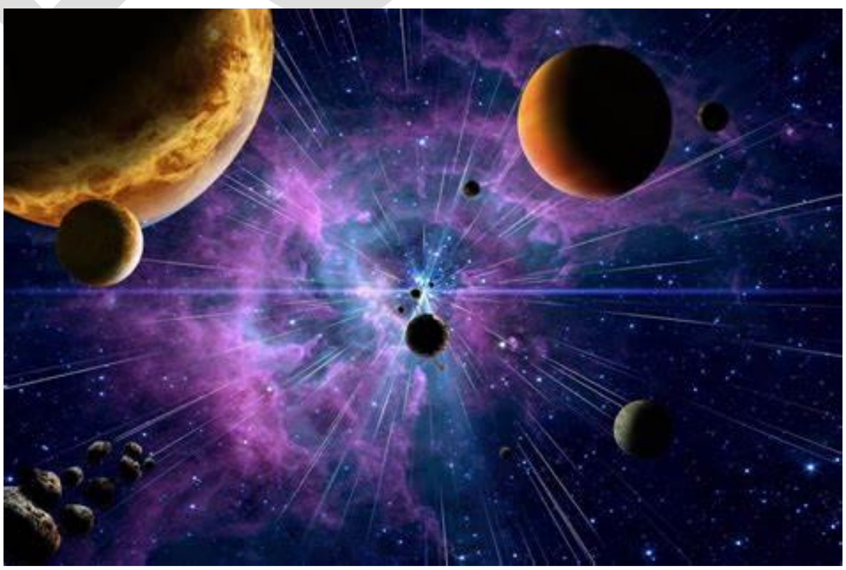
Edexcel IGCSE

Physics

CODE: (4MA1)

Unit 8

Astrophysics



8.1 Motion in the universe

The solar system

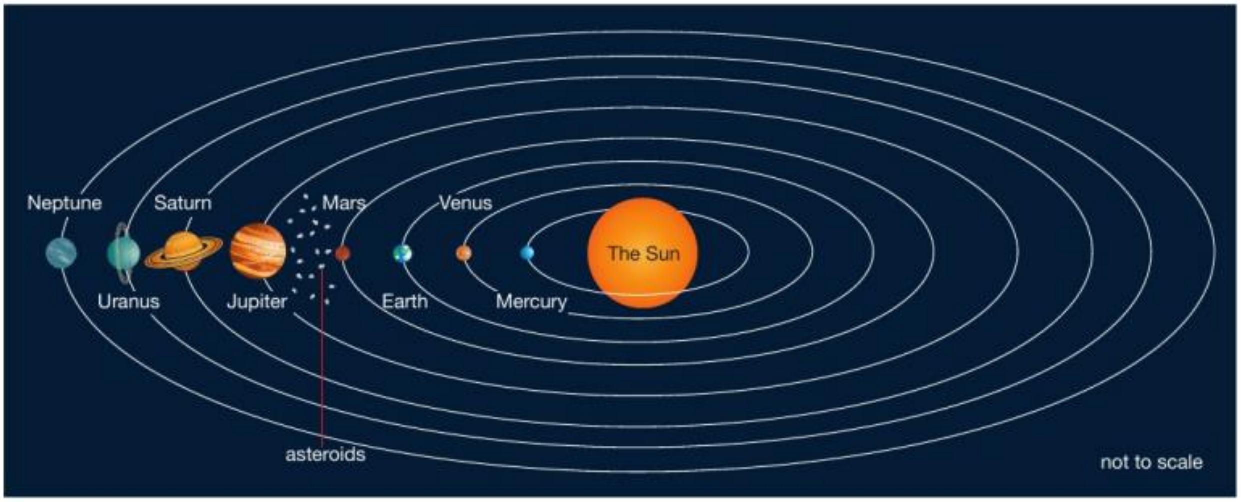


Figure 26.2 The Earth is one of eight planets that orbit the Sun. The orbits of the planets are elliptical (an oval shape) with the Sun close to the centre.

Why do objects move in a circle?

Figure 26.3 shows a boy swinging a heavy ball around on a wire. To make this ball travel in a circle he needs to spin around and at the same time pull on the wire. Without this continuous pulling force, the ball will not travel in a circle.

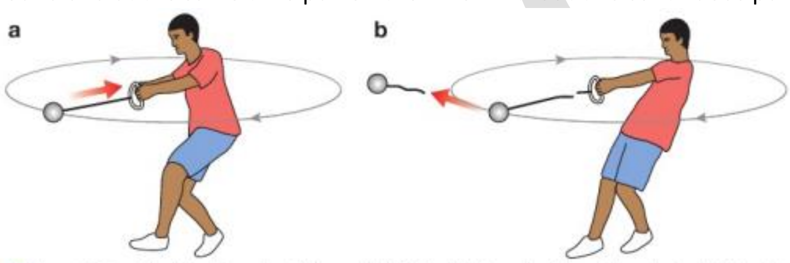


Figure 26.3 **a** A 'pulling' force has to be applied to the ball to make it travel in a circle. **b** If the wire breaks or the boy releases the handle the ball flies away.

Planets and comets travel around the Sun. Moons and satellites travel around the planets. For this to happen there must be forces being applied to them.

Newton suggested that between any two objects there is always a force of attraction. This attraction is due to the masses of the objects. He called this force gravitational force.

He suggested that the size of this force depends on the:

1. Mass of the two objects
2. Distances between the masses.

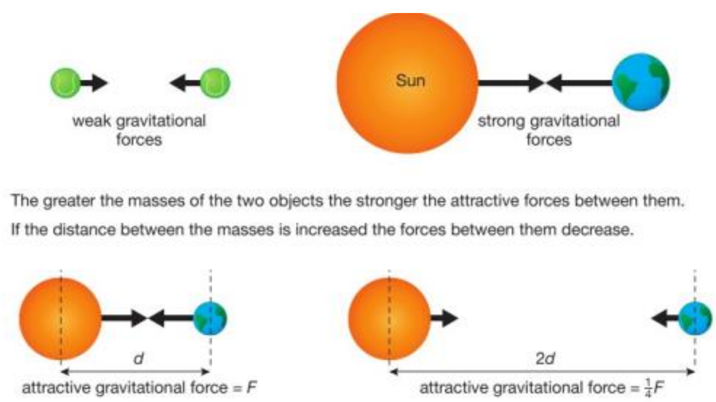


Figure 26.4 Gravitational forces obey an inverse square law – that is, if the distance between the masses is doubled, the forces between them are **quartered**; if the distance between them is **trebled**, the forces become one ninth of what they were.

Those planets that are closest to the Sun feel the greatest attraction and so follow the most curved paths. Planets that are the furthest from the Sun feel the weakest pull and follow the least curved path.

Planet	Average distance from Sun compared with the Earth	Time for one orbit of the Sun in Earth years
Mercury	0.4	0.2
Venus	0.7	0.6
Earth	1.0	1.0
Mars	1.5	1.9
Jupiter	5.0	12
Saturn	9.5	30
Uranus	19	84
Neptune	30	165

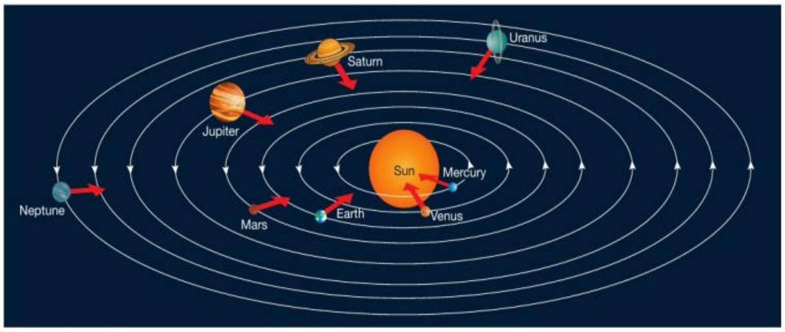


Figure 26.5 Gravitational forces make the planets follow nearly circular paths.

Satellites and moons

Satellites orbit planets, with natural ones being moons. Earth has one moon, the fifth largest in the Solar System. Many planets have multiple moons, such as Mars, Jupiter, and Saturn. All moons have circular orbits due to gravitational forces.


Figure 26.6 Some of the many moons of Saturn.


Figure 26.7 This satellite is held in orbit by the gravitational attraction between it and the Earth.

Comets

Comets are large rock-like pieces of ice that orbit the Sun. They have very elliptical (elongated) orbits which at times take them very close to the Sun. At other times they travel close to the very edge of our Solar System.

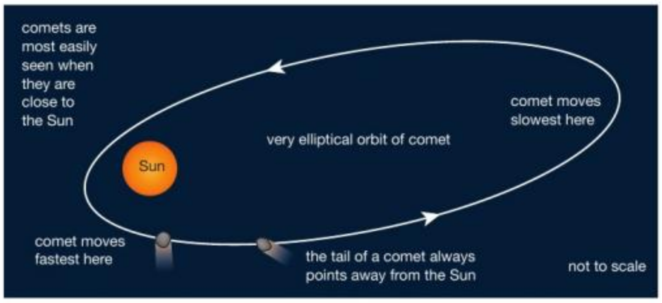


Figure 26.8 The speed of a comet varies enormously. They travel at their fastest when they are very close to the Sun.


Figure 26.9 Halley's comet could be last seen from Earth in 1986.

Gravitational field strength

The strength of gravity on a planet or moon is called its gravitational field strength and given the symbol g. Different planets have different masses and different radii - both will affect their gravitational field strengths.

■ The larger the mass of a planet the greater its gravitational field strength.
■ The larger the radius of a planet the smaller the gravitational field strength at its surface.

The gravitational field strength on the Earth is approximately 10 N/kg whilst on the Moon it is approximately 1.6 N/kg.

Planet	Diameter compared with the Earth	Mass compared with the Earth	Gravitational field strength/N/kg
Mercury	0.4	0.06	4
Venus	0.9	0.38	9
Earth	1.0	1.0	10
Mars	0.5	0.10	4
Jupiter	11	320	23
Saturn	9	95	9
Uranus	4	15	9
Neptune	4	17.0	11

Orbital speeds of planets and satellites

The orbital speeds of satellites vary greatly depending on the tasks they are performing. For example, communication satellites are put in high orbits and travel at approximately 3 km/s, while those observing the whole surface of the Earth are put into low polar orbits with speeds of about 8 km/s.

We can calculate the speed of a satellite using the equation:

$$\text{speed, } v = \frac{\text{distance moved, } s}{\text{time taken, } t}$$

The distance moved is the circumference of the circular orbit, r:

distance moved = $2 \times \pi \times$ orbital radius, r

The time period, T, is the time for one complete orbit.

So:

$$\text{orbital speed, } v = \frac{2 \times \pi \times \text{orbital radius, } r}{\text{time period, } T}$$

$$v = \frac{2 \times \pi \times r}{T}$$

8.2 Stellar evolution

The milk way

Our nearest star is the Sun. It is approximately 150 million kilometres from the Earth. Its surface temperature is approximately 6000 °C and temperatures within its core are about 15 000 000 °C. Attractive gravitational forces between stars cause them to group together in enormous groups called **galaxies.** Galaxies consist of billions of stars. Our galaxy is a **spiral galaxy** called the **Milky Way**.

Figure 27.2 Our galaxy, the Milky Way

Figure 27.3 Our galaxy takes the shape of a spiral, like the one shown here.

Classifying stars

Stars in our galaxy are diverse, with different colors, brightness levels, and sizes. Scientists study stars to create star groups based on these similarities and differences. The color of some stars, such as white, red, and yellow, reflects their temperatures. Traditional blacksmiths use color to determine when an iron is hot enough for shaping, while stars' colors indicate their temperature. Hot stars emit more blue, medium stars like the Sun appear yellow, and cooler stars appear red.

Star classification	Surface temperature/K	Colour
O	more than 33 000	blue
B	33 000–10 000	blue-white
A	10 000–7500	white
F	7500–6000	yellow-white
G	6000–5200	yellow
K	5200–3700	orange
M	3700–2000	red

Figure 27.4 The colour of the light emitted by this piece of iron tells us how hot it is.

The brightness of a star

The brightness of vehicle headlights and stars in the night sky is influenced by factors such as distance from Earth, star composition, and nuclear reactions. Similarly, the brightness of a star depends on the type of nuclear reactions occurring.

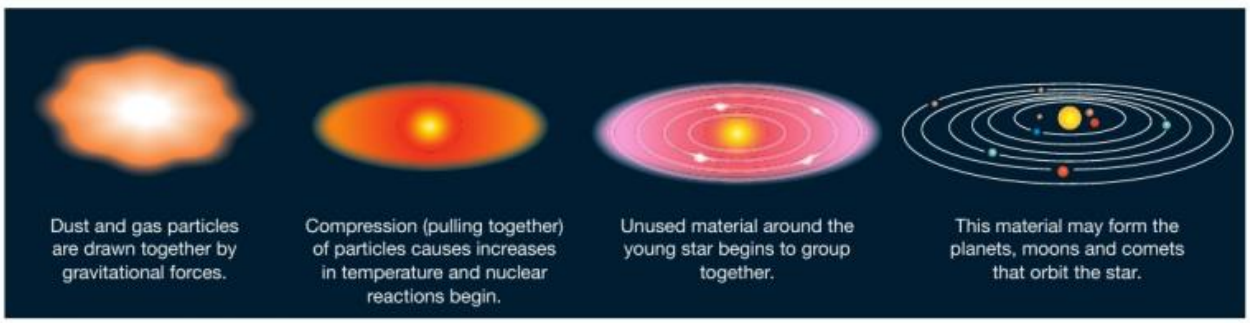
As a result, there are three different ways in which astronomers describe the brightness of a star:

1. The apparent brightness or magnitude of a star. This is the easiest method and is simply a measure of how bright a star is as seen from the Earth.

2. The absolute brightness or magnitude. This is a measure of how bright stars would appear if they were all placed the same distance away from the Earth.

3. The luminosity of a star. This measures how much energy in the form of light is emitted from a star's surface every second.

The birth of a star

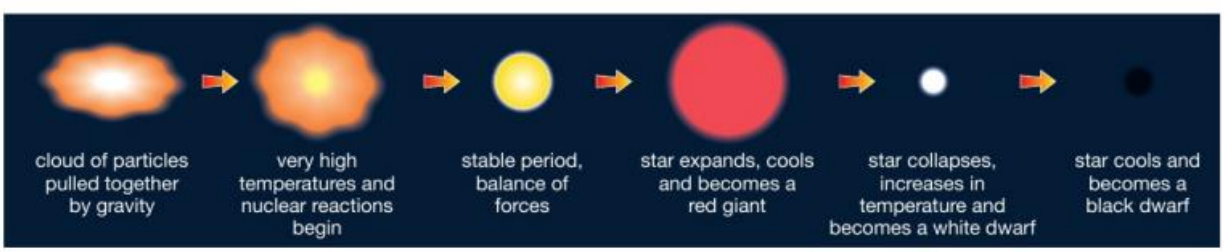


▲ Figure 27.6 Birth of a solar system

Stars like the Sun are formed from massive nebulae, or stellar nebulae, drawn together by gravitational forces. This results in a significant increase in temperature and pressure, leading to nuclear fusion reactions and the release of heat and light.

The life of a star

A star's appearance changes gradually over time, following a pattern. When a star first forms, gravitational forces pull particles together, and nuclear reactions create forces that push them apart. This period, known as the main stable period, can last millions of years. As hydrogen fusion reactions stop, gravitational forces compress the star, leading to fusion reactions and a red giant. When most helium nuclei fuse, new nuclear reactions begin, causing the star to contract and emit more blue and white light. As the star cools, it changes into a cold black dwarf star.



▲ Figure 27.7 The life-cycle of stars with a mass similar to that of our Sun

8.3 Cosmology

The doppler effect

If we look at the stars and galaxies in our Universe using a simple **optical telescope** it is impossible to tell if they are moving, and if they are moving then how fast or in which direction.

Figure 28.2 A telescope to look at stars

Figure 28.4 shows the spectra from four different objects. The first is the spectrum from our Sun. The dark lines we can see are called **absorption lines.**

Figure 28.4 displays spectra from four objects, revealing absorption lines, distant galaxy spectrums, and furthest galaxy spectrums. Dark lines move towards red, indicating a relative motion between galaxies and observers. The **red shift**, a shift in the positions of dark lines, is the greatest for the furthest galaxy.

Red shift indicates that the source of the light waves is moving away from the observer. Blue-shift would indicate that the source of light is moving towards the observer. We can see why this is the case in Figure 28.5.

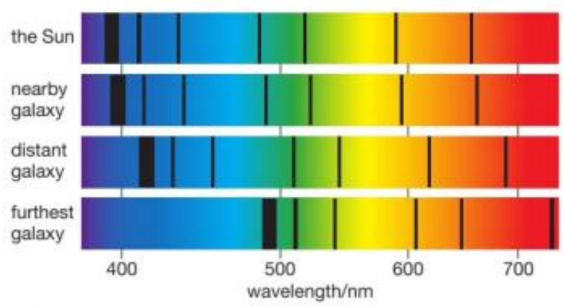


Figure 28.4 Light spectra for four different objects

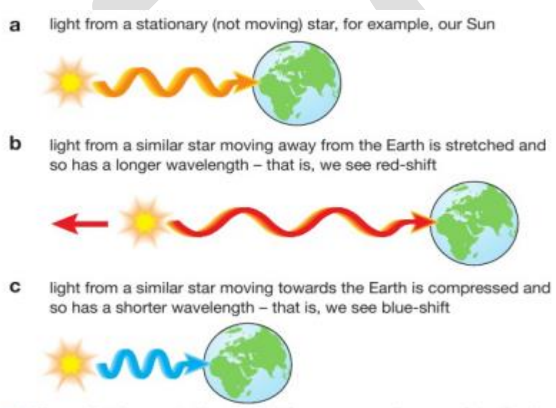


Figure 28.5 Demonstrations of light from a star moving away from Earth and moving towards it

Figure 28.3 An everyday example of the Doppler effect

The doppler equation

The equation below shows us how to calculate the speed at which a star or galaxy is moving relative to us.

$$\frac{\text{change in wavelength, } \Delta\lambda}{\text{reference wavelength, } \lambda_0} = \frac{\text{velocity of a galaxy, } v}{\text{speed of light, } c}$$

$$\frac{\lambda - \lambda_0}{\lambda_0} = \frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$$

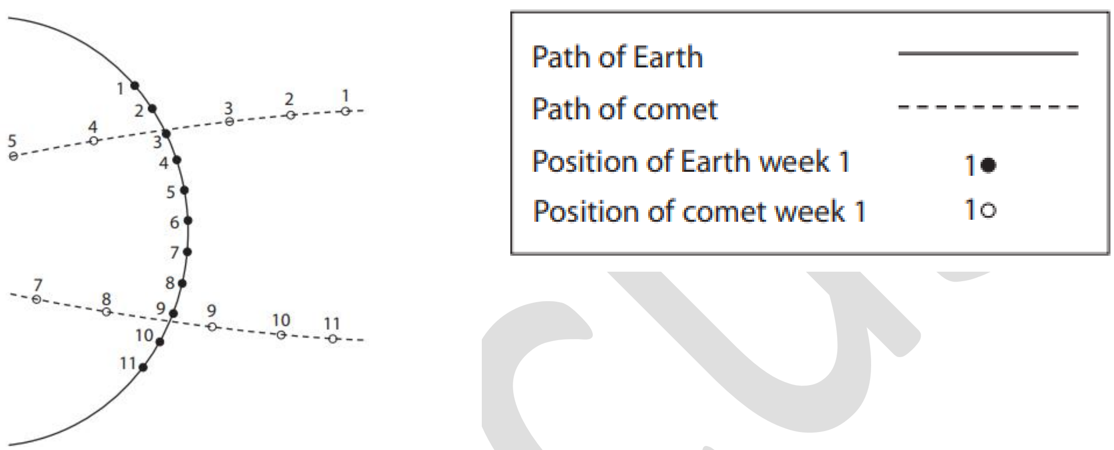
Cosmic microwave background (CMB) radiation

Scientists sought to connect the Big Bang to energy release in the Universe through waves with longer wavelengths. They predicted these waves would be in the microwave part of the electromagnetic spectrum. In the 1960s, they detected cosmic microwave background (CMB) radiation, which can be detected in all directions.

Revision questions

(1) A comet passes close to the Earth. An astronomer observes the position of the comet and the Earth on the same day each week for several weeks.

(a) The diagram shows her observations for weeks 1 to 11.



(i) Complete the path for the comet between week 5 and week 7.

(ii) Mark an X on the diagram to show the position of the Sun.

(iii) Suggest why the astronomer did not observe the comet during week 6.

(iv) Explain how the diagram shows that the speed of the comet changes as it moves from position 1 to position 5.

(v) Suggest why the speed of the comet changes

(b) The Earth orbits the Sun once in 365 days. The radius of the Earth's orbit is 150000000km. Calculate the orbital speed of the Earth in kilometres per hour

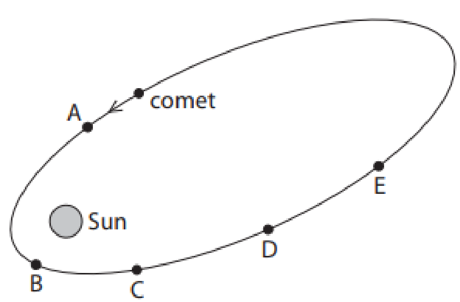
(2) (a) These sentences are about astronomy. Complete the sentences by writing words in the blank spaces

The Earth is an astronomical object.

One astronomical object smaller than the Earth is ....

Two astronomical objects larger than the Earth are .... and ....

The Milky Way is the name given to our..



(b) The diagram shows the path followed by a comet as it moves around the Sun. A, B, C, D and E are points on the comet's orbit

(i) State the name of the force that causes the comet to orbit the Sun.

(ii) At which of the points shown is the force on the comet greatest?

(iii) Draw an arrow at point D to show the direction of the force acting on the comet.

(iv) At which of the points shown does the comet have the greatest kinetic energy?

(3) The table shows some data about planets in our Solar System.

Planet	Diameter in km	Distance from Sun in 10^6 km	Time of orbit in Earth days or Earth years	Mass of planet in 10^{24} kg
Mercury	4 880	58	88 d	0.33
Venus	12 100	108	224 d	4.9
Earth	12 800	150	365 d	6.0
Mars	6 790	228	687 d	0.64
Jupiter	143 000	778	11.9 y	1 900
Saturn	121 000	1 427	29.5 y	570
Uranus	51 000	2 870	84 y	87
Neptune	50 000	4 497	165 y	100

Use data from the table to answer these questions.
(a) Which planet has about the same diameter as the Earth?
b) Jupiter has the largest gravitational field strength. Suggest a reason for this.
(c) (i) State the equation linking density, mass and volume
(ii) Calculate the density of Neptune in kg/km3 . You may assume that Neptune is a sphere and that its volume is given by

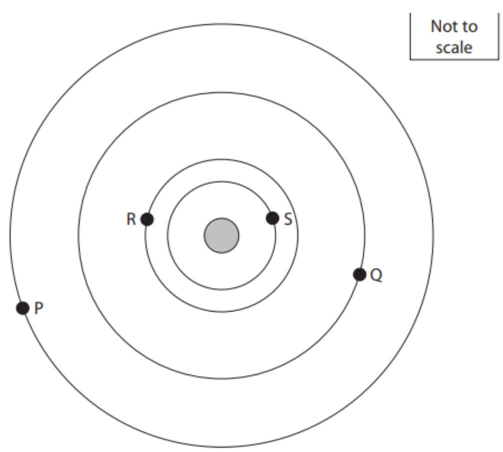
$$\text{volume} = \frac{4\pi r^3}{3}$$

(d) Calculate the orbital speed of Earth in km/s.
(e) A student says

'The smaller the planet, the shorter its period of orbit.'

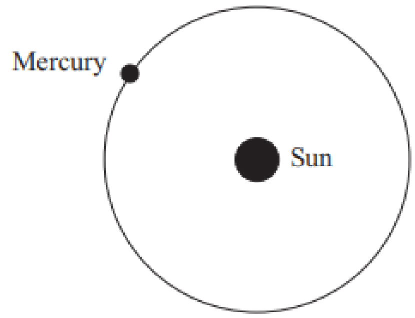
Use data from the table to evaluate this statement.

(4) The diagram shows four planets, P, Q, R and S, orbiting a star.



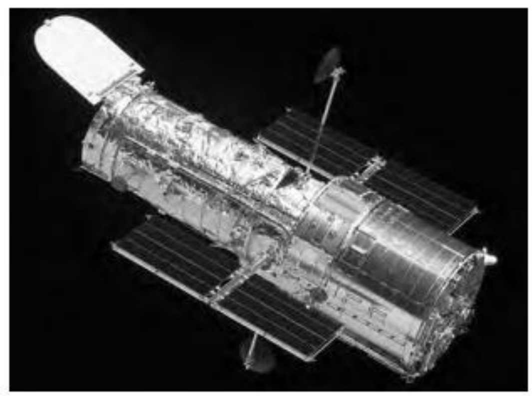
(a) This combination of planets and a star is most like?
(b) Planet Q has a moon. On the diagram, draw the orbit of this moon.
(c) On the diagram, draw the orbit of a comet
(d) Planets nearer to the star take less time to orbit the star.
(i) Suggest why
(e) As the planets orbit the star, the distances between the planets change. Planet P is 200 million km from the star and planet R is 50 million km from the star.
(i) Calculate the maximum distance between planet P and planet R.
(ii) Calculate the minimum distance between planet P and planet R

(5) The planet Mercury orbits the Sun.
(a) Mercury takes 88 days to orbit the Sun.
The average radius of the orbit is 58 million km.
Calculate the average orbital speed of Mercury. Give the unit.



(b) Comets also orbit the Sun.
(i) Name the force that causes comets and planets to orbit the Sun. (
ii) Add to the diagram opposite to show the orbit of a typical comet.
(iii) The speed of a comet changes during its orbit. On the orbit you have drawn, label with the letter X the position where the comet travels at its fastest speed.
(iv) Explain why the comet travels fastest at point X

(6) The Hubble Space Telescope is in orbit around the Earth. It detects visible light from distant objects



(a) Name the force that keeps the telescope in orbit around the Earth
(b) The Hubble Space Telescope moves in a circular orbit. Its distance above the Earth's surface is 560 km.
(i) The radius of the Earth is 6400 km. Calculate the radius of the orbit of the Hubble Space Telescope.
(ii) The Hubble Space Telescope completes one orbit in 96 minutes. Calculate its orbital speed in m/s
(c) The Chandra Telescope also orbits the Earth but does not move in a circular orbit. Its distance from the Earth and its speed change as it orbits the Earth.
It travels fastest when it is closest to the Earth. Use ideas about energy to explain why.

(d) The Chandra Telescope detects X-rays from distant objects.
(i) State the name of the type of wave that includes X-rays and visible light
(ii) Describe two differences between X-rays and visible light

(7) Planets and comets in our Solar System orbit the Sun.
(a) Which force causes planets and comets to orbit the Sun?
(b) The diagram shows the orbits of a planet and a comet around the Sun. [not to scale]
(i) On the diagram, label the planet, the comet and the Sun.
(ii) Explain why it is possible for a planet and a comet in our Solar System to collide