AQA Examination-style questions

1 **Black holes**

A black hole is an astronomical body which is so massive that nothing can escape from it. Anything that falls into a black hole would never be seen again. The radius of a black hole is defined by its **event horizon**, an imaginary spherical surface surrounding the body. Nothing inside the event horizon can escape, not even light. Radiation can be detected from matter drawn into a black hole before it is trapped inside the event horizon. Astronomers reckon there might be a black hole at the centre of our own galaxy, the Milky Way.

Figure 1 A black hole in space?

The idea of a black hole was first thought up by John Michell in 1783 although the term itself was first used much later by the American physicist, John Wheeler. Michell's idea was not tested until after Einstein published his *General Theory of Relativity* in 1916 in which he predicted mathematically that a strong gravitational field distorts space and time and bends light. He calculated that light grazing the Sun from a star would be deflected by 0.0005° due to the Sun's gravity. The prediction was confirmed by Sir Arthur Eddington in 1919 who led a scientific expedition to South America to test the prediction by photographing stars close to the Sun during a total solar eclipse. The eclipse photographs revealed that the star images were displaced relative to each other just as Einstein had predicted.

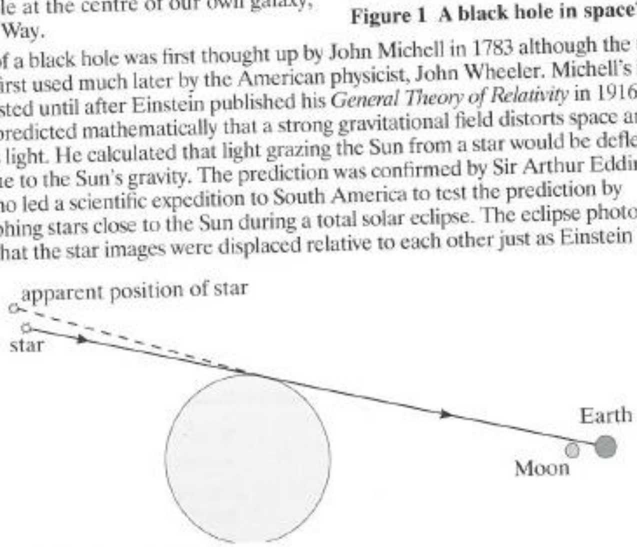

Figure 2 Bending starlight

The modern theory of black holes was started by Karl Schwarzschild who used Einstein's theory to prove light could not escape from an object with a sufficiently strong gravitational field. He showed that such an object is surrounded by an 'event horizon' which nothing inside can pass through and that radius, R, of the event horizon is given by $R = \frac{2GM}{c^2}$, where M is the mass of the black hole and c is the speed of light in free space.

Evidence for black holes has been obtained by astronomers. The central region of the galaxy *M87* is rotating so fast that there must be a massive black hole at its centre. The X-ray source, Cygnus X1, is a binary system consisting of supergiant star accompanied by a very dense invisible star thought to be a black hole pulling matter from its companion.

Questions

$c = 3.0 \times 10^8\,\mathrm{m\,s^{-1}}$, $G = 6.7 \times 10^{-11}\,\mathrm{N\,m^2\,kg^{-2}}$.

(a) (i) The mass of the Earth is 6.0×10^{24} kg. Show that the radius of the event horizon of a black hole that has the same mass as the Earth would be 8.9 mm.

(ii) Calculate the density of an object with the same mass as the Earth and a radius of 9.0 mm. The mass of the Earth = 6.0×10^{24} kg. *(5 marks)*

(b) (i) Use the scientific examples described above to explain what is meant by a scientific hypothesis.

(ii) What key discovery was made by Eddington in 1919 and what was the significance of this discovery? *(5 marks)*

(c) The Hubble Space Telescope has led to many new astronomical discoveries. Suppose your Government commits itself to establishing a manned space observatory on the Moon by 2025. Some people take the view this project could lead to many new discoveries. Other people take the view that the money for the project would be better spent helping to improve living conditions in poorer countries. Discuss **one** argument in support of each of these views and use your arguments to decide whether or not you would welcome such a project. *(5 marks)*

2 (a) (i) Explain what is meant by the *gravitational field strength* at a point in a gravitational field.

(ii) State the SI unit of gravitational field strength. *(2 marks)*

(b) Planet P has mass M and radius R. Planet Q has a radius $3R$. The values of the gravitational field strengths at the surfaces of P and Q are the same.

(i) Determine the mass of Q in terms of M.

(ii) **Figure 3** shows how the gravitational field strength above the surface of planet P varies with distance from its centre.

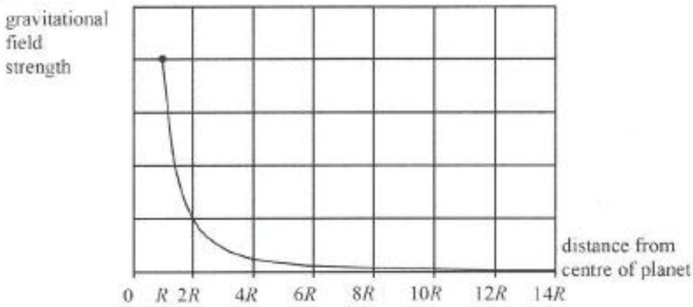

Figure 3

Copy the diagram and draw the variation of the gravitational field strength above the surface of Q over the range shown. *(6 marks)*

AQA, 2006

3 (a) Artificial satellites are used to monitor weather conditions on Earth, for surveillance and for communications. Such satellites may be placed in a *geo-synchronous* orbit or in a low polar orbit.

Describe the properties of the geo-synchronous orbit and the advantages it offers when a satellite is used for communications. *(3 marks)*

(b) A satellite of mass m travels at angular speed ω in a circular orbit at a height h above the surface of a planet of mass M and radius R.

(i) Using these symbols, give an equation that relates the gravitational force on the satellite to the centripetal force.

(ii) Use your equation from part (b)(i) to show that the orbital period, T, of the satellite is given by

$$T^2 = \frac{4\pi^2(R+h)^3}{GM}$$

(iii) Explain why the period of a satellite in orbit around the Earth cannot be less than 85 minutes. Your answer should include a calculation to justify this value. *(6 marks)*

(c) Describe and explain what happens to the speed of a satellite when it moves to an orbit that is closer to the Earth. *(2 marks)*

AQA, 2006

4 (a) (i) Show that the gravitational field strength of the Earth at height h above the surface is given by

$$g = g_s\left(\frac{R}{R+h}\right)^2$$

where g_s is the gravitational field strength at the surface and R is the radius of the Earth.

(ii) Calculate the gravitational field strength of the Earth at a height of 200 km above its surface. *(5 marks)*

(b) An astronaut floats in a spacecraft which is in a circular orbit around the Earth. Discuss whether or not the astronaut is weightless in this situation. *(3 marks)*

AQA, 2007

5 NASA wishes to recover a satellite, at present stranded on the Moon's surface, and to place it in orbit around the Moon.

(a) (i) **Figure 4** shows a graph of how gravitational field strength due to the Moon varies with distance from the centre of the Moon. Mark on the figure the area that corresponds to the energy needed to move 1 kg from the surface of the Moon to a vertical height of 4000 km above the surface.

radius of the Moon = 1700 km

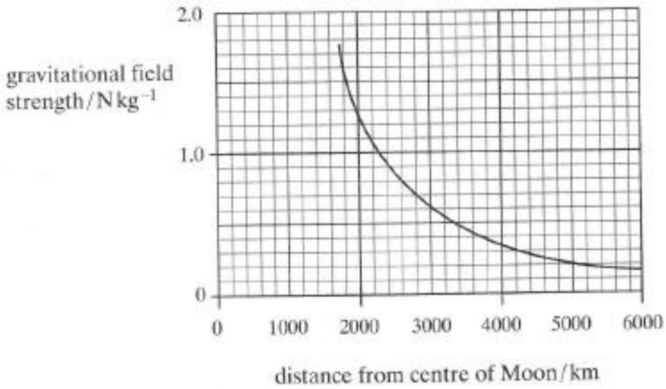

Figure 4

(ii) The satellite has a mass of 450 kg. Estimate the change in gravitational potential energy of the satellite when it is moved from the surface of the Moon to a vertical height of 4000 km above the surface. *(6 marks)*

(b) NASA now decides to bring the satellite back to Earth. Explain why the amount of fuel required to return the satellite to Earth will be *much* less than the amount required to send it to the Moon originally. *(5 marks)*

AQA, 2004

6 (a) Explain what is meant by the *gravitational potential* at a point in a gravitational field. *(2 marks)*

(b) Use the following data to calculate the gravitational potential at the surface of the Moon.

mass of Earth = 81 × mass of Moon

radius of Earth = 3.7 × radius of Moon

gravitational potential at surface of the Earth = $-63\,\text{MJ kg}^{-1}$ *(3 marks)*

(c) Sketch a graph using axes as in Figure 5 to indicate how the gravitational potential due to the Moon varies with distance along a line outwards from the surface of the Earth to the surface of the Moon. *(3 marks)*

AQA, 2005

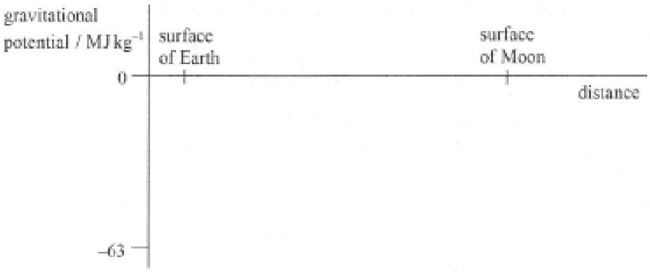

Figure 5

7 (a) State the law that governs the magnitude of the force between two point masses. *(2 marks)*

(b) Table 1 shows how the gravitational potential varies for three points above the centre of the Sun.

Table 1

distance from centre of Sun/10^8 m	gravitational potential/10^{10} J kg^{-1}
7.0 (surface of Sun)	–19
16	–8.3
35	–3.8

(i) Show that the data suggest that the potential is inversely proportional to the distance from the centre of the Sun. *(2 marks)*

(ii) Use the data to determine the gravitational field strength near the surface of the Sun. *(3 marks)*

(iii) Calculate the change in gravitational potential energy needed for the Earth to escape from the gravitational attraction of the Sun.

mass of the Earth = 6.0×10^{24} kg

distance of Earth from centre of Sun = 1.5×10^{11} m *(3 marks)*

(iv) Calculate the kinetic energy of the Earth due to its orbital speed around the Sun and hence find the minimum energy that would be needed for the Earth to escape from its orbit.

Assume that the Earth moves in a circular orbit. *(3 marks)*

AQA, 2005

8 For an object, such as a space rocket, to escape from the gravitational attraction of the Earth it must be given an amount of energy equal to the gravitational potential energy that it has on the Earth's surface. The minimum initial vertical velocity at the surface of the Earth that it requires to achieve this is known as the escape velocity.

(a) (i) Write down the equation for the gravitational potential energy of a rocket when it is on the Earth's surface. Take the mass of the Earth to be M, that of the rocket to be m and the radius of the Earth to be R.

(ii) Show that the escape velocity, v, of the rocket is given by the equation

$$v = \sqrt{\frac{2GM}{R}}$$

(3 marks)

(b) The nominal escape velocity from the Earth is 11.2 km s^{-1}. Calculate a value for the escape velocity from a planet of mass four times that of the Earth and radius twice that of the Earth. *(2 marks)*

(c) Explain why the actual escape velocity from the Earth would be greater than the nominal value calculated from the equation given in part (a)(ii). *(2 marks)*

AQA, 2004