attracted to the cloth or each other.

Use Precautions

Electropop-corn uses a scrubber that has a flexible tether attached. The tether should not be tampered with, and the scrubber should not be damaged, or otherwise removed, or be used to damage or scratch the exhibit housing by dropping the scrubber against the table or the side of the housing.

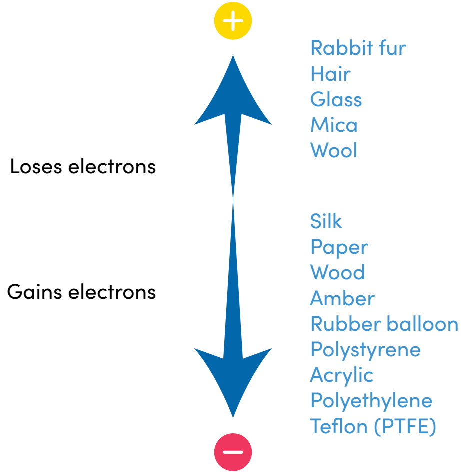
Do not shake the housing in an attempt to loosen the balls evenly.

Exploratory Questions

Q. What is static electricity?

Static electricity, also called triboelectricity, is produced by physical interaction of two objects on the far end of the triboelectric series. This series is a list of materials that gain or lose electrons easily when rubbed against each other. It causes electric charges to be lost or gained by the object, becoming either (+)positively charged or (-)negatively charged.

Triboelectric series



Q. How does the cloth under the scrubber work to attract/repel the styrofoam balls?
When you rub the scrubber against the clear window, the window is able to gain/lose electric charges. The styrofoam balls themselves are highly electrically insulating but can **polarise**, gaining a weak charge that causes them to be attracted or repelled by the cloth and plastic window.

Exhibit Interactions

Rub the scrubber on the plastic window. You might notice that the movement of the balls are influenced by your movement. The faster you rub the scrubber, the more electrically charged the cloth and window become and the greater the hopping effect of the balls.

Extended Thinking

Static electricity is generated when 2 different materials brush against each other. Electrons will flow from one material towards the others based on their *electron affinity.* Using simple materials, you can generate voltages up to the thousands! There are machines such as the Van de Graaff Generator that can get up to very high voltage of electricity using a belt against a comb.

3.2 Keeping A Positive Beat

On The Exhibit

A Wimshurst static machine is used, with its 2 electrodes connected to the two plates. When the crank of the machine is turned, the plates become oppositely charged and cause the hanging metal ball to be polarised and clack back and forth.

Use Precautions

The crank should not be churned excessively. A steady rhythm allows the plates to be discharged and cause the ball wrapped in aluminium to be displaced. With a few random discharges, the ball may be displaced sufficiently to touch a plate and begin the clacking motion.

Exploratory Questions

Q. What is the force involved that causes the metal ball to swing rapidly back and forth between the 2 metal plates?

The force causing the movement is electrostatic attraction and repulsion. By turning the crank, charges build up on the plates, one side being positive and one side being negative. In the default position, the metal ball as a conductor becomes polarised – the charges on the ball move towards the side they are attracted to.

The ball displaces towards one side randomly. The occasional discharge causes random movement as the attraction and repulsion varies. With enough random displacement for the ball to touch a plate, discharging happens. Assuming that the ball touches the (+) plate, the (-) electrons leave the ball, resulting in a (+) ball that is immediately both repelled by the (+) plate and attracted by the (-) plate. This causes it to swing the other way.

The ball will swing back and forth as long as the Wimshurst machine is running to keep the metal plates charged.

Q. If you stop spinning the Wimshurst machine, does the metal ball still swing between the 2 metal plates?

The ball will continue to clack back and forth due to inertia and rebound forces, but the electrostatic attraction driving the motion quickly drops. Each time the ball touches the plate, it discharges and "completes the circuit" between the two plates, resulting in the set up losing electric potential (or, "the difference in voltage") between the plates. The sound produced is also converted from the kinetic energy of the ball, and it will lose energy over time.

Exhibit Interactions

Turn the crank of the Wimshurst static machine. As the machine speeds up, the hanging metal ball is drawn toward one plate. Once the ball touches one side, it gains more force and continuously swing back and forth.

Extended Thinking

One of the key components of the Wimshurst machine is the Leyden jar, capable of storing over 10,000 volts of potential difference between the two metal electrodes. It simply involves an electric insulator sandwiched between two pieces of metal conductor (metal foil).

If you have ever placed your finger close enough for discharge to happen, you might feel a slight jolt or prick. Are the sparks that we observe dangerous?

While the voltage can be high, to determine whether the discharge is dangerous, we must consider how large the current is, i.e. the flow of electric charges per second. Most of the electrostatic discharges that we feel daily only involves a tiny current and do not pose physical harm, though some people may have electronic implants in their bodies that may malfunction as a result.

Similar to how wires heat up as current pass through, the air around the exhibit would heat up as the discharges happen.

4. Pressure

4.1 Total Baller

On The Exhibit

Gravity causes objects to fall. A blower is used to lift the ball, but how does it suspend the ball instead of launching it away?

Use Precautions

Total Baller houses loose balls. The free movement forms an integral part of experiencing the suspension effect. The Science Centre Board does not condone the theft of loose parts, and implores that users refrain from misuse of the parts.

The flexible tube is intended to bend with some tolerance. Users should refrain from folding and pressing the tube to make creases and tears. Users should not point the air jet towards others.

Users should also refrain from leaving trash on or inside the exhibits.

Exploratory Questions

Q. What is the maximum angle that the suspension will still work?

The more the blower is tilted, the less the jet of air used to counteract the vertical pull of the gravitational force and the more the jet of air used to propel the ball horizontally. Beyond 45°, the horizontal force takes precedence over the pressure holding it in place and the ball is launched rather than suspended.

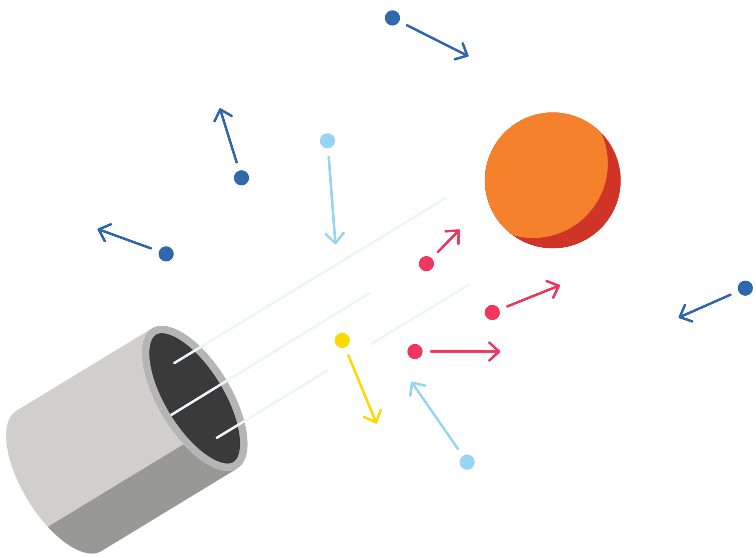
Q. Why does fast moving air creates region of lower pressure perpendicular to the flow, i.e. what is the physical phenomena that makes Bernoulli's principle true?

Bernoulli's Principle states that fast moving fluid (like air) creates lower pressure perpendicular to the direction of the flow. The lower pressure along the jet of air from the blower means that the air around, which is at higher pressure, flows inwards towards the jet stream. This inwards pressure is applied on the ball from many sides, propping it in place.

Atmospheric air pressure exerted by the air molecules is equal in all directions; up, down, sideways, etc, and is formed by the collision of the air molecules against the objects they are in contact with.

However, a jet stream of fast-moving air molecules moves more in the direction it is travelling than other directions (less in the perpendicular direction). The atmospheric air with random motions of air molecules are more likely to have molecules travelling perpendicular toward the air stream.

This means that there are more molecules moving inward, than from the air molecules from the blower moving outward perpendicular to its direction of travel. This is what creates the difference in air pressure.



The air stream has a lot of air molecules that are directed to move roughly in a forward direction, and very little close to 90˚ angle outward. The surrounding air has much more molecules moving randomly, including inward towards the air stream. This means that there is a net amount of air molecules undergoing collision to push toward the air stream.

Exhibit Interactions

Turn on the blower. Position the ball within the stream of air and let it suspend.
You may move the blower around and try to direct the ball into the hoops.

Extended Thinking

Aerodynamics and fluid mechanics remain an incredibly complex topic for scientists and engineers. Aeroplanes have been flying around for ages, yet the scientific theories that explain how they work are still massively debated.

Back on the topic of the blower, do you think you can suspend the ball using an angle parallel to the ground with a strong enough blower? The ball is able to lift off the blower mainly due to the upward force counteracting gravity, while the air pressure prevents the ball from falling off the path of the jet stream. If the jet stream is parallel to the ground, there is little upward force contributed by the moving air and the difference in air pressure within the jet stream compared to the surrounding air is too small to act as a suspending force. In this case, the ball will shoot out of reach of the air stream and fall off where the strength of the stream tapers.

4.2 Press the Advantage

On The Exhibit

A pair of same-sized syringes are connected by a tube, filled with a fluid. Another pair has one of the syringes being wider.

When competing in a "push of war" against each other, feel the difference in difficulty between the two pairs of syringes.

Safety Precautions

Pressing the Advantage uses syringes that move in one direction. Users should refrain from applying their full body weight against these plungers, slamming them beyond their range of motion, or attempting to bend them at an angle, or twist the gripper.

As the interactive involves two competing users, they should take care not to overexert strength and lose awareness of their surroundings, such as other nearby observers, causing potential danger when they suddenly move sideways or backward.

Exploratory Questions

Q. Why is it easier to push in the plunger of the smaller syringe against the larger one?

There are two concepts at play here:

1) The relationship between force and pressure: $pressure = \frac{force}{area}$.

2) Pascal's principle which describes that pressure applied to a contained fluid is transmitted to all parts equally.

When you apply force on the fluid through the plunger, the fluid also applies a reaction force on all parts that it is in contact with, applying the same amount of pressure throughout.

Because the surface area for the plunger of the wider syringe is greater, the force applied by the fluid against the plunger is also greater ($pressure \times area = force$). This is the force felt by the player pushing into the plunger on their side as their opponent also pushes into their plunger on the opposite side.

Q. Isn't it simpler to just use air instead of a liquid for the exhibit?

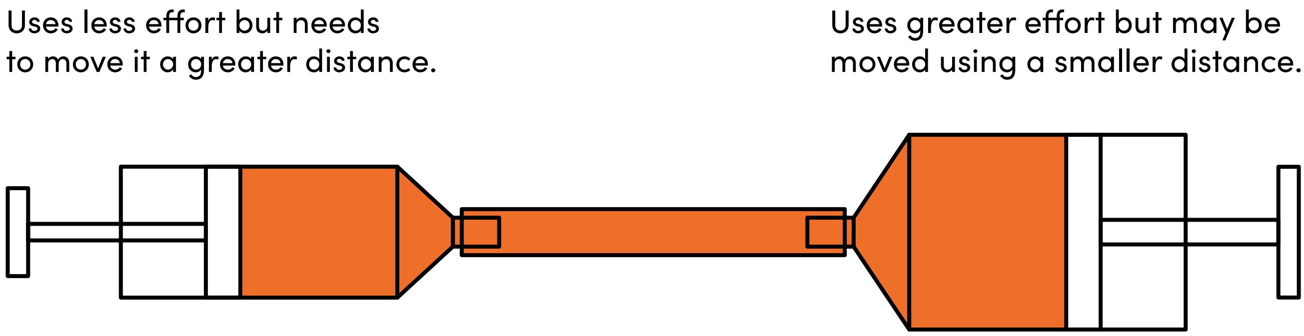
Gases/air are much more compressible than a liquid. If a gas was used instead of a liquid, both players may be able to push in their plungers fully to greatly compress the air within the syringes, making the effect of the difference in force against the wider tube difficult to detect.

Exhibit Interactions

Start with the pair of syringes with equal width on opposite sides. As you push the plunger in, one of you may find that you have a greater strength against your opponent. You may then try to handicap yourself by taking the side with the wider syringe against your opponent. Is it harder to outcompete them now?

Extended Thinking

When you pushed or pull the plunger, the volume (and mass) of fluid that has been moved to the other plunger is the same. This means that total amount of work done, i.e. energy spent, to move the fluid on both the large and small plunger are the same, despite the larger plunger moving a smaller distance.



4.3 A Gripping Activity

On The Exhibit

Five levers are used to push or pull syringes, that each connect through tubes to another syringe on the opposite end. The plungers for the end syringes are used as pistons for movement across joints, allowing us to operate a claw with several joints to grab a ball.

Use Precautions

A Gripping Activity involves levers that users can move in one plane of motion. Users should avoid applying their full body weight against these levers, slamming them beyond their range of motion, or attempting to bend them at an angle.

In case the balls become stuck, users should refrain from rocking the cabinet in an attempt to dislodge the balls, but instead report the issue to operators managing the exhibits.

Exploratory Questions

Q. How does pulling or pushing the lever control the motion of the arm?

When you "push" the lever, you squeeze the liquid through the tube from the input syringe to the output syringe. You should be able to observe small bubbles indicating that the liquid is being moved through the tube and transmitting force to the other end. When you "pull" on the lever, you create a suction to draw the liquid from the output syringe to the side you are controlling. The extension of the plunger forms the lever that tugs at the joint to bend or straighten it.

Q. Do the levers work similar to the way that our muscles do?

No, the muscles in our body cause movement by contraction and relaxation of paired muscle groups. Only the contraction motion uses energy, while the claw arm takes effort to "extend". Our muscles contract by pulling toward itself, while the pistons pass the fluid through a tube to create the output. However, certain animals like spiders rely on hydraulic power within their legs to move and jump.

Exhibit Interactions

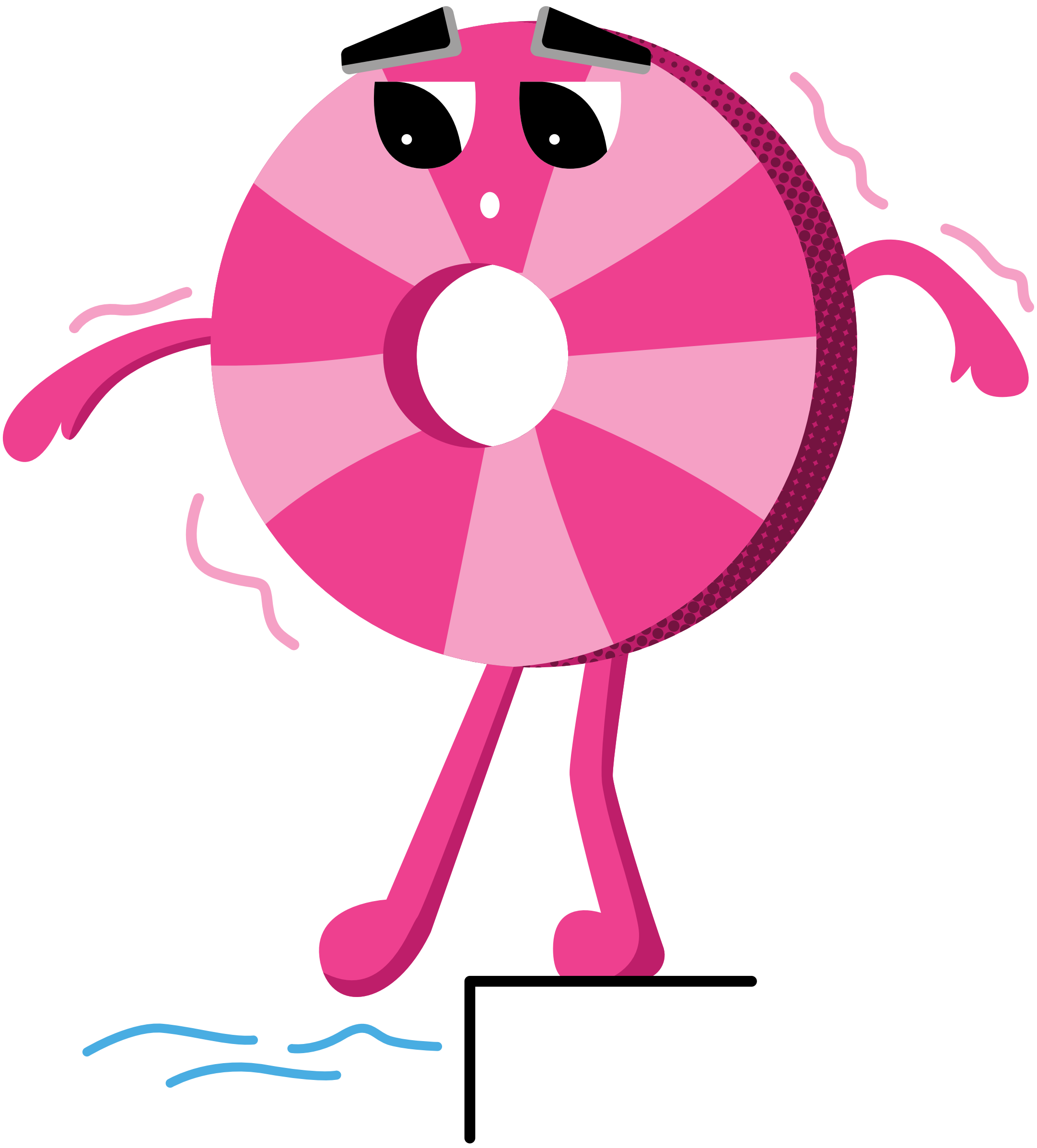
Manipulate the levers to pick up the ball and drop them in the goals. You will find the need for control and precision to manoeuvre a “throw” for one of the goals.

Extended Thinking

Hydraulics are extremely useful in our daily lives for heavy machinery in construction, because of their capabilities to transmit force through tubes that bend around angles to exact force in a different direction. They also allow humans to make use of mechanical advantage to lift something much heavier than by using their own strength.

You can make your own toy version of claw arms by looking up DIY versions of “hydraulic-powered robotic arm”.

5. Buoyancy



5.1 Dive into Action

On The Exhibit

A ball containing air is weighed down carefully such that when the pressure is increased by pumping more air in, the ball compresses, the diver reaches negative buoyancy and the diver sinks, and vice versa. This setup is known classically as the Cartesian diver.

Use Precautions

Dive into Action uses a plunger that users can move in one plane of motion. Users should refrain from applying their full body weight against the syringe plunger which has a narrow arm, slamming it beyond their range of motion, or attempting to bend it horizontally.

Exploratory Questions

Q. When the pump is pressed, are we increasing the water pressure in the tank?

There is a pocket of air at the top of the water column. Water is hard to compress, so the volume of water remains constant. When the pump is pressed and more air enters the column, the air applies pressure on the water, which applies pressure onto the soft ball and the air inside, causing it to collapse and the air inside to take up less volume (thereby increasing its density given the mass of air molecules trapped inside).

Q. If water pressure increases with depth, assuming we have an infinitely long water column, is there a depth beyond which the diver is no longer able to float back upwards because of the high water pressure above pressing down?

Following the Archimede's principle, whether the Cartesian diver floats is ultimately determined only by the average density of the diver (the weights and the air pocket), not the water pressure being applied above them. However, given enough depth, the pressure may be enough to prevent the air pocket from rebounding to being lower than the density of water, and the diver would become unable to float upwards even from releasing the pump.

This would be one reason why the diver cannot float upward, rather than because the pressure overcame the buoyant force of the diver at its default air density.

Exhibit Interactions

Press down on the plunger. Observe what happens to the Cartesian diver inside column. As the plunger is pushed down more, the air in the ball is compressed further, and the faster the Cartesian diver will descend.

Extended Thinking

The *overall density* of an object ultimately determines its buoyancy. Metal ships are able to float on water even though metal is denser than water is due to the air that is contained within the hull that forms part of the ship's weight. Like the Cartesian diver, the inside structures of ships are filled with air. This means ships with air in them will have positive buoyancy. If you were to crush the steel structure of the ship such that there is less air within the total structure that is submerged, the wrecked ship will sink.

Similarly, in cartoons and movie scenes where there are holes on a boat, the reason you see the passengers scooping water out is not to "decrease the weight" of the boat in-so-far as it is to keep it floating by maintain an overall density lower than the surrounding water.

Additional Resources

The following is a list of resources recommended by the National Library Board to learn more about this topic of forces and motion. If you wish to better understand the world of physics and how things move and work, do take a look!

For Young Students

Books (Physical and/or digital)		
Title	**Content**	**Link**
Explore Gravity!	How can something that grounds us and keeps us here on this Earth be so invisible and mysterious? We're not talking about anything abstract and undetectable. We're talking about GRAVITY! Gravity is a force that affects everyone and everything. Gravity is something we can easily understand, even kids, especially if they have the right tools to teach them. Explore Gravity! With 25 Great Projects will introduce kids ages 6-9 to the basics of gravity, including concepts of matter, attraction, and gravitational pull.	https://go.gov.sg/scb-forces-p-ebook1 https://go.gov.sg/scb-forces-p-ebook 1
Gravity Is Bringing Me Down	Gravity becomes a very personal problem for a girl as she stumbles and tumbles through a long day. When Leda wakes up by falling out of bed, she knows that gravity is in a very bad mood. Again. Sure enough, she struggles with stumbles and bumbles at home, trips and blips on the bus, and bashes and crashes in the classroom. But a lesson on gravity helps her understand what's really going on. And after a visit to a science centre, Leda's mood is lifted...just in time for her to tumble—happily!—into bed.	https://go.gov.sg/scb-forces-p-ebook2 https://go.gov.sg/scb-forces-p-ebook 2
75 Fantastic Physics Facts Every Kid Should Know!	Whether you're a budding Einstein or taking your first steps in STEM, you'll be amazed by the fascinating facts inside. You'll rediscover subjects such as light and sound, machines, and forces in an entirely new light. Each new concept is kicked off with a surprising fact-and then we take you behind the scenes to discover the science secrets behind that particular phenomenon.	https://go.gov.sg/scb-forces-p-ebook3 https://go.gov.sg/scb-forces-p-ebook 3

Books (Physical and/or digital)		
Title	**Content**	**Link**
Let's Get Moving!	Red Kangaroo is playing with her favourite ball-she throws it into the air and it comes back down. But what makes this happen? She knows that Dr. Chris will have the answer! Soon, Red Kangaroo learns about force, mass, and acceleration- and that Newton's Laws are at work anytime anything moves! Chris Ferrie offers a kid-friendly introduction to Newtonian physics in this installment of his new Everyday Science Academy series. Written by an expert, with real-world and practical examples, young readers will have a firm grasp of scientific and mathematical concepts to help answer many of their "why" questions.	https://go.gov.sg/scb-forces-p-eb-ook4 https://go.gov.sg/scb-forces-p-ebook 4
Isaac Newton and the Laws of Motion	Isaac Newton's youth was marked by constant curiosity. As he began a life of research and experiments, he turned this curiosity into major insights about the workings of the Earth and the universe. He even developed three laws to explain the motions of objects. This graphic biography moves from Newton's childhood inventions to the breakthrough theories of his adult life. It also spotlights his time at England's Royal Mint, where he combatted counterfeiting, and his gift of knighthood from Queen Anne.	https://go.gov.sg/scb-forces-p-ebook5 https://go.gov.sg/scb-forces-p-ebook 5
Magnets Push, Magnets Pull	Explore the fascinating field of magnetism with this interactive picture book for young learners. Magnetism is all around us-even the Earth is a giant magnet. A world without magnets would be a world without cell phones, computers, and more! David A. Adler covers the basics of magnetism and provides hands-on experiments for aspiring scientists. Anna Raff's lively art illustrates scientific concepts clearly, with the added fun of two siblings and their dog exploring and learning together. A glossary at the back defines such terms as attraction, pole, electromagnetism, force, and more.	https://go.gov.sg/scb-forces-p-eb-ook6 https://go.gov.sg/scb-forces-p-ebook 6

Books (Physical and/or digital)		
Title	**Content**	**Link**
Electricity: Energy in Action	Giant monsters are on the warpath, and it's Menlo the mech's job to protect the city! But when this metal marvel is shut down by an unlucky lightning strike, a resourceful engineer and his high-energy niece will have to find a way to plug in and power up to save everyone from certain doom! From simple circuits to giant grids, fossil fuel power plants to wind farms, electricity keeps the world running. In Electricity: Energy in Action, you'll discover where electricity comes from, why lightning suddenly strikes, and how we've harnessed it all to turn the lights on in your room.	https://go.gov.sg/scb-forces-p-ebook7 https://go.gov.sg/scb-forces-p-ebook 7
Things That Float and Things That Don't	It can be surprising which objects float and which don't. An apple floats, but a ball of aluminum foil does not. If that same ball of foil is shaped into a boat, it floats! Why? And how is it possible that a huge ship made of steel can float? Answering these questions about density and flotation is David A. Adler's clear, concise text, paired with Anna Raff's delightful illustrations. Activities that demonstrate the properties of flotation are included.	https://go.gov.sg/scb-forces-p-ebook8 https://go.gov.sg/scb-forces-p-ebook 8
How Do Seesaws Go Up and Down?	Have you ever wondered how seesaws go up and down or how screws stay secure in walls? Beginning concepts of mechanical engineering including levers, wedges, inclined planes, and more are learned through diagrams, photos, and informative and engaging text.	https://go.gov.sg/scb-forces-p-ebook9 https://go.gov.sg/scb-forces-p-ebook 9

Books (Physical and/or digital)		
Title	**Content**	**Link**
The Dr. Wu Brain Switcheroo!	When Qianna creates a device that can link people with their favourite figures throughout history, Quinn can't wait to use it. He wants to learn a thing or two from Dr. Chien-Shiung Wu in time for an upcoming science test. But something goes awry, causing Quinn and the genius doc to find themselves swapped in time. Can Qianna and the QTs reverse the brain switcheroo before Quinn becomes trapped in the past? Find out in a dynamic graphic novel that gives science, engineering, and invention a hip-hop spin!	https://go.gov.sg/scb-forces-p-ebook10 https://go.gov.sg/scb-forces-p-ebook 10

For Older Students

Books (Physical and/or digital)		
Title	**Content**	**Link**
The Physics of Superheroes	A complete update to the hit book on the real physics at work in comic books, featuring more heroes, more villains, and more science. Kakalios presents findings from the cutting edge of science to explains why Spider-Man's webbing failed his girlfriend, the probable cause of Krypton's explosion, the Newtonian physics at work in Gotham City, and more.	https://go.gov.sg_ scb-forces-s-ebook1 https://go.gov.sg/scb-forces-s-ebook 1
The Physics of Everyday Things	What's the simple science behind motion sensors, touch screens, and toasters? How do we glide through tolls using an E-Z Pass, or find our way to new places using GPS? In The Physics of Everyday Things, James Kakalios reveals the mind-bending science behind the seemingly basic things that keep our daily lives running, from digital "clouds" to hybrid vehicles. Breaking down the world of things into a single day, he explains how our refrigerators keep food cool, how a plane manages to remain airborne, and how our wrist fitness monitors keep track of our steps. In the end, sophisticated science is also quite practical.	https://go.gov.sg/ scb-forces-s-audio-book1 https://go.gov.sg/scb-forces-s-audio book1

Books (Physical and/or digital)		
Title	**Content**	**Link**
The Physics of Star Wars	Ever wish you could have your very own lightsaber like Luke Skywalker and Obi-Wan Kenobi? Or that you could fly through space at the speed of light like Han Solo and Poe Dameron? Explore the physics behind the world of Star Wars, with engaging topics and accessible information that show how we're closer than ever before to creating technology from the galaxy far, far away. The fantastical world of Star Wars may become a reality!	https://go.gov.sg/scb-forces-s-audiobook2 https://go.gov.sg/scb-forces-s-audio book2
Falling Felines and Fundamental Physics	The question of how falling cats land on their feet has long intrigued humans. In this playful and eye-opening history, physicist and cat parent Gregory Gbur explores how attempts to understand the cat-righting reflex have provided crucial insights into puzzles in mathematics, geophysics, neuroscience, and human space exploration. You'll learn the solution—but also discover that the finer details still inspire heated arguments. As with other cat behaviour, the more we investigate, the more surprises we discover.	https://go.gov.sg/scb-forces-s-ebook2 https://go.gov.sg/scb-forces-s-ebook 2
Breakfast with Einstein	Your humble alarm clock, digital cameras, the smell of coffee, the glow of a grill, fibre broadband, smoke detectors... all hold secrets about quantum physics. Beginning at sunrise, Chad Orzel reveals the extraordinary science that underpins the simplest activities we all do every day, from making toast to shopping online. It's all around us, the wonderful weirdness of quantum – you just have to know where to look.	https://go.gov.sg/scb-forces-s-ebook3 https://go.gov.sg/scb-forces-s-ebook 3

For Educators and General Public

Books (Physical and/or digital)		
Title	**Content**	**Link**
Conquering the Electron	Conquering the Electron provides a history of the world of electronics, from the discoveries of static electricity and magnetism, each advancement interconnected to the next, up to the creation of the modern day smartphone and the iPad. Exploring the genius, infighting, and luck behind the creation of today's electronic age, Conquering the Electron debunks the hero worship so often plaguing the stories of great advances. Want to know how AT&T's Bell Labs developed semiconductor technology—and how its leading scientists almost came to blows in the process? Conquering the Electron offers these stories and more, presenting each revolutionary technological advance alongside blow-by-blow personal battles that took place.	https://go.gov.sg/scb-forces-ep-ebook1 https://go.gov.sg/scb-forces-ep-ebook1
Relativity	This new edition of Einstein's celebrated book features an authoritative English translation of the text along with an introduction and a reading companion by Hanoch Gutfreund and Jürgen Renn that examines the evolution of Einstein's thinking and casts his ideas in a broader present-day context. A special chapter explores the history of and the stories behind the early foreign-language editions in light of the reception of relativity in different countries. This edition also includes a survey of the introductions from those editions, covers from selected early editions, a letter from Walther Rathenau to Einstein discussing the book, and a revealing sample from Einstein's handwritten manuscript.	https://go.gov.sg/scb-forces-ep-ebook2 https://go.gov.sg/scb-forces-ep-ebook2

Books (Physical and/or digital)		
Title	**Content**	**Link**
Ten Days in Physics that shook the World	Physics informs our understanding of how the world works – but beyond that, it has transformed everyday life. We journey back to ten separate days in history to understand how particular breakthroughs were achieved, meet the individuals responsible and see how each breakthrough has influenced our lives. We have the relatively little-known Rudolf Clausius and his work on thermodynamics and Heike Kamerlingh Onnes on superconductivity, while Albert Einstein is included for the short paper that gave us E=mc2 that raises the possiblity of nuclear fission. Later chapters feature other breakthroughs with transformative practical impacts, such as transistors, LEDs and the Internet.	https://go.gov.sg/scb-forces-ep-audiobook1 https://go.gov.sg/scb-forces-ep-audiobook1
The World According to Physics	Quantum physicist, New York Times bestselling author, and BBC host Jim Al-Khalili offers a fascinating and illuminating look at what physics reveals about the world. Shining a light on the most profound insights revealed by modern physics, Jim Al-Khalili invites us all to understand what this crucially important science tells us about the universe and the nature of reality itself.	https://go.gov.sg/scb-forces-ep-ebook3 https://go.gov.sg/scb-forces-ep-ebook3
Existential Physics	Do we have free will? Is the universe compatible with God? Do we live in a computer simulation? Does the universe think? Physicists are great at complicated research, but they are less good at telling us why it matters. In this entertaining and groundbreaking book, theoretical physicist Sabine Hossenfelder breaks down why we should care. Filled with counterintuitive insights and including interviews with other leading scientists, this clear and yet profound book will reshape your understanding of science and the limits of what we can know.	https://go.gov.sg/scb-forces-ep-ebook4 https://go.gov.sg/scb-forces-ep-ebook4

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For any queries or feedback about this guide or the exhibition, please contact the following personnel:

Ken Lam
Email: lam_yat_hin@science.edu.sg