KS4 BepiColombo Lesson Plan – Gravity

GCSE Physics

LEARNING OBJECTIVES

- To understand the phenomena of 'action at a distance' and the related concept of the field as the key to analysing gravitational effects. (KS4 physics curriculum) Relate this to gravitational field strength (KS4 physics curriculum).
- To understand that weight is a force, and to understand the proportionality between weight and mass (KS4 physics curriculum).
- Equations:
    - GPE = mgh
    - W = mg

Bonus:

- To know a use of the X-ray region of the EM spectrum (KS4 physics curriculum)
    - MIXS uses X-ray fluorescence to work out surface materials on Mercury

BACKGROUND

BepiColombo and MIXS

BepiColombo is Europe's first mission to Mercury. It launched in October 2018 and will arrive at Mercury in 2025. There have been two previous NASA missions; Mariner 10 and MESSENGER. The data from these missions have given us our current understanding of this mysterious planet, however, they also raised many interesting questions, which BepiColombo hopes to answer.

The UK's contribution to the mission is MIXS, the Mercury Imaging X-ray Spectrometer, which was developed by the University of Leicester. MIXS will detect fluorescent X-rays. This is when X-rays (in this case that come from the Sun) are absorbed and then emitted from the surface of Mercury. These X-rays will have an energy signature corresponding to the type of atom (chemical element) that emitted it. More information on X-ray fluorescence can be found on our website.

National Curriculum

In KS3 the students developed a basic understanding of forces. Their current understanding is outlined in the KS3 curriculum. Relevant parts of the KS3 curriculum are shown below:

- forces as pushes or pulls, arising from the interaction between two objects
- using force arrows in diagrams, adding forces in one dimension, balanced and unbalanced forces
- moment as the turning effect of a force
- forces: associated with deforming objects; stretching and squashing – springs; with rubbing and friction between surfaces, with pushing things out of the way; resistance to motion of air and water
- forces measured in newtons, measurements of stretch or compression as force is changed

- force-extension linear relation; Hooke's Law as a special case
- work done and energy changes on deformation
- non-contact forces: gravity forces acting at a distance on Earth and in space, forces between magnets and forces due to static electricity.

In KS4 the student's current understanding is developed. Highlighted points above reflect the understanding needed in order to complete this lesson.

The KS4 curriculum points covered in this lesson are shown below:

General:

- ✓ the phenomena of 'action at a distance' and the related concept of the field as the key to analysing electrical, magnetic and gravitational effects
- ✓ that proportionality, for example between weight and mass of an object or between force and extension in a spring, is an important aspect of many models in science.

Forces:

- ✓ forces and fields: electrostatic, magnetic, gravity
- ✓ weight and gravitational field strength
- ✓ acceleration caused by forces; Newton's First Law

Wave motion: (bonus)

- ✓ uses in the radio, microwave, infra-red, visible, ultra-violet, X-ray and gamma-ray regions, hazardous effects on bodily tissues.

Note: The electromagnetic spectrum will need to have been briefly covered/ mentioned so that the bonus objective can be of use.

Gravity

BepiColombo takes seven years to get into its final orbit around Mercury. This may seem like a long time, considering that Mercury is not far from Earth in comparison to other planets. In fact, Mercury is one of the hardest planets to get into orbit around. For example, JUNO took 5 years to get to Jupiter, and Jupiter is 588 million km from Earth (average) and Mercury is only 77 million km away from us! Mercury has a weak gravitational pull on the BepiColombo spacecraft, whereas Jupiter had a huge gravitational pull on the Juno spacecraft. This is due to the sizes of the two planets. (Mercury is small, Jupiter is big).

The reason that it is so hard to get into orbit around Mercury is largely to do with the Sun's gravity. Mercury is the inner most planet to the Sun, and orbits around it quickly. The Sun has as huge gravitational pull on anything that is near it, so if a spacecraft was sent directly to Mercury, it would not be able to enter into orbit around Mercury but would fly past into the Sun.

As such, BepiColombo needs to decelerate so that it can get into orbit around Mercury. The way it will decelerate is by using the gravitational pull of planets in the opposite direction to its motion. To do this, BepiColombo will do a flyby of Earth once, Venus twice, and Mercury six times before settling into its final orbit. It uses these planet's gravity to slow down. BepiColombo also has an ion drive, which will accelerate it in the opposite direction, slowing it further.

LESSON PLAN

Introduction – slides 1 – 2, 5 minutes

Brainstorm with the class their current ideas about gravity, weight and mass. Ask them what the difference between mass and weight is. Ask if they think gravity is stronger on Earth or Mercury – prompt them by telling them that Earth has a greater mass than Mercury. Then ask them about the gravity of the Sun. Is that bigger?

Main – slides 3 – 8 - 20 mins

Acting at a distance

If you have a cloth, you can demonstrate the effects of gravity. What happens when a heavier object is placed on the cloth? i.e. the Sun.

Weight

Address any misconceptions between weight and mass. Explain that mass remains constant, and that weight is a force. Draw a force diagram on the board including weight.

Explain that g is the acceleration due to gravity, and at Earth's surface g = 9.81 m/s^2. It does not remain constant. Ask the students whether they think it will decrease or increase as you move further away from the Earth's surface. (Decrease).

Introduce the equation W=mg on the board. You may go through an example;

M = 53 kg

W = 53kg x 9.81 m/s^2 = 520 N

Explain that on Mercury, g is approximately 1/3 of what it is on Earth. How will this affect a person's weight? g = 3.61 m/s^2 on Mercury.

W = 53kg x 3.61 kg = 191 N

On the board, write W = m X k

Explain that you have written the equation W = mg, but written k instead of g, to show that it is a constant in the equation we don't need to worry about. (Remind them that the value of g isn't a constant, however, the equation doesn't change).

On the board, write $W \propto m$

Explain that $\propto$ means 'is proportional to'. It tells us there is a relationship between weight and mass.

Gravitational Potential Energy

Remind students that there are different types of energy.

After explaining the slide, ask the class which of the two places on the roller-coaster (marked with arrows) has the greatest GPE. (The larger arrow).

Newton's First Law

An object in motion will stay in motion until it is acted upon by an external force. Then it will accelerate.

BepiColombo

Ask the students if they have any ideas as to why it takes BepiColombo so long to get to Mercury. (Before showing them the slide).

BepiColombo takes seven years to get into its final orbit around Mercury. This may seem like a long time, considering that Mercury is not far from Earth in comparison to other planets. In fact, Mercury is one of the hardest planets to get into orbit around. For example, JUNO took 5 years to get to Jupiter, and Jupiter is 588 million km from Earth (average) and Mercury is only 77 million km away from us!

The reason that it is so hard to get into orbit around Mercury is largely to do with the Sun's gravity. Mercury is the innermost planet to the Sun, and orbits around it quickly. The Sun has as huge gravitational pull on anything that is near it, so if a spacecraft was sent directly to Mercury, it would not be able to enter into orbit around Mercury but would fly past into the Sun.

As such, BepiColombo needs to decelerate so that it can get into orbit around Mercury. To do this, BepiColombo will do a flyby of Earth once, Venus twice, and Mercury six times before settling into its final orbit. It uses these planet's gravity to slow down. BepiColombo also has an ion drive, which will accelerate it in the opposite direction, slowing it further.

Worksheet – 30 minutes

The worksheet is included at the end of this document, along with answers. It may be useful to go through the answers on the board after the majority of the class has completed the worksheet.

Bonus slide – 5 mins

Explain that the UK's contribution to BepiColombo is MIXS, which was developed by the University of Leicester.

Ask the class if they remember the different types of light. (Radio waves, microwaves, infra-red, visible light, ultra-violet, X-rays, gamma rays).

Ask them for a use of X-rays. (They will probably talk about X-rays being used in the hospital or dentist.)

Explain that MIXS also uses X-rays to work out what the surface of Mercury is made of.

Homework- Their homework may be to find out more about the BepiColombo mission. They could make a poster linking it to what they have learnt in the lesson.

Name_____

BepiColombo - Gravity Worksheet

BepiColombo is Europe's first mission to Mercury. In order to get there, it has to decelerate because the Sun's gravitational force is so strong that if the spacecraft had a direct path to the Sun, it would fly past Mercury and into the Sun.

Key Equations

Gravitational Potential Energy = mass x acceleration of gravity x height

$$GPE = m \times g \times h$$

Weight = mass x acceleration of gravity

$$W = m \times g$$

$g = 9.81\ m/s^2$ on Earth

$g = 3.61\ m/s^2$ on Mercury

Task 1:

Fill in the SI units. The first one has been done for you.

g m/s^2

GPE _____

m _____

h _____

W _____

Task 2:

Explain why BepiColombo takes 7 years to get to Mercury, even though Mercury is not too far from Earth.

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_____

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Task 3:

A person's mass is 60 kg.

a) What is their mass on Mercury?

_____

b) What is their weight on Earth?

c) What is their weight on Mercury?

Task 4:

A person's weight on **Mercury** is 195 N.

a) What is their mass?

b) What is their weight on Earth?

Task 5:

A stone with mass 10 kg is dropped from a height of 30 m on Earth.

a) What is the stone's gravitational potential energy?

b) The stone is now moved to Mercury. It is dropped, and has a GPE of 1552 J. What height was it dropped from?

Name_____

BepiColombo - Gravity Worksheet Answers

BepiColombo is Europe's first mission to Mercury. In order to get there, it has to decelerate because the Sun's gravitational force is so strong that if the spacecraft had a direct path to the Sun, it would fly past Mercury and into the Sun.

Key Equations

Gravitational Potential Energy = mass x acceleration of gravity x height

$$GPE = m \times g \times h$$

Weight = mass x acceleration of gravity

$$W = m \times g$$

$g = 9.81\ m/s^2$ on Earth

$g = 3.61\ m/s^2$ on Mercury

Task 1:

Fill in the SI units. The first one has been done for you.

g	m/s^2
GPE	J
m	kg
h	m
W	N

Task 2:

Explain why BepiColombo takes 7 years to get to Mercury, even though Mercury is not too far from Earth.

The Sun has a strong gravitational field. This makes it difficult to get a spacecraft into orbit around Mercury, because Mercury is the closest planet to the Sun. This means that BepiColombo must decelerate on its way to Mercury.

Task 3:

A person's mass is 60 kg.

d) What is their mass on Mercury?

$$60\ kg$$

e) What is their weight on Earth?

$$W = m \times g$$

$$g = 9.81\ m/s^2$$

$$W = 60\ kg \times 9.81\ m/s^2$$

$$W = 588.6\ N$$

f) What is their weight on Mercury?

$$\mathrm{W} = \mathrm{m} \times \mathrm{g} \qquad \mathrm{g} = 3.61\ \mathrm{m/s^2}$$

$$W = 60\ kg \times 3.61\ m/s^2$$

$$W = 216.6\ N$$

Task 4:

A person's weight on **Mercury** is 195 N.

c) What is their mass?

$$W = m \times g$$

$$m = W / g$$

$$m = 195\ N / 3.61\ \mathrm{m/s^2}$$

$$m = 54\ kg$$

d) What is their weight on Earth?

$$W = m \times g$$

$$W = 54\ kg \times 9.81\ m/s^2$$

$$W = 530\ N$$

Task 5:

A stone with mass 10 kg is dropped from a height of 30 m on Earth.

c) What is the stone's gravitational potential energy?

$$GPE = m \times g \times h$$

$$GPE = 10kg \times 9.81\, m/s^2 \times 30m$$

$$GPE = 2943\, N$$

d) The stone is now moved to Mercury. It is dropped, and has a GPE of 1552 J. What height was it dropped from?

$$GPE = m \times g \times h$$

$$h = \frac{GPE}{m \times g} = \frac{1552\, J}{10\, kg \times 3.61 m/s^2}$$

$$h = 43\, m$$