10.2 Fields at Work

Question Paper

Course	DP IB Physics
Section	10. Fields (HL only)
Topic	10.2 Fields at Work
Difficulty	Medium

Time allowed: 70

Score: /51

Percentage: /100

Question 1a

(a)
Outline why the gravitational potential is negative everywhere in space.

[2]

[2 marks]

Question 1b

The gravitational potential of the Sun at its surface is V is -1.9×10^{11} J kg^{-1} at a radial distance r from its core.

The following data are available:

- Mass of Earth = 6.0×10^{24} kg
- Distance from Earth to Sun = 1.5×10^{11} m
- Radius of Sun = 7.0×10^{8} m

(b)
Calculate the Earth's gravitational potential energy in its orbit around the Sun.

[2]

[2 marks]

Question 1c

(c)
While the Earth orbits the Sun, terrestrial shuttles often enter orbit around Earth. One such shuttle is launched with a kinetic energy E_K given by the expression below:

$$E_K = \frac{5GM_E m}{8R_E}$$

where G is the gravitational constant, M_E is the mass of Earth, and m is the mass of the shuttle. Deduce that the shuttle cannot escape the gravitational field of the Earth.

[2]

[2 marks]

Question 1d

(d)

Show that, if the shuttle enters an orbit of radius *R* about the Earth, then its total energy is given by $-\frac{GM_E m}{2R}$ stating an appropriate assumption required.

[3]

[3 marks]

Question 2a

(a)
Evaluate this statement of Newton's law of gravitation: "The gravitational force between two masses is proportional to the masses and inversely proportional to the square of the distance between them."

[2]

[2 marks]

Question 2b

(b)

A satellite of mass *m* orbits a planet of mass *M*. If the orbital radius is *R* and the orbital period is *T*, show that the ratio $\frac{R^3}{T^2}$ is constant.

[3]

[3 marks]

Question 2c

(c)

Calculate the change in gravitational potential energy of the satellite, of mass 39 kg, as it moves from an orbit of height 1100 km above the Earth's surface to one of height 2100 km.

Use the following data:

- Mass of Earth = 6.0×10^{24} kg
- Average radius of Earth = 6.4×10^{6} m

[3]

[3 marks]

Question 2d

(d)

Explain whether the gravitational potential energy has increased, decreased or stayed the same when the orbit changes as in part (c).

[2]

[2 marks]

Question 3a

(a)

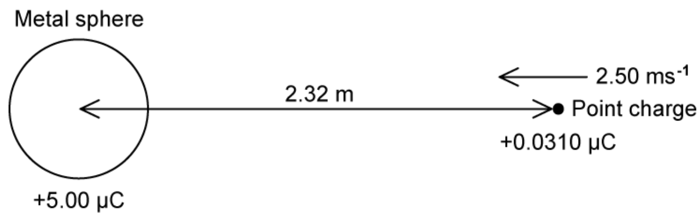
Define *electric potential* at a point in an electric field.

[2]

[2 marks]

Question 3b

A point charge of mass 1.30×10^{-4} kg is moving radially towards a small, charged metal sphere as shown.



(b)
The electric potential at the surface of the sphere is 9.00×10^{4} V. Determine if the point charge will collide with the metal sphere.

[5]

[5 marks]

Question 3c

(c)
Determine the speed at which the point charge is certain to collide with the metal sphere.

[2]

[2 marks]

Question 3d

Protons are positively charged and are often described as "colliding" in particle accelerator experiments, as well as in the core of stars.

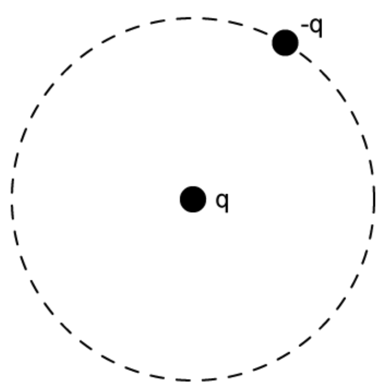
(d)
Discuss the implications of two protons colliding in terms of the forces between them. Describe the conditions necessary for such a collision to take place.

[4]

[4 marks]

Question 4a

A charge $-q$ with mass m orbits a stationary charge q with a constant orbital radius r.



(a)
Draw the electrostatic force on $-q$ due to the electric field created by q.

[2]

[2 marks]

Question 4b

(b)

Show that the orbital speed of *v* is given by:

$$v = \sqrt{\frac{1}{4\pi\varepsilon_0 mr}}\, q$$

[2]

[2 marks]

Question 4c

(c)

Show that the total energy *E* of the orbiting charge is given by:

$$E = -\frac{1}{8\pi\varepsilon_0}\frac{q^2}{r}$$

[3]

[3 marks]

Question 4d

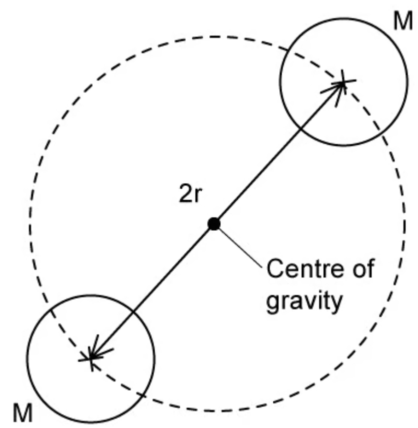
(d)
Hence, determine an equation for how much energy must be supplied to –*q* if it is to orbit the stationary charge *q* at twice the radius in part (c), 2*r*.

[2]

[2 marks]

Question 5a

Binary star systems involve two stars that orbit a common centre of gravity. One such system is shown.



Each star has a mass *M* and orbital radius *r*, such that their separation is 2*r*.

(a)
Deduce that the time period *T* of each star's orbit is related to the orbital radius *r* by the following equation:

$$T^2 = \frac{16\pi^2 r^3}{GM}$$

[3]

[3 marks]

Question 5b

(b)
Show that the kinetic energy of each star in the binary system is given by:

$$E_K = \frac{GM^2}{8r}$$

[2]

[2 marks]

Question 5c

(c)
Hence, show that the total energy of the binary star system is given by the equation:

$$E = -\frac{GM^2}{4r}$$

[2]

[2 marks]

Question 5d

The binary system radiates energy in the form of gravitational waves.

(d)
Deduce that the stars move closer to each other as the binary system emits gravitational waves.

[3]

[3 marks]