



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, gravitational field strength 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 answer 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.

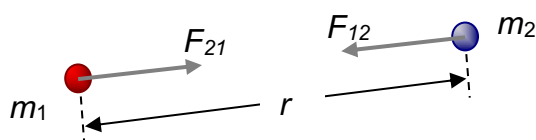
2 Newton's law of gravitation

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

- is **directly proportional** to the product of their masses and
- **inversely proportional** to the **square** of the distance between them

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

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



F_{12} : Force by mass 1 on mass 2
 F_{21} : Force by mass 2 on mass 1

where F : gravitation force

m_1 and m_2 : mass of two masses

r : distance between (centres of) masses

G : universal gravitational constant

$G = 6.7 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$

- 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.

$$g = \frac{F}{m}$$

Unit of $g = \text{N kg}^{-1}$

- 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

$$F = \frac{GMm}{r^2}, \text{ directed towards the source mass } M.$$

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

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

direction of g : towards mass M

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) $2.8 \times 10^{-3} \text{ N kg}^{-1}$, (c) $2.1 \times 10^{20} \text{ N}$]

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**.
- $\text{Weight} = F = m g$ since gravitational field strength $g = \frac{F}{m}$

[**Note: 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]

Exercises

1. A geostationary satellite completes one revolution around the Earth in 24 hours. Given that the mass of the Earth is 6.0×10^{24} kg, determine the orbital radius of the satellite.

2. Two stars of mass M and $2M$, a distance $3x$ apart, rotate in circles about their common centre of mass O as shown in **Fig. 2.1**.

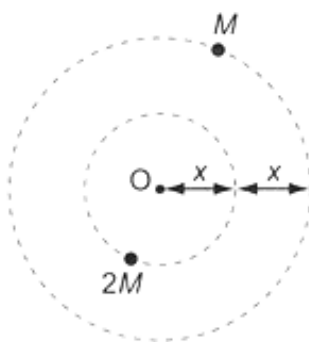


Fig. 2.1

- (a) The gravitational force acting on the stars can be written as $\frac{kGM^2}{x^2}$. Calculate the value of k .

- (b) The orbital speed of the star of mass M can be written as $n\sqrt{\frac{GM}{x}}$. Determine the value of n .

Answer:	1. 7780 m s^{-1}	2(a) 0.22	2(b) 0.67
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