2020 Sec 3 Advanced Physics

Gravitational Fields

Name: ____________________ ( ) Class: 3 / ___

Gravitational field
- Gravitational field
- Gravitational force between point masses
- Gravitational field of a point mass
- Gravitational field near to the surface of the Earth
- Circular orbits

Learning Outcomes

(a) show an understanding of the concept of a gravitational field as an example of field of force

(b) define the gravitational field strength at a point as the gravitational force exerted per unit mass placed at that point

(c) recall and use Newton's law of gravitation in the form $F = \frac{Gm_1m_2}{r^2}$

(d) recall and apply the equation $g = \frac{GM}{r^2}$ for the gravitational field strength of a point mass M, to new situations or to solve related problems

(e) show an understanding that near the surface of the Earth g is approximately constant and equal to the acceleration of free fall

(f) analyse circular orbits in inverse square law fields by relating the gravitational force to the centripetal acceleration it causes

1 Gravitational field

- How does the force 'travel' from one body to another? How does a mass 'know' that another mass is attracting it? To answers these questions, physicists introduce the idea of a **field**.
- We say that a mass creates a **gravitational field** in a region of space around it. Other masses respond to this field by having a gravitational force act on them. This field is a property of the mass.

2 Newton's law of gravitation

This law states that the **gravitational force** between two point masses

- is **directly proportional** to the product of their masses and
- **inversely proportional** to their distance apart.

$$F = \frac{Gm_1m_2}{r^2}$$

This formula would be given in EOY / MYE papers if needed.

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where
F: gravitation force
m_1 and m_2: mass of two masses
r: distance between (centres of) masses
G: universal gravitational constant
$G = 6.7 \times 10^{-11}$ N m^2 kg^{-2}

- This law is an **inverse square law** equation.
- The gravitational force is always attractive.

Example 1
The weight of a body is 20 N on a planet's surface.
Calculate the weight of the body at a height from the surface equal to the planet's radius.

[5.0 N]

3 Gravitational field strength *g*

- Gravitational field strength at a point is the **gravitational force** exerted **per unit mass** placed at that point. This is a vector.
- $g = \frac{F}{m}$
- Consider the gravitational field created by a spherical mass *M*.
- A point mass *m* placed a distance r from the centre of M will experience a force

  $$F = \frac{GMm}{r^2}$$

- The gravitational field strength at a point a distance r from M is

  $$g = \frac{GM}{r^2}$$

Example 2

The mass of Jupiter is 1.9×10^{27} kg and its radius is 7.1×10^{7} m.
Calculate the gravitational field strength at the surface of Jupiter.

[25 N kg^{-1}]

Example 3

The radius of the Earth is 6.4×10^{6} m and the gravitational field strength at its surface is 9.8 N kg^{-1}.

(a) Assuming that the field is radial, calculate the mass of the Earth.

(b) The radius of the Moon's orbit about the Earth is 3.8×10^{8} m. Calculate the strength of the Earth's gravitational field at this distance.

(c) The mass of the Moon is 7.4×10^{22} kg. Calculate the gravitational attraction between the Earth and the Moon.

[(a) 6.0×10^{24} kg, (b) 2.8×10^{-3} N kg^{-1}, (c) 2.1×10^{20} N]

4 Gravitational field of a point mass

- The gravitational field of a point mass is **radial**.
- We may consider the Earth as behaving like a point mass, so its gravitational field is also radial.
- The gravitational force acting on a body placed at a distance from a planet or star is often called its **weight**.
- Weight $= F = \text{m}\, g$ since gravitational field strength $g = \dfrac{F}{m}$
- **Near the surface of Earth**, the gravitational field is approximately uniform (or constant. The gravitational field lines would be parallel to each other.

5 Circular orbits

- Most planets in the Solar system have orbits which are nearly circular.
- Similarly, most artificial satellites moving round the Earth and natural satellites (moons) moving round the planets have almost circular orbits.
- We can apply the equations for **circular motion** and the concept of **centripetal force** for these orbits.

Example 4
The Earth orbits the Sun in a circular orbit of radius 1.5×10^{11} m.
Determine the mass of the Sun.

[2.0×10^{30} kg]