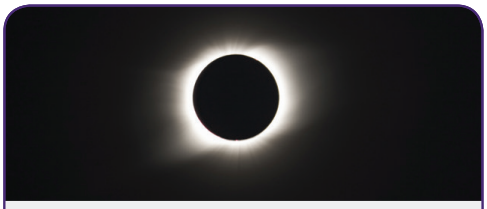
The Moon

Section 1: The Earth and the Moon

• What is a moon?

A moon is a natural satellite. Usually a moon orbits a planet, but there are also moons in our Solar System, which orbit asteroids and dwarf planets. There are over 160 moons orbiting planets in our Solar System. Of the eight planets, only two do not have moons.



At times, the Moon can perfectly block out the Sun

- **Suggested Films**
  - **The Moon**
  - **Moon Measuring**

Extension Questions

Q1. How do we know the distance to the Moon?

Reflectors were left on the Moon during the Apollo missions. By firing a laser from Earth at these reflectors, and timing how long it takes for the light to return, the distance from the Earth to the Moon can be calculated extremely accurately (to within centimetres). We know the speed of light, and since it takes around 2.5 seconds for the light to make the journey to the Moon and back, we can calculate the distance to Moon as around 380,000km. This compares to the diameter of the Earth, which is about 12,800km.

These experiments are also used to measure the possible size of the Moon's core, and to test our theories of gravity. These measurements have provided precise information regarding the rotation of the Moon. These results also suggest that the Moon has a small liquid core, and that the Moon is receding from the Earth by about 4cm each year.

As well as telling us about the Moon-Earth system, these measurements have demonstrated that the universal gravitational constant has not varied by more than 1 part in 100 billion since the experiment began, showing that the force of gravity is very stable. They have also provided a test of general relativity, as this predicts the shape of the Moon's orbit. So far the results agree with Einstein's equations, but more accurate measurements are planned, which will provide a more powerful test. These measurements are intended to be accurate to within a few millimetres.

Q2. What is an eclipse?

As the Moon orbits the Earth, the Earth is also orbiting the Sun. We would therefore expect that sometimes the Moon would be between the Sun and the Earth, and would block out the light from the Sun. What makes eclipses special is that the Moon is 400 times smaller than the Sun, but also 400 times closer to Earth. So when the two align, they appear to be the same size, and the Moon perfectly blocks out the Sun. This is unusual, but is probably just a coincidence, particularly as this situation is temporary. The Moon is gradually moving away from Earth (at around 4cm every year) and there is only a window of a few hundred million years when the Moon and the Sun are the same apparent size in the sky.

Eclipses happen far less often than we might expect because the Moon's orbit is tilted at 5° relative to the Earth's, and so it does not often pass directly in front of the Sun.

Extension Question

Q3. Does the Moon look different from the southern hemisphere?

Yes. How the Moon looks depends where you are on Earth. From Australia and from the UK the Moon looks quite different. In Australia the Moon appears upside down, and the phases appear to occur from the opposite direction. Imagine standing at the North Pole and looking horizontally at the Moon. Then imagine doing the same from the South Pole. The Moon would appear upside-down compared to the view from the North Pole.

For this reason in the northern hemisphere, when the Moon is waxing (becoming brighter), it does this from the right side first. When it is waning (becoming darker), this left side of the Moon is the last part to be illuminated before the Moon becomes completely dark.

In the southern hemisphere this happens in reverse. The left side of the Moon is illuminated first while the Moon is waxing, and when the Moon is waning, the right side of the Moon is the last part to be illuminated.

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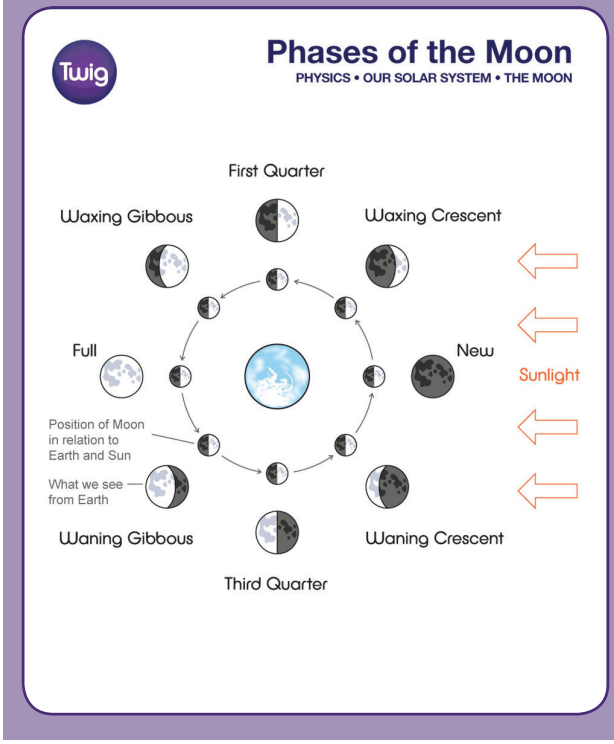

• How was the Moon formed?

There have been many theories as to how the Moon formed.

Some theories suggest that the Earth and Moon may have formed at the same time, either by the material coalescing into two bodies, or by the Earth throwing off material which then became the Moon.

But the mineral composition of the Moon suggests that the Moon and Earth did not form in the same way. For the Earth to have thrown off the Moon it would have been spinning very quickly, and this would still be visible in their spins and orbits today.

Alternatively, it was suggested that the Moon may have been a body captured by the gravity of the Earth. However, we now know that the Moon's composition is too similar to Earth's for it to have been an entirely separate body.

Today, the most accepted theory is that the Moon was formed in a collision between Earth and another large body, which has been called Theia, and this collision debris coalesced to form the Moon.

- **Suggested Films**
  - **The Moon**
  - **Rare Earth 1: Earth's Twin**

Extension Questions

Q4. Do we have any samples from the Moon?

The Apollo missions brought back almost 400kg of rocks from the Moon. The unmanned Soviet Luna missions in the 1970s also returned samples of Moon dust. There are also dozens of lunar meteorites which have fallen to Earth.

Moon rock is extremely dry and contains no water. Radioactive dating has shown these rocks have an age of around 4.5 billion years, showing that the Moon formed about 30 million years after the Solar System. The composition of the rocks suggests that a large part of the Moon was once molten. In addition, their oxygen isotope ratios are very similar to Earth rock. This suggests that parts of the Moon were once part of the Earth.

Most of the Apollo Moon rocks are kept at the Johnson Space Centre in Texas, and are considered to be priceless. A small number of samples were sent out as gifts to governments and officials. In 2002, two workers at NASA stole Moon rock samples; these were recovered and the workers were arrested.

Q5. Is there water on the Moon?

Water cannot last on the surface of the Moon, but there is a suggestion that water could exist in the permanently dark craters of its poles. Various probes may have detected water, but the data is still inconclusive. If water does exist on the Moon, this would make is easier for humans to construct bases on the Moon in the future.

• Does the Moon have day and night?

Yes. The Moon rotates on its axis once every 27.3 days. A day on the Moon is actually longer than this because of the rotation of the Earth-Moon system around the Sun: it lasts around 29.5 days. The time it takes for the Moon to rotate on its axis is the same as the time it takes to orbit the Earth. This results in the same side of the Moon always facing the Earth. The side which is never seen from the Earth is known as the dark side of the Moon.

Phases of the Moon occur as it orbits the Earth

- **Suggested Film**
  - **Dark Side of the Moon**

- **Suggested Activities**
  - **Use a lamp and two balls to show how the phases of the Moon arise**
  - **Demonstrate synchronous rotation of the Earth and Moon. One person should stand in the middle (the Earth) and spin on the spot or stand still (it's the Moon's rotation that matters). A second person (the Moon) should slowly spin on the spot (this is the rotation of the Moon) and circle around the Earth person at the same time. They will reach a speed where they are circling the Earth and rotating, but they are always facing the Earth person. This is what happens when the Moon orbits the Earth: the speed means that we only see one side or face.**

Extension Questions

Q6. Why is the Moon in synchronous rotation with the Earth?

In the past, the Moon would have rotated more rapidly on its axis, but the Earth's gravity exerts a tidal force on the Moon. It causes the Moon to bulge slightly, in the same way that the Moon causes the oceans of the Earth to bulge. Over time this caused the Moon's rotation to slow down. Eventually, we might expect the Moon's gravity to have the same effect on the Earth, and the Earth to become tidally locked, ending up with the same side always facing the Moon. However, as the Moon's mass is only 1% of the Earth, this will take billions of years.

Q7. When the Moon is not 'full' why is the dark part faintly visible?

This is known as earthshine. Light from the Sun is reflected by the Earth and partially illuminates the Moon. This light has been used to measure the amount of light reflected by the Earth (its albedo). This is related to the amount of cloud cover, and these measurements are used into research into the Earth's climate and global warming.

Q8. Why can we see the Moon during the day?

The Moon is often on the same side of the Earth as the Sun. When this happens, the Moon will be in the sky in the daytime. However, as the daytime sky is so bright, the Moon will often be invisible or hard to see unless it is fully illuminated.

Section 2: Effect of the Moon

• What would the consequences be if the Earth did not have a moon?

The Earth rotates on an axis tilted at 23.5°. This means that for half a year one hemisphere is tilted further away from the Sun than the other, and receives less sunlight, thus causing the seasons on Earth. The tilt changes by around 2° every 40,000 years and also precesses. This means the axis changes orientation gradually, while staying at an angle of 23.5°, the North Pole completes a circle every 26,000 years.

The orbit of the Moon stabilises the rotation of the Earth. Without the Moon the rotational axis of the Earth may have been very different, with a tilt that varied much more widely than the current 2° every 40,000 years. Ocean tides would be greatly reduced without the Moon (although the Sun's gravitational pull would still cause small tides). It is believed by some that life would never have evolved on Earth without the Moon.

- **Suggested Films**
  - **Life Without the Moon**
  - **The Moon and Its Effect on Life**

Extension Question

Q9. Does the Moon have an effect on human behaviour?

The word 'lunatic' is derived from the ancient belief that the lunar cycle had an effect on human behaviour. This "lunar effect" has been said to affect crime rates and mental illness; however, research has shown that, although the lunar cycle can impact humans physically, it has no effect on human behaviour.

• What causes the tides?

The Moon's gravitational force falls off with distance. For this reason, the side of the Earth closest to the Moon experiences a greater gravitational force than the far side, and the water on the near side bulges towards the Moon.

The Earth is also pulled towards the Moon, however, as the gravitational force is weaker at the far side of the Earth, the water is being pulled towards the Moon less strongly, and so it bulges away from the Moon.

At the surface of the Earth the gravitational force due to the Sun is actually larger than that due to the Moon. However, the Sun is much further away, and so there is a much smaller difference between the force on the near and far sides of the Earth. This means the tidal effect due to the Sun is much smaller.

Tides occur in other places in the Solar System. The Sun's influence on Mercury produces a much stronger tidal force than the Moon does on the Earth, and causes the surface of Mercury to bulge.

- **Suggested Film**
  - **The Moon and Spring Tides**

The Moon's gravity has an effect on the tides

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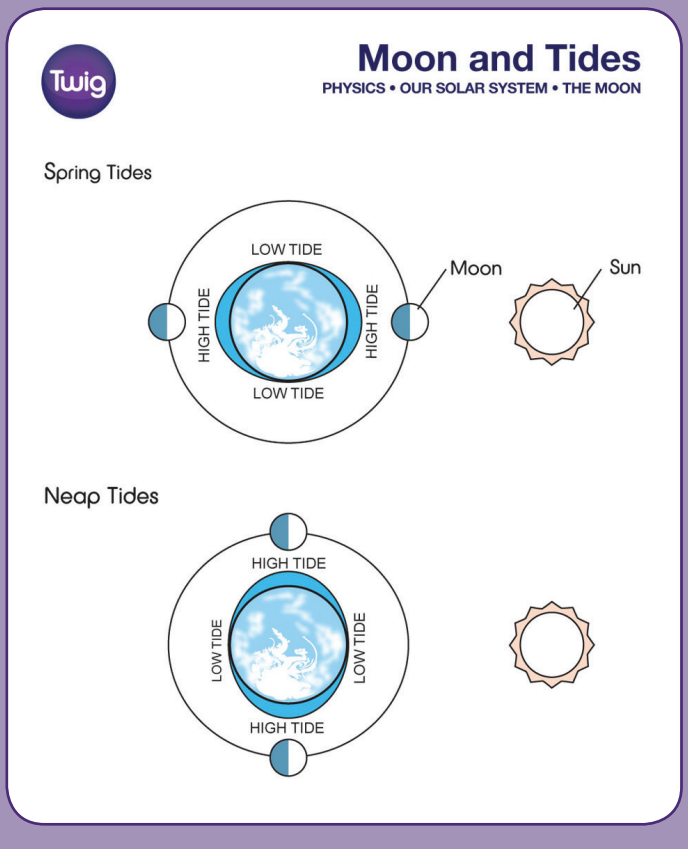

Extension Question

Q10. Why does the tidal bulge on the side of the Earth furthest from the Moon bulge away from the Moon not towards it?

You would perhaps expect the faraway tidal bulge to move towards the Moon in the same way as the near side, only less dramatically. Instead, the faraway bulge moves away from the Moon rather than towards it. It may be hard to understand this apparent contradiction without considering the rotational motion of both the Moon and Earth.

For simplicity, let's consider the opposite case and think about the similar bulges on the Moon caused by the Earth. The Moon orbits Earth. The near side is being pulled on very strongly, causing a bulge to appear, whereas the far side is being pulled on more weakly. The Moon is whirling round, being forced to follow a circular path by the Earth's gravitational pull, which provides the central force. Anything on the far side of the Moon is holding on by its fingertips, its feet flying through the air. The central force and the Earth's gravitational pull is pulling it round, but the Earth's gravitational force isn't as powerful out at the far side. And so you get a bulge or 'flailing feet'.

This bulge on the far side is an example of what used to be called centrifugal force, but we now use the term central force. Or, if you prefer, it is the result of the far side of the Moon trying to continue in a tangential path and being forced to follow a circular path.

Another way to think about the far side bulge on Earth, is the Earth being pulled through the water and coming closer to the Moon. The Earth is held closer to the Moon by the central force, whereas the water on the far side isn't, and so bulges outwards.

Section 3: Going to the Moon

• How easy is it to travel to the Moon?

To travel from the Earth to the Moon presents several challenges. First, the launch vehicle must achieve sufficient velocity to leave the surface of the Earth and enter orbit. On reaching the Moon, the craft must slow down enough to make a 'soft' landing. To return, it must leave the Moon, and on reaching Earth it must then slow down enough to land safely.

The Apollo missions followed an approximate figure 8 trajectory. They first used the massive Saturn V rockets to reach low Earth orbit. From there they increased their velocity in order to break orbit and head towards the Moon, where the spacecraft entered lunar orbit. This spacecraft then released the lunar module; firing its rockets to slow down, drop out of orbit, and land on the Moon.

After the mission was completed, the lunar module's ascent stage would then launch and rendezvous with the orbiting spacecraft. The lunar module would be discarded, and the crew would travel back to Earth on the main spacecraft. On reaching Earth, the spacecraft would re-enter the atmosphere using heat shields to survive the heat generated by friction. Finally, parachutes were used to slow the descent of the spacecraft, meaning it could land safely.

Buzz Aldrin landing on the Moon (image processed from original flight footage)

Extension Question

Q11. How difficult is travel to the Moon?

Astronauts have not returned to the Moon since 1972. NASA's current launch vehicle, the space shuttle, only takes astronauts to low-Earth orbit. The Constellation programme aimed to send astronauts to the Moon again using massive 'Ares' rockets, but President Obama announced that this programme was to be cancelled early in 2010.

In addition to this, space travel is a dangerous business. In 1967, three astronauts were killed in a fire on Apollo 1 during a launch test, and in 1970, an accident on board Apollo 13 almost resulted in the loss of the three crew members. At around the same time four Soviet cosmonauts were also killed in two separate accidents. In 1986, seven astronauts were killed when the space shuttle Challenger disintegrated soon after launch, and in 2003 another seven were lost when the space shuttle Columbia broke up on re-entry.

Q12. How did the Apollo programme take astronauts to the Moon?

The American Apollo programme used the enormous Saturn V rockets. These were over 100m high and had a mass of over 3000 tonnes. They were designed with the help of Wernher von Braun and other German scientists who were captured after the Second World War and brought to the USA. These scientists used their experience, designing and building V2 rockets for Germany, to help the American space programme.

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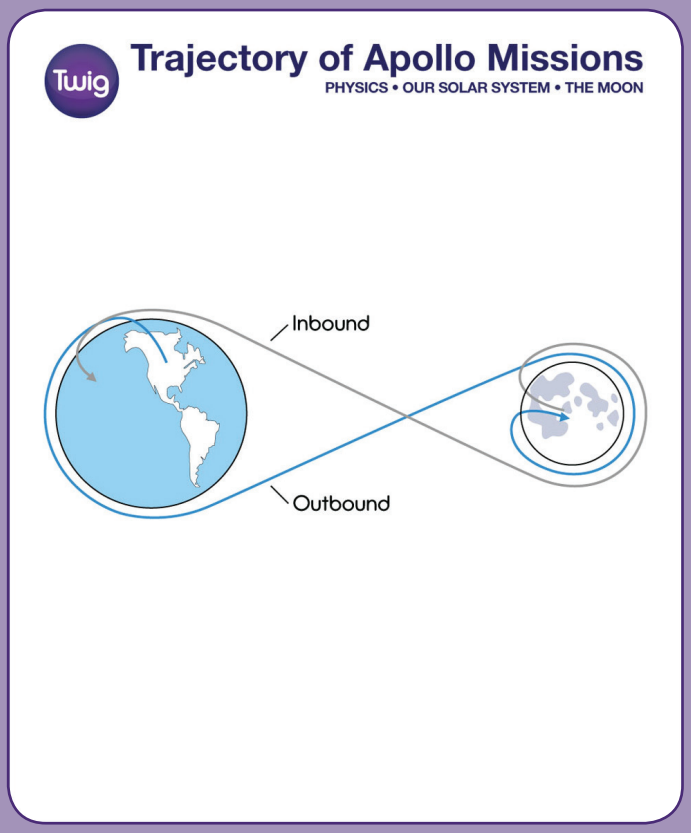


- **Suggested Film**
  - **Fly Me to the Moon**

• Why go to the Moon?

After the Second World War the two superpowers, the Soviet Union and the United States, entered into the Cold War. This led to enormous tension and competition between the two powers.

In 1957, the Soviet Union launched Sputnik 1 the first artificial satellite. This, combined with other Soviet successes, such as putting the first man in space, led to intense competition between the two countries. In 1961, President Kennedy announced that the USA intended to send a man to the Moon by the end of the decade.

Although the two superpowers were ostensibly competing for technological supremacy in outer space, they were actually demonstrating their military potential. The USA's thinking during the Cold War was: if Russia could put a man into space, they could easily land a missile on New York City.

- **Suggested Film**
  - **Man On the Moon: Part 1**

Extension Questions

Q13. Is the Great Wall of China the only man-made object which can be seen from the Moon?

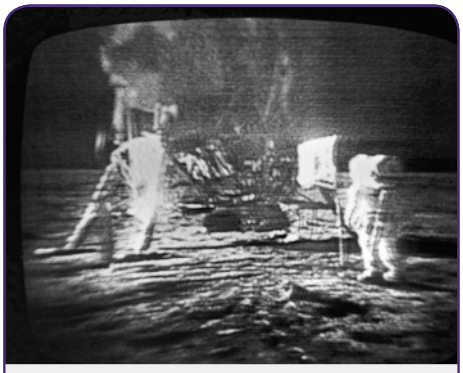
No. In fact no man-made objects can be seen from the Moon. This myth has been around for over a hundred years, but the Great Wall of China is likely not even visible from a low-Earth orbit of around 160km.

• What did the Apollo astronauts do?

The Apollo programme aimed to fulfil President Kennedy's pledge. Astronauts were selected from military test pilots, and Apollo 11 finally landed astronauts on the Moon in 1969. Five more missions followed.

On the six Apollo missions the astronauts collected rock samples, photographed the lunar surface, and conducted experiments. The last Apollo mission took place in 1972 and astronauts have not returned to the Moon since then.

- **Suggested Film**
  - **Man On the Moon: Part 2**



Televised view of Apollo astronauts on the Moon

• Quizzes

The Moon

Basic

• How long (approximately) does the Moon take to orbit the Earth?

A – 1 day

B – 1 month

C – 1 year

• How big is the Moon compared to the Earth?

A – a sixth of the size

B – half the size

C – a quarter the size

• What is the Moon made of?

A – rock

B – ice

C – iron

• Why is the Moon bright?

A – because it is a star and emits light

B – because it reflects light from the Sun

C – because it reflects light from the Earth

Advanced

• How many moons does Jupiter have?

A – 1

B – about 20

C – more than 60

• Which of the following is a moon of Jupiter?

A – Titan

B – Callisto

C – Dione

• How many other moons are there in the Solar System?

A – 8

B – about 50

C – over 160

• Why will the craters on the Moon never be worn away?

A – because the Moon has a very thin atmosphere

B – because the Moon rotates very slowly

C – because they are made of solid rock

The Moon

Basic

• Why does the Moon seem to change shape in the sky?

A – because it is not a perfect sphere

B – because the Earth is rotating

C – because part of it is in shadow

• What is the surface of the Moon like?

A – smooth

B – dry and rocky

C – rocky with water-filled craters

Advanced

• What is the average distance to the Moon?

A – 10,000 km

B – 384,000 km

C – 2,000,000 km

• Answers

The Moon

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