

State Examination Commission – Physics Higher Level, 2010

Question 6

State Newton’s law of universal gravitation.

Use this law to calculate the acceleration due to gravity at a height above the surface of the earth, which is twice the radius of the earth. (18)

A spacecraft carrying astronauts is on a straight line flight from the earth to the moon and after a while its engines are turned off.

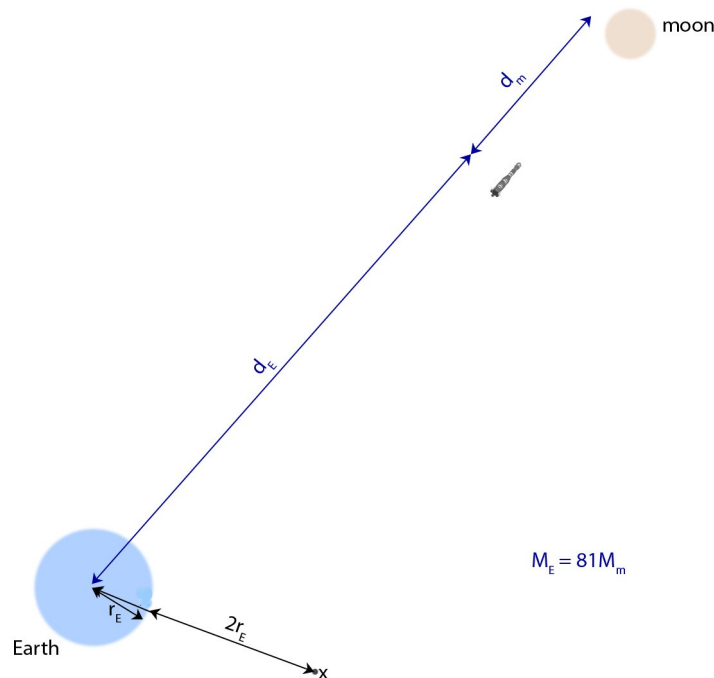
- (i) Explain why the spacecraft continues on its journey to the moon, even though the engines are turned off. (6)
- (ii) Describe the variation in the weight of the astronauts as they travel to the moon. (6)
- (iii) At what height above the earth’s surface will the astronauts experience weightlessness? (12)
- (iv) The moon orbits the earth every 27.3 days.
What is its velocity, expressed in metres per second? (9)
- (v) Why is there no atmosphere on the moon? (5)

(Radius of the earth = 6.36×10^6 m
 Acceleration due to gravity at the earth’s surface = 9.81 m s^{-2}
 Distance from the centre of the earth to the centre of the moon = 3.84×10^8 m
 Assume the mass of the earth is 81 times the mass of the moon.)

State Newton’s law of universal gravitation.

Standard statement

Use this law to calculate the acceleration due to gravity at a height above the surface of the earth, which is twice the radius of the earth. (18)



At position x in the diagram, an object is a distance $3r_E$ from the centre of the earth

$$\text{Since, } mg = \frac{GMm}{d^2},$$

$$\text{then, } g = \frac{GM}{d^2},$$

$$\text{That is, } g \propto \frac{1}{d^2}.$$

Now, if d increases by a factor of 3, i.e., increases $r_E \rightarrow 3r_E$,

then g decreases by factor of 3^2 i.e., factor of 9.

$$\text{So new value of } g \text{ is } g = \frac{9.81}{9} = 1.09 \text{ m s}^{-2}$$

A spacecraft carrying astronauts is on a straight line flight from the earth to the moon and after a while its engines are turned off.

(i) Explain why the spacecraft continues on its journey to the moon, even though the engines are turned off. (6)

Because Newton's First Law (The law of Inertia) tells us that any object will continue moving in a straight line, with constant speed, unless a resultant force acts. Once the engines are switched off, there is only a very small force acting which could affect the velocity of the space craft. Friction is non-existent, and gravity very weak so the object continues to move along its straight line path.

(ii) Describe the variation in the weight of the astronauts as they travel to the moon. (6)

Their weight gets less and less as they move away from the earth, eventually reaching zero before starting to increase again due to the gravitational pull of the moon.

(iii) At what height above the earth's surface will the astronauts experience weightlessness? (12)

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When the gravitational pull of the earth equals that of the moon, i.e.,

$$\begin{aligned} \frac{GM_E m}{d_E^2} &= \frac{GM_m m}{d_m^2} \\ \frac{G(81M_m)m}{d_E^2} &= \frac{GM_m m}{d_m^2} \\ \frac{81GM_m m}{d_E^2} &= \frac{GM_m m}{d_m^2} \\ \frac{81}{d_E^2} &= \frac{1}{d_m^2} \\ \frac{d_E^2}{d_m^2} &= 81 \\ \frac{d_E}{d_m} &= 9 \\ d_E &= 9d_m \end{aligned}$$

Since the distance from the centre of the earth to the centre of the moon = 3.84×10^8 m, if this is split in 9:1 ratio, we get distance from centre of earth to spacecraft = $0.9 \times 3.84 \times 10^8 = 3.456 \times 10^8$ m.

Therefore distance above surface of earth = $3.456 \times 10^8 - 6.36 \times 10^6 = 3.39 \times 10^8$ m .

(iv) The moon orbits the earth every 27.3 days. What is its velocity, expressed in metres per second? (9)

$T = 27.3 \text{ days} = 27.3 \times 24 \times 60 \times 60 = 2.36 \times 10^6 \text{ s}$.

Length of orbital path = $2\pi d = 2\pi(3.84 \times 10^8) = 2.41 \times 10^9 \text{ m}$

=> velocity = $2.41 \times 10^9 / 2.36 \times 10^6 = 1.02 \times 10^3 \text{ ms}^{-1}$

(v) Why is there no atmosphere on the moon? (5)

There is no atmosphere on the moon because it does not have sufficient gravity to hold an atmosphere to its surface.