Applying Force

PHYSICS • FORCES • APPLYING FORCE

Section 1: Forces

• What are the four forces of nature?

There are four fundamental forces in nature: gravitation, electromagnetism and the strong and weak nuclear forces. The strong and weak nuclear forces only apply over very short ranges, comparable to the diameter of an atomic nucleus, but both the electromagnetic and gravitational forces have long ranges.

The gravitational force is always attractive, as all mass in the Universe attracts all other mass. However, the electromagnetic force can be repulsive as well as attractive. Opposite charges attract each other so there is a tendency for charges to 'pair up', which means that the force due to the positive and negative charges cancels out. For this reason the gravitational force tends to be more important than the electromagnetic force over large distances as large bodies tend to be electrically neutral.

Extension Question

Q1. How weak is gravity?

The gravitational force is responsible for the motion of large objects like planets, stars and galaxies. Because of this it is often thought of as a strong force. However, gravity is by far the weakest of the four fundamental forces. It is a trillion, trillion, trillion times weaker than the electromagnetic force. This can easily be demonstrated. A charged balloon will easily pick up small pieces of paper as the electromagnetic force (due to the charge on the balloon) easily overcomes the gravitational force (due to the entire mass of the planet Earth), which tries to pull the paper in the opposite direction.

The reason for the relative weakness of the gravitational force is unknown, but may be related to the particular way the Universe evolved soon after the Big Bang. Alternative theories suggest that the gravitational force 'escapes' into higher dimensions, but these remain speculative, as the existence of these dimensions has never been confirmed by experiment.

• Suggested Films

- Forces of Nature
- FactPack: G-Force

• How do forces cause circular motion?

Rollercoasters rely on forces to provide an exhilarating ride

Newton's first law tells us that objects will continue travelling at a constant speed in the same direction unless acted on by an external force. Objects require a force to maintain a circular path, even if they are travelling at constant speed, as their direction is constantly changing.

To produce circular motion this force must be directed at right angles to the direction of motion at all times. This is known as the central, or centripetal, force. There are various ways this force can be provided. If an object is being whirled on a string the tension in the string provides the central force. For charged particles, which follow circular paths in magnetic fields, the force due to the magnetic field provides the central force. For planets orbiting a star, gravitational attraction provides the central force.

Extension Questions

Q2. What is moment of inertia?

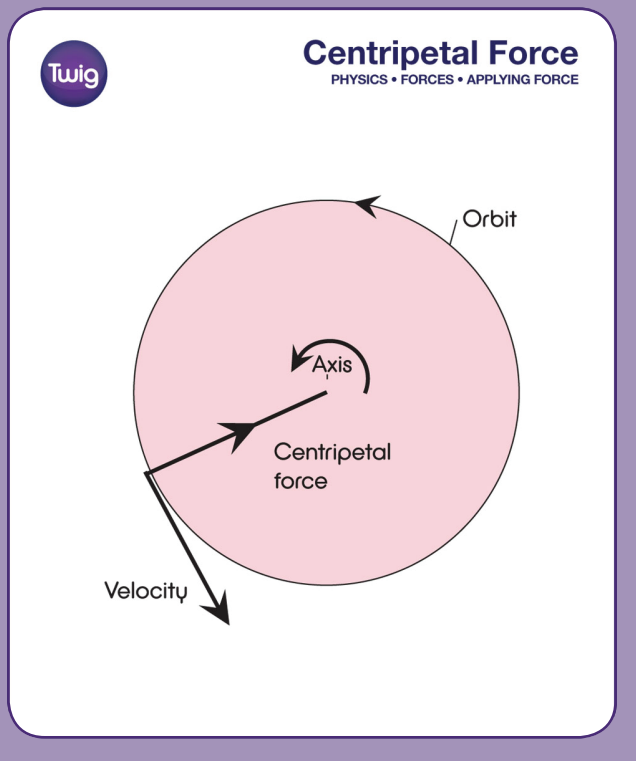
Inertia is the resistance of an object to being accelerated. In linear motion this is equivalent to the mass of an object. The resistance of an object to changes in rotational acceleration is known as its moment of inertia. This not only depends on the mass, but also on the distance of the object from the axis of rotation. The further the distance from the axis of rotation, the greater the moment of inertia and the greater the force required to change the speed of rotation of the object.

Q3. What is angular momentum?

Angular momentum depends on the moment of inertia of an object and how fast it is rotating. Like linear momentum, angular momentum must be conserved. This means that the amount of angular momentum in a system must remain constant unless an outside force (a torque, when dealing with rotational motion) acts.

This is why a spinning ice skater speeds up when they pull their arms in. The average distance from the rotating mass to the axis of rotation decreases, causing the moment of inertia of the skater to decrease. For angular momentum to be conserved the speed of rotation must increase.

DIAGRAM 01:



• Suggested Films

- Centripetal Force
- Rollercoasters

Section 2: Friction

• What is friction?

Friction is a force which acts to oppose movement, always acting in the opposite direction to motion. This causes objects to slow down, converting their kinetic energy to heat. Friction is not a fundamental force, but instead results from the electromagnetic force between particles. As well as occurring between two solid surfaces friction also occurs in gases and liquids.

• Suggested Films

- Friction
- FactPack: Experience Friction

Extension Questions

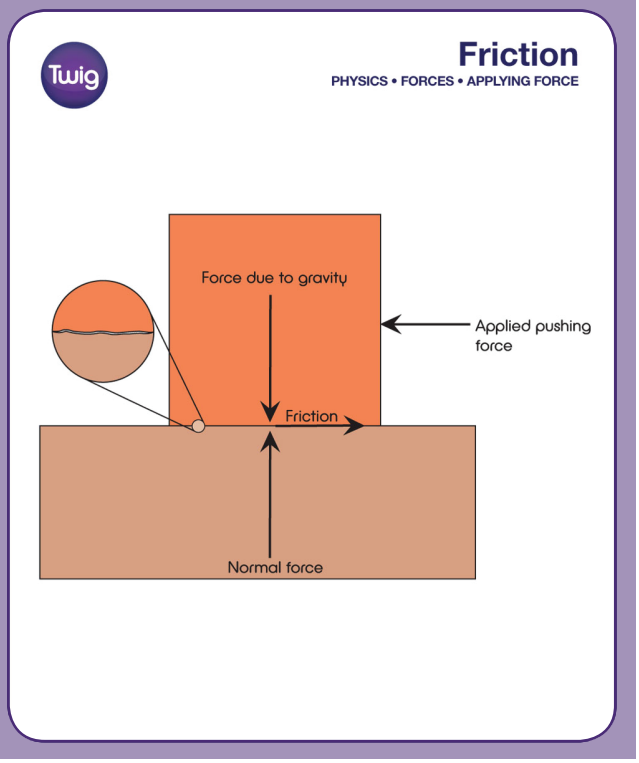
Q4. What does friction depend on?

The size of the frictional force between two surfaces is given by multiplying the force acting perpendicular to the surfaces, pressing them together (the normal force) by a constant known as the coefficient of friction.

The coefficient of friction has to be measured experimentally. There are two different values, for static and kinetic friction. In general, the value for kinetic friction is smaller than the value for static friction, meaning that it is easier to keep something moving than it is to start it moving.

It is perhaps surprising that the size of the contact area does not affect the friction between two surfaces. However, this is easily understood by imagining a block sitting on a horizontal surface. The weight of the block provides the normal force and the area of contact is equal to the face of the block, which is in contact with the surface.

DIAGRAM 02:



If the block were turned so that a face with a smaller area was in contact with the surface we might expect the friction to decrease. However, the weight of the block is the same and is now acting over a smaller area, resulting in a greater force per unit area. The effect of the smaller area is exactly offset by the increase in force per unit area and so the area of contact does not affect the frictional force.

Q5. What causes wheelspin?

When a car begins to move the wheels roll because of the friction between the tyres and the road. This causes the bottom of the wheel to “stick” and the wheel turns, moving the car forward. If the force applied to the wheel is great enough to overcome the static friction it will spin.

Leaves falling onto railway lines can cause problems for trains because they make the rails slippery, As well as making braking difficult, this causes train wheels to spin, making it difficult for the train to move forward. This is a common cause of delays on British and American railways.

• How can friction be reduced?

Attempts are often made to reduce friction in order to prevent wear on machinery, or to enable objects to move with minimum effort.

Wheels and ball bearings are methods of reducing friction. Pushing a car with the wheels turning freely requires a much smaller force than pushing a car with wheels which are locked and unable to turn. This is because rolling friction is far smaller than sliding friction. Friction can also be reduced using lubrication. A lubricant can be used between two surfaces to reduce the amount of contact between them and prevent or reduce wear. Oil in car engines is used for this purpose.

• Suggested Films

- Friction in Curling

- Friction

• What is drag?

Drag refers to the resistance due to an object passing through a gas or a liquid. Air resistance is also known as drag. Unlike the friction between two surfaces, drag depends on the speed of the object.

When a car is travelling at a steady speed, much of the energy it requires is being used to overcome air resistance. As drag increases with speed this also limits the top speed of the car.

Dolphins can swim faster than humans because they are more streamlined and encounter less drag

• Suggested Films

- Aerodynamics in Cycling
- Streamlined: Dolphins vs People
- Friction

Extension Questions

Q6. What is a boundary layer?

As a liquid (or a gas) flows past a surface, the liquid near the surface will be slowed down by its interaction with the surface. The area where this slows down the liquid significantly is known as the boundary layer.

This is the reason that the flow of water in a river is fastest at the centre, away from the riverbank or river bed which will slow it down.

Q7. What is the difference between laminar and turbulent flow?

At low speeds, air (or water) flows smoothly past an object. This is known as laminar flow. At higher speeds the flow is no longer smooth. Eddies form and the flow becomes chaotic. This is known as turbulent flow.

Golf balls are dimpled because this causes turbulent flow to occur at lower speeds. This reduces drag and allows the ball to travel longer distances, because the turbulent boundary layer takes longer to separate from the surface of the ball, reducing overall drag.

Section 3: Machines

• Who was Archimedes?

A portrait of the Greek mathematician and engineer Archimedes

Archimedes was a mathematician and engineer who lived from around 287 to 212 BC. Although he made enormous contributions to mathematics he is perhaps most famous for his mechanical inventions. He is said to have built various machines to defend Syracuse, in Sicily, when it was attacked by the Romans during the Second Punic war.

A common story about Archimedes is that he determined whether a crown was really made of gold, by noting the volume of liquid it displaced when it was immersed in water, an idea that came to him while he was bathing. Although it is far from certain that this event ever took place, in his work On Floating Bodies, Archimedes did state the basic laws of hydrostatics and explains the principles behind buoyancy.

Extension Questions

Q8. What is an Archimedes screw?

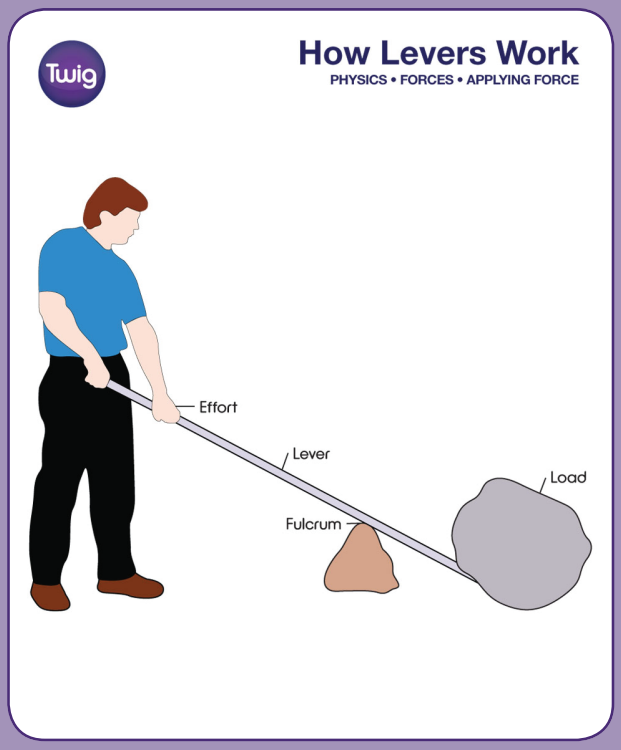
An Archimedes screw is made of a screw inside a hollow cylinder. If the cylinder is tilted then, as the screw is turned, water will be carried up the cylinder by the screw. Archimedes is said to have designed these to remove bilge water from ships, but the Archimedes screw still has many applications today. They have been used to drain water and in the irrigation of farmland and, because they are less likely clog than pumps, they are often used at wastewater treatment plants.

Q9. Why do levers make it easier to move large objects?

When a large force is required over a small distance, a lever provides a method of applying a small force over a larger distance. This allows humans to lift objects which would otherwise be impossible to move. Archimedes did not invent levers but he explained the principle behind their operation.

There are several different types of lever, but perhaps the simplest is the class 1 lever. A seesaw is a class 1 lever. However, if the load is closer to the pivot (the fulcrum) than the applied force, then the force applied to the load will be greater than the applied force. This is the principle behind simple levers, which are used to prise up heavy objects or force objects apart, like a crowbar.

DIAGRAM 03:



- **Suggested Films**
  - **Levers, Wheels and Pulleys**

Q10. What are the advantages of using wheels?

The wheel and axle allows loads to be transported relatively easily, as rolling friction is so much less than sliding friction. Wheels have been used for thousands of years. However, some civilisations lacked access to domesticated animals like horses which could pull wheeled vehicles and so the wheel would only have been of limited use.

Wheels can only be used extensively where roads are available as they are of limited use on soft or uneven terrain. Modern vehicles, which have to travel across this type of terrain, often use wheels to drive tracks that distribute the weight of the vehicle more evenly and are less troubled by small obstacles.

• How were the pyramids built?

There are over 100 pyramids in Egypt. They were built as tombs in a period spanning about a thousand years, beginning in around 2600 BC. The largest is almost 150m high and its construction involved the movement and placing of over 2 million blocks, the heaviest of which have a mass of 80 tonnes. In addition to this, many of the blocks, totalling thousands of tonnes, would have had to have been transported hundreds of kilometres for use in construction. At the time the Great Pyramid was built, the Egyptians did not use wheeled vehicles and so the stones were presumably dragged on sleds to the construction site.

Although the exact construction method is still a matter of debate, it is generally agreed that the Egyptians must have used ramps, levers and a workforce of tens of thousands. It is thought that construction took 10 or 20 years.

Some people argue that the Egyptians built the Great Pyramids using simple machines, including inclined planes, pulleys and levers

• Suggested Films

- **Machines: Building the Pyramids**
- **Planes, Wedges and Screws**

• Quizzes

Forces of Nature

Basic

• How many fundamental forces of nature are there?

A – one

B – four

C – three

D – five

• What is the name of the force which pulls us towards the Earth's surface?

A – the gravitational force

B – friction

C – magnetism

D – the strong nuclear force

• How does the force of gravity behave?

A – it only exerts a pull on charged objects

B – it causes objects to attract or repel

C – it causes all objects to be attracted to each other

D – it causes objects to attract as long as they are close to each other

Advanced

• How does the gravitational force depend on mass?

A – the force does not depend on mass

B – the larger the mass, the greater the force

C – the smaller the mass, the greater the force

D – a very large mass is needed to produce a force

• How strong is the force of gravity?

A – it is weak compared to the other forces

B – it is weaker than the electromagnetic force, but stronger than the others

C – it is the strongest of all the forces of nature

D – it has the same strength as the other forces

• How does the electromagnetic force behave?

A – it causes oppositely charged particles to attract

B – it causes all objects to attract

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Forces of Nature

Basic

• How does the force of gravity depend on distance?

A – it only acts over very short distances

B – it remains constant with distance

C – the greater the distance, the greater the force

D – the shorter the distance, the stronger the force

• Which of these is a clear demonstration of the electromagnetic force in action?

A – neutrons transforming into protons

B – planets orbiting the Sun

C – the behaviour of magnets

D – objects falling towards the Earth

Advanced

• Why is the weak nuclear force important?

A – it is the strongest of the fundamental forces of nature

B – it is responsible for gravitational attraction

C – it causes charged particles to attract each other

D – it can transform protons into neutrons and vice versa

• Which force holds the nucleus of an atom together?

A – the force of gravity

B – the strong nuclear force

C – the weak nuclear force

D – magnetism

Friction

Basic

• What is friction?

A – the force that pulls us towards Earth

B – a force that opposes motion

C – the heat released when something is burned

D – the force between two charged particles

• Which of the following is not an example of friction?

A – brakes stopping a car

B – an object slowing down as it slides across a surface

C – meteors burning up as they enter our atmosphere

D – a ball falling towards the ground

• What eventually happens to cars if brakes are not applied?

A – they will stop due to the force of gravity

B – they will stop because there is no force acting on them

C – they will stop due to friction between the tyres and the road

D – they will continue forever

Advanced

• How does the weight of an object affect friction as it is pushed along a surface?

A – the greater the weight, the smaller the friction

B – it has no effect

C – the greater the weight, the greater the friction

D – the weight only affects friction if it is very large

• What is drag?

A – friction due to two solid surfaces rubbing together

B – the small amount of friction objects experience in space

C – friction that is encountered after lubrication

D – friction due to a solid moving through a fluid like air or water

• Why does a feather fall more slowly than a hammer?

A – it experiences more air resistance relative to its weight

B – because heavier objects always fall more quickly

C – because larger objects always fall more quickly

D – it experiences less air resistance relative to its weight

Friction

Basic

• What happens to the energy of an object when friction slows it down?

A – it remains unchanged

B – it is converted to heat

C – it increases

D – it is converted to potential energy

Advanced

• Why does a feather fall at the same rate as a hammer on the Moon?

A – because the force due to gravity on the Moon is very small

B – there is no air resistance on the Moon

C – because the force due to gravity on the Moon is very strong

D – because it is so cold on the Moon

Centripetal Force

Basic

• When would you experience a centripetal force?

A – when falling through the air

B – when you turn a corner at high speed

C – in a car travelling in a straight line which brakes suddenly

D – in a rocket which is accelerating upwards

• What does a centripetal force do?

A – it makes an object follow a circular path

B – it causes objects to fall towards Earth

C – it stops objects moving

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• What provides the centripetal force for satellites orbiting the Earth?

A – the electromagnetic force

B – no centripetal force is required

C – the gravitational force

D – friction

• What is always required for circular motion?

A – a gravitational force

B – a magnetic force

C – friction

D – a centripetal force

Advanced

• What does Newton's first law mean for an object in circular motion?

A – its acceleration would be equal to the force divided by its mass

B – no force is required as the speed of the object does not change

C – a force is required as otherwise it would continue in a straight line

D – any force exerted on it requires an equal force in the opposite direction

• Which of these statements is true for a spinning object?

A – it will stop unless a force is applied to keep it moving

B – a force is required to start it spinning but not to stop it

C – its speed of rotation will vary if no external force is applied

D – it will continue spinning until an external force is applied

• What is the "moment of inertia" of an object?

A – its resistance to having its speed of rotation changed

B – the mass of the object

C – the rotational speed of the object

D – the force required to stop the object spinning

Centripetal Force

Basic

Advanced

• What is the axis of rotation?

A – the position of the object before it starts rotating

B – any line which can be drawn through a rotating object

C – the line around which an object spins

D – the line along which the force acts which starts the object spinning

• How does the average distance of a mass from the axis affect the moment of inertia?

A – the greater the distance, the greater the moment of inertia

B – the greater the distance, the smaller the moment of inertia

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• Answers

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