3

GRAVITATIONAL FIELDS

Universal gravitation

Objects released from a height falls towards the centre of the earth. The earth exerts an attractive force on them. A story was told about Isaac Newton sitting under an apple tree when an apple fruit fell. Newton reasoned that the force making the apple to fall towards the centre of the earth, is the same as the force that keeps the moon moving round the earth. He called the force **gravity.** *The force of attraction between objects is called **gravitational force.*** Gravitational force keeps the planets in orbit round the Sun with a constant acceleration.

OBJECTIVES

At the end of this topic, students should be able to:

→calculate the gravitational force between two masses;
→calculate the gravitational force between two planets;
→explain the meaning of â€˜Gâ€™ and show that â€˜gâ€™ is the force per unit mass on the earthâ€™s surface;
→use the inverse square law to calculate the escape velocity of an object from the earthâ€™s gravitational field.

Newtonâ€™s law of universal gravitation

The earth attracts any object within its gravitational field. The earth exerts a force on the object; the object also exerts an equal but opposite force on the earth according to Newtonâ€™s third law of motion. Two masses in space exert equal and opposite forces on each other. Newton, after studying Keplerâ€™s works on the motion of planets round the sun, discovered that the gravitational force between any two masses in space depends on the:

- **product of the masses:** Gravitational force F_g is proportional to the product of the two masses.

$$(F_g\text{Î±}m_1m_2)...........i$$

- **distance (r) between the masses:** Gravitational force F_g is inversely proportional to the square of the distance (r^2) between the masses.

$$F_g \alpha \frac{1}{r^2} \quad ....ii$$

Combining equations (i) and (ii) above:

$$F_g \, \alpha \, \frac{m_1 m_2}{r^2}$$

Gravitational force is proportional to the product of the masses and inversely proportional to the square of the distance between the masses.
Newtonâ€™s universal gravitational law states that the force of attraction between any two objects in the universe is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

This is stated mathematically as:

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

F = gravitational force between the two masses M and m, r = distance between the masses and G = Newtonâ€™s universal gravitational constant. The value of G is about 6.67 Ã— 10^{-11}N m^2 kg^{-2}.

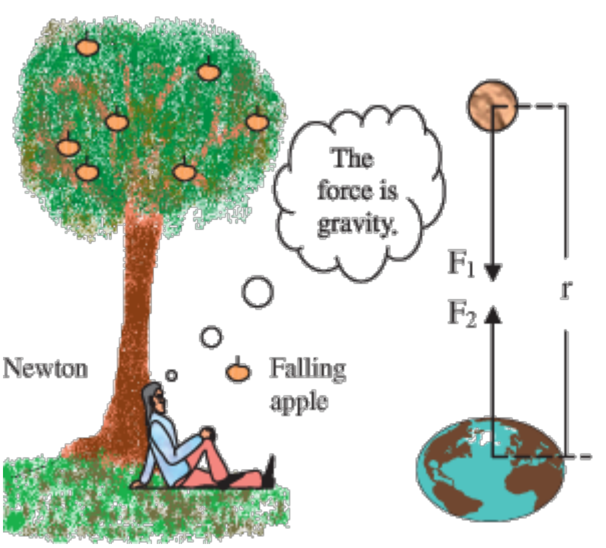


Figure 3.1 : Gravitational attraction

Newtonâ€™s universal constant is (G) is the force of attraction between two unit masses when they are 1 m apart.

Worked examples

1.Calculate the gravitational force of attraction between the earth and moon if the mass of the earth is 6.0 Ã— 10^{24}kg, the mass of the moon is 7.4 Ã— 10^{22}kg and the distance between the earth and moon is 3.00 Ã— 10^{8} m.
{G = 6.67 Ã— 10^{-11}Nm^{2}kg^{-2}.}

Solution

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

$$F = \frac{6.67\times10^{-11}\times6.0\times10^{-24}\times7.4\times10^{22}}{\left(3.0\times10^{8}\right)^2}$$

F = 3.29 Ã— 10^{20} N.

2.An electron of mass 9.10 Ã— 10^{-31}kg revolves round a hydrogen nucleus with a proton of mass 1.67 Ã— 10^{-27}kg. If the radius of orbit is 5.90 Ã— 10^{-11} m. Calculate the gravitational force of attraction between the proton and the electron. {G = 6.67 Ã— 10^{-11}Nm^{2}kg^{-2}.}

Solution

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

$$F = \frac{6.67\times10^{-11}\times1.67\times10^{-27}\times9.1\times10^{-31}}{\left(5.90\times10^{-11}\right)^2}$$

F = 2.91 Ã— 10^{-47} N.

3. The gravitational force which keeps the earth moving round the Sun at a distance of 1.5 Ã— 10^{11} m is 3.80 Ã— 10^{22} N. Estimate the mass of the Sun given that the mass of the earth is 6.4 Ã— 10^{24}kg. {G = 6.67 Ã— 10^{-11}Nm^{2}kg^{-2}.}

Solution

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

$$3.80\times10^{22} = \frac{6.67\times10^{-11}\times M_s\times6.4\times10^{24}}{\left(1.5\times10^{11}\right)^2}$$

$$M_s = \frac{3.80\times10^{22}\times\left(1.5\times10^{11}\right)^2}{6.67\times10^{-11}\times6.4\times10^{24}}$$

$$M_s = 2.0\times10^{30}\,kg.$$

Gravitational field

A gravitational field is set up around any object in space. If another object comes into the field of another object, they exert forces on each other. The earth exerts gravitational force on a falling orange fruit. The earth also exerts gravitational force on the moon. The resultant force is in the direction of the bigger mass; therefore, the smaller mass is pulled towards the bigger mass. The force of attraction increases as the masses move closer to each other as illustrated in Figure 3.2.

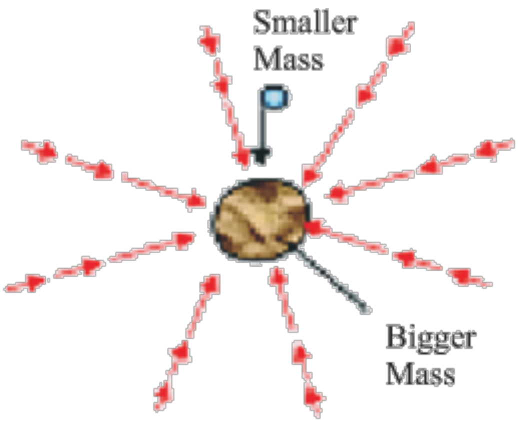


Figure 3.2: Gravitational fields around a mass

The gravitational field is the space or region around a mass where the gravitational force of the mass can be exerted on other masses.

The gravitational field is radial and points towards the centre of the source (mass). The field around a mass is not uniform; it is stronger as the falling object moves closer to the surface of the source of the field. The gravitational force at regions near the source of the field is approximately a constant.

Gravitational field strength or intensity (g)

Gravitational field strength is the gravitational force acting on a unit mass in a particular location. In other words;

Gravitational field strength is the gravitational force per unit mass in a particular location.

The strength of the earthâ€™s gravitational field at any point around the earthâ€™s surface is measured by the strength of the force it exerts on other masses.

$$\text{Gravitational field strength} = \frac{\textit{Gravitational force}}{\textit{Mass}}$$

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

The gravitational field strength or intensity is also called **acceleration due to gravity** (g) at a location. Acceleration due to gravity or simply **gravity,** is a constant at a location near the earthâ€™s surface.

The unit of gravitational field strength (g) is Newton per kilogram (Nkg^{-1}).

Variation of gravity (g) with distance (r)

The force of attraction due to the earth on another mass (m) in space is related to its distance (r) from the earthâ€™s centre by:

$$F = \frac{GMm}{r^2} \text{ ....} i$$

Also F = mg ii

Combining equation i and ii gives;

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

$$g = \frac{GM}{r^2} \text{............} iii$$

M = mass of the earth, G is the Newtonâ€™s universal gravitational constant and r = distance of the mass (m) from the centre of the earth. Equation (iii) shows that gravitational field strength (g):

- is inversely proportional to the square of the distance (r) of the mass from the centre of the earth;
- varies as the radius of the earth varies since M and G are constants on the earthâ€™s surface, *g* varies as we move from the equator to the poles. This is because the radius of the earth decreases as one moves from the equator to the poles.
- is a constant at places where the radius of the earth is a constant.
- obeys an inverse square law (i.e. gravity decreases very fast as the distance of the mass from the centre of the earth increases.) *Gravity (g)*

Variation of gravity (g) with height (h)

The value of acceleration due to gravity (g) decreases as the mass moves away from the centre *R* of the earth. On the earthâ€™s surface, the acceleration due to gravity (g) is given by:

$$g = \frac{GM}{r^2} \text{............(i)}$$

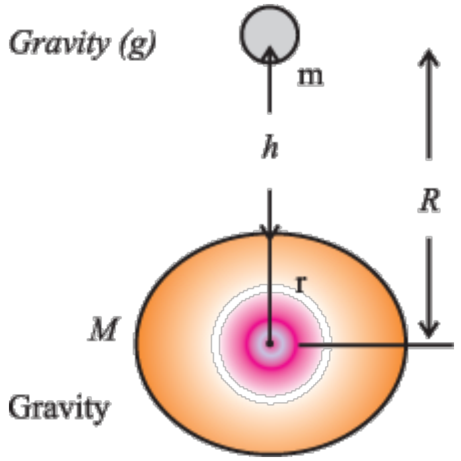


Figure: 3.3

Acceleration decreases as the mass moves away from earthâ€™s centre.
At a height (h) from the earthâ€™s surface, the acceleration due gravity ($g^/$) is given by:

$$g^/ = \frac{GM}{(r+h)^2} = \frac{GM}{R^2}.............(ii)$$

Dividing equations *i* and *ii* gives:

$$\frac{g^/}{g} = \frac{r^2}{(r+h)^2} = \frac{r^2}{R^2}$$

$$g^/ = g\left(\frac{r}{R}\right)^2$$

Worked examples

1.The earth attracts a mass of 5kg with a force of 49N, calculate the gravitational field intensity at the location.

Solution

$$g = \frac{F}{m} = \frac{49}{5} = 9.8\,N\,kg^{-1}$$

2.The gravitational field strength near the earthâ€™s surface is about $10ms^{-2}$. Calculate:

(a) the gravitational field strength at a height twice the radius of the earth;

(b) the weight of a rocket with mass 5000kg at this height.

Solution

$$(a)\ g' = g\left(\frac{r}{R}\right)^2 = 10\left(\frac{r}{2r}\right)^2$$

$$g' = 10\left(\frac{1}{2}\right)^2 = 2.5\,m\,s^{-2}$$

(b) Weight of rocket = Mass of rocket ×gravity

$$W = 5000 \times 2.5 = 12\ 500N$$

Gravitational potential (V)

Work is done in a gravitational field on a body wherever it is lifted against the pull of gravity. Work is done if a body is lifted from the earthâ€™s surface to a new position above the surface of the earth and stored in the body as gravitational potential energy. Suppose the body is moved to a new position **r** from the earthâ€™s surface, the work done is given by:

Work done = Force Ã— distance moved

$$\text{Force } F = \frac{GMm}{r^2} \text{ and distance moved} = \text{r}$$

$$\text{Work done} = \frac{GMm}{r^2} \times \text{r} = \frac{GMm}{r}$$

$$V = \frac{GMm}{r}$$

M = mass of the earth, m = mass lifted against earthâ€™s gravity and r = distance of the mass from the earthâ€™s surface

Maximum gravitational potential energy is obtained if the mass is moved to a point outside the earthâ€™s gravitational field. A mass outside the earthâ€™s gravitational field is said to be at infinity (âˆž). The potential energy of a body at infinity is by convention equal to zero (0).

If a mass at infinity is moved to a new point inside the earthâ€™s gravitational field, work done is given by:

$$\text{V} = \text{V}_{\text{âˆž}} - \text{V}_{\text{r}}$$

$V_{âˆž}$ = potential energy at infinity and V_r = potential energy at the new position

$$\frac{GMm}{r} = 0 - \text{V}_{\text{r}}$$

$$\therefore V_r = -\frac{GMm}{r}$$

The work done per unit mass (1 kg) is called **gravitational potential** (V) and is given by:

$$\therefore V_r = -\frac{GM}{r}$$

Gravitational potential is the work done in moving a unit mass (1 kg) from a point at infinity or zero potential to another point in the earthâ€™s gravitational field.

The gravitational potential at a point in the earthâ€™s gravitational field is negative since the maximum potential at infinity is zero. The minus (–) in front of V_r implies that the potential V_r is less than the potential at infinity $V_{âˆž}$.

Worked example

A rocket of mass 1000 kg is resting on the earthâ€™s surface. Assuming the earth is a sphere of radius 6.4 Ã— 10^6 m and mass 6.0 Ã— 10^{24} kg, calculate:

(a)the potential energy of the rocket on the earthâ€™s surface;

(b)the potential energy of the rocket at a height of 1.0 Ã— 10^6 m;

(c)the gain in potential energy of the rocket in the new position.

{G = 6.67 Ã— 10^{-11}N m^2 kg^{-2}}

$$\text{(a)} \quad V_o = -\frac{GM}{r}$$

$$V_0 = -\frac{6.67\times10^{-11} \times 6.0 \times10^{24} \times 1000}{6.4 \times 10^6}$$

$$V_o = -\,6.253 \times 10^{10}\text{J}$$

$$(b) \quad V_r = -V_o \quad \frac{r}{r+h}$$

$$V_r = -6.253\times 10^{10} \quad \frac{6.4\times 10^6}{6.4\times 10^6 + 1.0\times 10^6}$$

$V_r = -\,5.408 \times 10^{10} J$

Gain in potential energy = $V_r - V_0$

$V_r - V_0 = 5.408\times10^{10} - (-\,6.253\times10^{10})$

$= 8.45 \times 10^9$ J.

television to homes around the world. This how it becomes possible to live telecast of football going on in one country all over the world.

The velocity of escape (v)

Escape velocity is the minimum velocity given to a body to enable it escape from the

gravitational attraction of the earth.

Wherever a body is projected upwards from the earthâ€™s surface, it moves against the velocity which decreases as the body gains height. The body stops momentarily when the velocity is zero, changes direction and returns to the earth. Maximum height reached by the body depends on the velocity given to the body. If the body is given enough velocity, it will escape from the earthâ€™s gravitational attraction.

Suppose a rocket of mass (m) escapes from the earthâ€™s gravitational attraction when the velocity is v, the work done by the rocket is given by:

$$V = \frac{GMm}{r}$$

The kinetic energy of the rocket at the time of launching is equal to the work done in lifting it against the gravitational attraction of the earth. Kinetic energy of rocket = Work done against gravity

$$\frac{1}{2}mv^2 = \frac{GMm}{r}$$

$$V^2 = \frac{2GM}{r} = 2\,\frac{GM}{r^2}\,r$$

$$V^2 = 2gr$$

$$v = \sqrt{2gr}$$

v = escape velocity, g = gravity and r = radius of the earth.

Escape velocity is independent of the **mass** of the body. It depends only on **gravity** and the **height** from which the body is lunched. The magnitude of escape velocity from the earthâ€™s surface is approximately 1.13 Ã— 10^4 ms^{-1}.

Body escapes from the earthâ€™s gravitational attraction if its velocity is greater than the escape velocity

Velocity less than escape velocity, body returns to the earth.

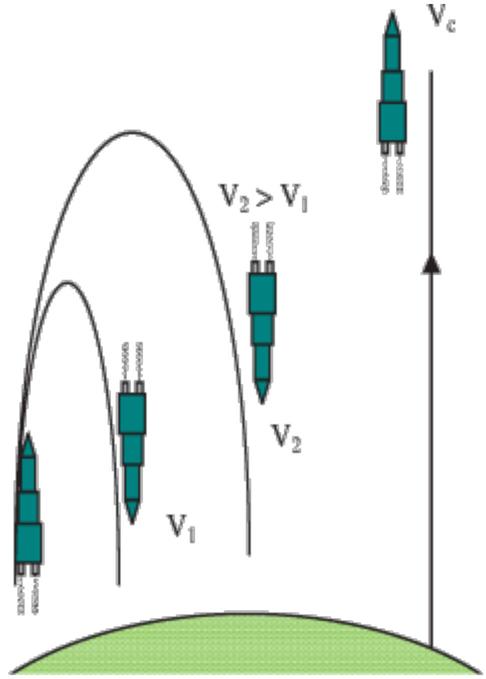


Figure: 3.4 : Earthâ€™s surface

Worked example

What velocity will be given to rocket of mass 5000 kg to enable it escape from:

(a) earthâ€™s gravitational field?

(b) Jupiterâ€™s gravitational field?

Radius of earth is 6.4 Ã— 10^6 m and radius of Jupiter is approximately 6.4 Ã—10^7 m.

Solution

$$(a) \quad v = \sqrt{2gr} = \sqrt{2 \times 10 \times 6.4 \times 10^6}$$

$$v = 1.13 \times 10^4 ms^{-1}$$

$$(b) \quad v = \sqrt{2gr} = \sqrt{2 \times 10 \times 6.4 \times 10^7}$$

$$v = 3.58 \times 10^4 ms^{-1}$$

Geostationary or parking orbits

When a rocket or satellite is given sufficient velocity, it goes into orbit round the earth. To make the satellite stay over the same location on the earth, its period as it moves round the earth must be precisely equal to the period of the earth about its axis. **When a satellite has the same period as the earth, it is said to be in parking orbit.** Communication satellites must be in parking orbit in order to pick and relay information about a location.

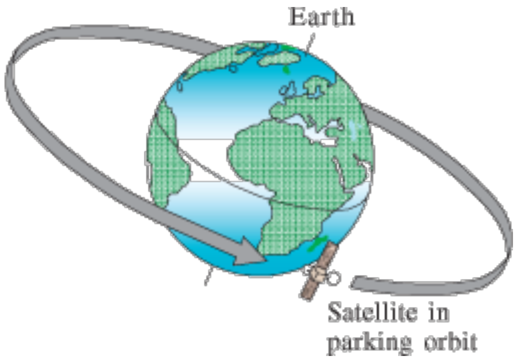


Figure 3.5 : A satellite in parking orbit

Summary

- **Gravitational force** is the force of attraction between two objects in space. Gravitational force keeps the planets in an orbit round the Sun with a constant acceleration.
    - gravitational force between any two masses in space depends on the:
    - product of the masses;
- distance (r) between the masses.
- Newtonâ€™s **universal gravitational law** states that the force of attraction between any two objects in the universe is directly proportional to the product of their masses and inversely proportional to the square of the distance between them.

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

- **The gravitational field** is the space or region around a mass where the gravitational force of the mass can be exerted on other masses.
- **Gravitational field strength** is the gravitational force acting on a unit mass in a particular location.

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

- **Gravitational potential** is the work done in moving a unit mass (1kg) from a point at infinity or zero potential to another point in the earthâ€™s gravitational field. The unit of gravitational potential is JKg^{-1}.

$$V = -\frac{GM}{r}$$

- **Escape velocity** is the minimum velocity given to a body to enable it escape from the gravitational attraction of the earth.

$$v = \sqrt{2gr}$$

•**Parking orbit** occurs when a satellite has the same period as the earth.

Practice Questions 3

1. (a) State Newtonâ€™s law of universal gravitation.

   (b) The planet Jupiter orbits the Sun at a distance 7.73 Ã— 10^{11} m from the centre of the Sun if the masses of the Sun and Jupiter are 2.00 Ã— 10^{30} kg and 1.89 Ã— 10^{27} kg respectively. Calculate the gravitational force of attraction between the Sun and Jupiter. {Newtonâ€™s universal gravitation constant G is 6.67 Ã— 10^{-11}N m^2 kg^{-2}.}

2. (a) Define Newtonâ€™s universal gravitational constant (G).

   (b) Two protons each of mass 1.67 Ã— 10^{-27} kg are 5.70 Ã— 10^{-15} m apart. What is the gravitational force of attraction between the protons? {G = 6.67 Ã— 10^{-11}N m^2 kg^{-2}.}

3. (a) Explain the term *gravitational field intensity* and state its unit.

   (b) Explain precisely the reason for the variation of gravitational field intensity as one moves away from the centre of the earth.

   (c) The gravitational field intensity at the earthâ€™s surface at a particular location is $10Nkg^{-1}$, estimate the mass of the earth if the radius of the earth is 6.4 Ã— 10^6 m. {G = 6.67 Ã— 10^{-11}N m^2 kg^{-2}.}

4. (a) What do you understand by *gravity?*

   (b) A space shuttle of total mass 15 000 kg is orbiting the earth at a height 5.0 Ã— 10^5 m above the earthâ€™s surface. Assuming the radius of the earth is 6.4 Ã— 10^6 m and the gravitational pull of the earth at the surface of the earth is approximately $10ms^{-2}$. Calculate the:

      (i) gravitational pull of the earth on the space shuttle at that height;

      (ii) weight of the space shuttle at that height;

      (iii) loss of weight of the space shuttle because of its height above the ground.

5. (a) What do you understand by *gravitational potential?*

   (b) Explain why the gravitational potential in the earthâ€™s gravitational field is negative.

   (c) A rocket of mass 25 000 kg is to be launched from the earthâ€™s surface. Calculate its gravitational potential energy at:

      (i) the earthâ€™s surface;

      (ii) a height 3.0 Ã— 10^4 m above the earthâ€™s surface.

      {Radius of the earth = 6.4 Ã— 10^6 m, mass of the earth is 6.0 Ã— 10^{24}kg and G = 6.67 Ã— $10^{-11}$$Nm^2kg^2$.}

6.Find the gravitational field intensity on a space shuttle orbiting the earth at a height thrice the radius of the earth if the intensity of gravity on the earthâ€™s surface is 10 N kg^{-1}.

7. (a) Explain what you understand by term *escape velocity.*

   (b) Explain why it is easier to launch a rocket from the moonâ€™s surface than from the earthâ€™s surface.

   (c) A space shuttle of mass 40 000 kg is to be lunched from the earthâ€™s surface. What is the minimum velocity it requires to escape from the earthâ€™s gravitational attraction? {Radius of earth = 6.4 Ã— 10^6 m and gravitational field intensity at site of lunching is 9.8 m s^{-2}.}

Solar system

Our solar system consists of the Sun at its centre, the planets Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. It includes the satellites of the planets; an example is the moon, which is a satellite of the Earth, numerous comets, asteroids, and meteoroids and the interplanetary dust and gas.

Figure 3.6 The sun and the nine planets

The planets are divided into two groups called terrestrial or inner planets and the Jovian (Jupiter-like) or the outer planets.

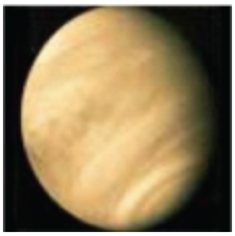
The terrestrial or inner planets

The four planets closest to the Sun are ***Mercury, Venus, Earth,*** and ***Mars*** are called the terrestrial planets because they have solid rocky surfaces. The planets, Venus, Earth, and Mars have significant atmospheres while Mercury has almost none.

The jovian or outer planets

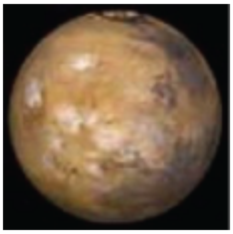
The four large planets beyond the orbit of Mars are ***Jupiter, Saturn, Uranus,*** and ***Neptune.*** They are called Jovian (Jupiter-like) planets because they are gas giants (big compared with Earth). This is because they are composed mainly gas and frozen liquids.

Mercury



Venus

Earth

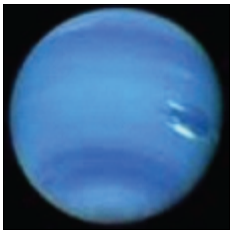


Mars

Jupiter

Saturn

Neptune



Uranus

Pluto

Figure 3.7 The planets

Dwarf planets

Recently, scientists have discovered objects orbiting the Earth far away from the Sun. They are called dwarf planets. Eris was discovered in July 2005 at a distant of 97 astronomical units (AU) from the Sun. One AU is 150 million km. Other dwarf planets are Ceres, Haumea and Makemake. In 2006, Pluto was named dwarf planets because its characteristics do not fit the characteristics of the other planets. It means that we now have only eight planets in our solar system. Study the pictures in Figure 3.7 above. Why do you think Pluto is not a planet?

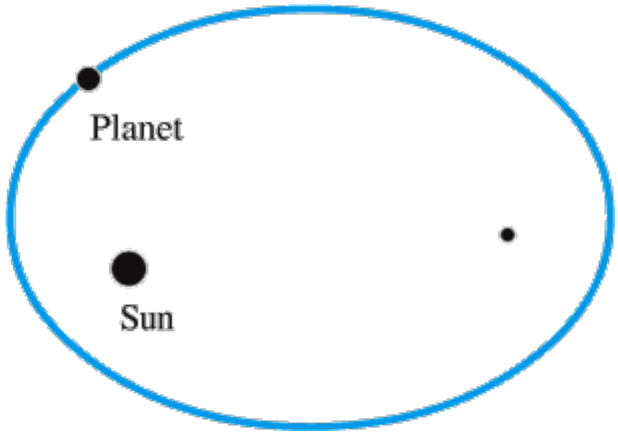


Figure 3.8 The Keplerâ€™s first law: the sun at one focus of the ellipse

Planetary motion and Keplerâ€™s laws

The planets move in an elliptical path round the Sun. Johannes Kepler, using accurate observations made by Tycho Brahe, proposed three laws of planetary motion that describe the motions of planets in their orbit. The laws are:

1. ***The orbits of the planets are ellipses with the Sun at the common focus.***
2. ***The line joining the planet to the Sun sweeps out equal areas in equal times as the planet travels around the ellipse.***
3. ***The square of period of revolution of the planets (T) is proportional to the mean square of the distance of the planets from the Sun*** (Radius of revolution r). That is T^2 âˆ r^3.

Keplerâ€™s laws imply that the speed of revolution of a planet around the Sun is not uniform, but changes as the planet moves round the Sun. It is fastest when the planet is nearest the Sun (perihelion) and slowest when the planet is farthest away (aphelion).

Isaac Newton, using his famous equations of motion and gravitational attraction of the planets and the Sun, mathematically proved Keplerâ€™s third law of planetary motion. Suppose a planet of mass m is orbiting the Sun of mass M at a distance (radius r); the gravitational attraction of the Sun on the planet provides the required centripetal force to keep the Planet in orbit round the Sun. Then:

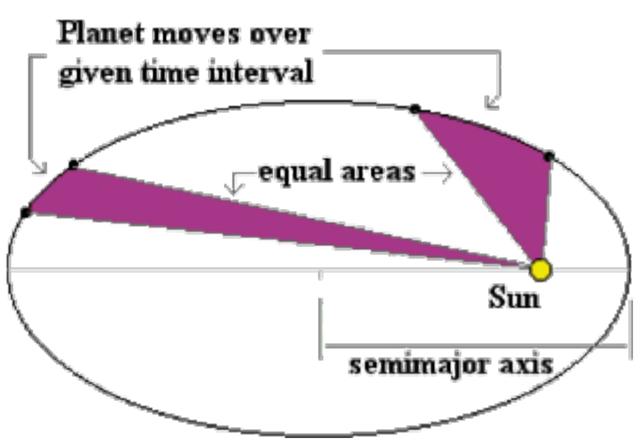


Figure 3.9 Keplerâ€™s second law: equal area swept out in equal time intervals

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

$$\frac{GM}{r^2} = \frac{v^2}{r} \quad \ldots\ldots\ldots \text{(i)}$$

The period of revolution T is given by $T = \frac{2\pi r}{v}$

Where 2Ï€ r is the circumference of the circular path.

$$\therefore v = \frac{2\pi r}{T} \quad \ldots\ldots\ldots \text{(ii)}$$

Substituting (ii) into (i) $\frac{GM}{r^2} = \frac{(2\pi r)^2}{rT^2}$

$$\frac{GM}{r^2} = \frac{4\pi^2 r}{T^2}$$

Making T^2 the subject of the formula yields $T^2 = \frac{4\pi^2 r^3}{GM}$

âˆ´ T^2 âˆ r^3 (Keplerâ€™s third law of planetary motion)

Natural and artificial satellites

A natural satellite is a natural body in space that orbits a larger body or a moon orbiting another body. In our planetary system, only Mercury and Venus have no satellites. Others have at least one satellite orbiting them. Mars has two satellites, Earth has one, Jupiter has more than 60 natural satellites, Saturn has at least 60 natural satellites; the largest of which is Titan, Uranus has at least 27 moons, Neptuneâ€™s largest natural satellite is Triton and Pluto has only one moon. ***An artificial satellite is a man-made device or any object purposely placed into orbit around Earth, another planet or the Sun.*** The first artificial object lunched into space was the Russian rocket called, the Sputnic in 1957. After the Russian breakthrough, many artificial satellites have been lunched. Today, artificial satellites are lunched for communications, military intelligence, and for scientific study of both Earth and the outer space. Nigeria launched its satellite for weather control and security called Niger-SAT1. Weather satellites like a, Niger-SAT1 carry cameras and other instruments pointed toward Earthâ€™s atmosphere around Nigeria and her neighbouring countries to warn of any severe weather or natural disasters. It is also used in weather forecasting.

Figure 3.10 : Artificial satellite orbiting the earth

Satellites carry communications equipment into ***geostationary orbit;*** that is, ***an orbit that keeps the satellite over the same spot above Earthâ€™s equator.*** More than 300 communications satellites have been launched since 1957 including Niger-SAT1. Today satellites in geostationary orbit are used in television communications, including the direct broadcast of

Rockets

A rocket is also called rocket vehicle. It can be a missile or an aircraft.

Components of a rocket

A rocket has a propellant and a propellant tank, one or more rocket engines and nozzle, directional stabilization device and a structure to hold these components together. Rockets intended for high-speed atmospheric use also have an aerodynamic fairing such as a nose cone.

Rocketâ€™s propellants

Rockets carry chemical fuel called propellant. A rocket engine uses the following chemical propellants gas, solid, liquid, or a hybrid mixture of both solid and liquid. Other non-chemical propellantâ€™s engines include steam rockets, solar thermal rockets, and nuclear thermal rocket.

How rockets work

Rockets work on the principle of jet propulsion. The combustion of the propellant inside the combustion chamber produces hot gases, which are ejected from the nozzle of the rocket at a great speed. The acceleration of the escaping hot gases through the engine exerts a force or thrust on the combustion chamber and nozzle, moving the rocket forward according to Newtonâ€™s third law of motion.

Figure 3.11 Serial multistage rocker during lunching

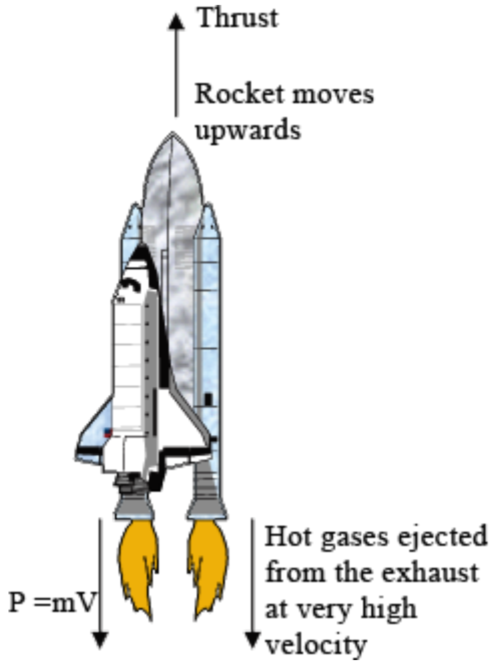


Figure 3.12 Space shuttle works on the law of conservation of momentum

Figure 3.13 Space shuttle in flight

Forces on a rocket in flight

The general study of the forces on a rocket or other spacecraft is called astrodynamics. Flying rockets are primarily affected by the following:

1.Thrust from the engine(s)

2.Gravity from celestial bodies

3.Drag if moving in the atmosphere

4.Lift; usually relatively small effect except for rocket-powered aircraft

Uses of rockets

1.Rockets are used in fireworks and weaponry.

2.Rockets are used as a launch vehicles for artificial satellites.

3.Rockets are used for human spaceflight and exploration of other planets.

4.Rockets are used to study high-altitude conditions, by radio telemetry of temperature and pressure of the atmosphere, detection of cosmic rays.

5.In military term, a rocket and its payloads is called a missile. A payload is a nuclear, chemical or biological weapon meant for a target.

6.Rockets are used to carry instruments that take readings from 50 kilometres to 1500 kilometres above the surface of the Earth.

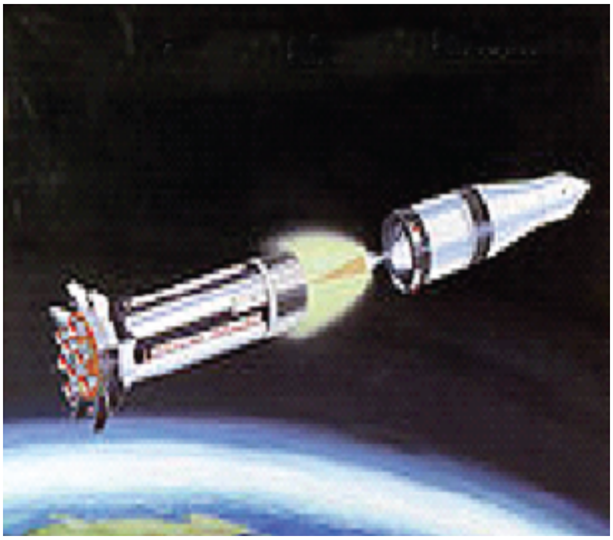


Figure 3.14: Stagging involves dropping burnt out part of a rocket

Staging

Staging involves dropping off unnecessary parts of the rocket to reduce weight. A **multistage rocket** is a rocket that has two or more *stages*. Each of the stage contains its own engines and propellant. There are two types of staging, a ***serial*** **stage** and a ***parallel*** **stage.** In a serial stage rocket, one stage is mounted on top of another stage while in a *parallel* staged rocket the stages are attached side by side. The advantage of staging is that by dropping a stage when propellant finishes, the mass of the remaining rocket is reduced. This makes the thrust of the remaining stages to accelerate the rocket faster to its final speed and height.

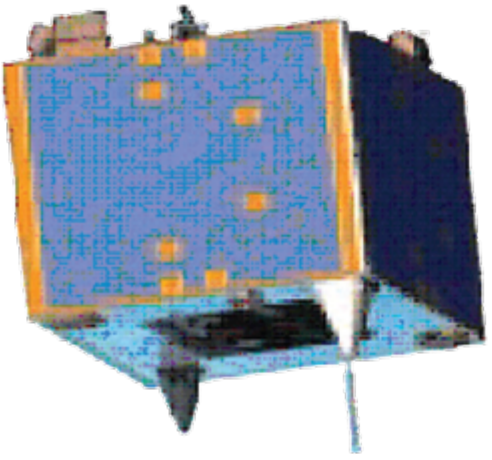


Figure 3.15 NigeriaSat-1

NigeriaSat-1

NigeriaSat-1 is a satellite built for the Federal Ministry of Science and Technology (FMST) of Nigeria. It was launched in September 2003 as one of the three satellites simultaneously launched to complete the first phase of the Disaster Monitoring group, in order to provide medium-resolution imagery with daily worldwide revisit. The programme of NigeriaSat-1 involves a satellite, a control station and a team of Nigerian engineers. National Space Research and Development Agency (NASRDA), was also formed to manage the NigeriaSat-1 program. The satellite carries an optical imaging payload to provide 32-m ground resolution to cover a swath width of over 640 km. It can cover an area as large as 640 Ã— 560 km. NigeriaSat-1 can give useful information about pollution and disaster. Uses of NigeriaSat-1 include:

â€¢To watch for **natural disasters** (floods, earthquakes, volcanic eruptions and storm) that may occur and warn in advance before it happens.

â€¢To detect **man-made disasters** (oil pollution, desertification, erosion, forest fire, and deforestation).

â€¢It is used in **agriculture** for management of sustainable grazing, forest logging, planning, afforestation programmes, crop inventory and yield forecast.

â€¢It is used for weather forecast, rainfall prediction, drought, and other disaster forecast and to monitor the quantity and quality of surface and underground water.

â€¢It is used in mineral exploration and exploitation in Nigeria (oil, gas and solid mineral exploration).

â€¢It is used in demographic mapping and planning of population surveys, census enumeration areas, as well as mapping, planning and monitoring of rural and urban growth.

â€¢It is used to map state and international boundaries, for defence and security purposes, to identify and track down international criminals.

â€¢It is used to monitor environments that breed mosquitoes and to control the spreading of malaria.

â€¢Its remote sensing devices can detect and warn on outbreaks of meningitis.

â€¢It is used to provide education through distant learning to many Nigerians.

NigeriaSat-2

The Federal Government proposed launching of a higher resolution Satellite (NigeriaSat-2) Surrey Satellite Technology Ltd (SSTL) signed in November 2006 as contract in Abuja for the supply of the **Nigeriasat-2** Earth observation satellite, related ground infrastructure and a training programme to further establish a national indigenous space capability in the Federal Republic of Nigeria. The new 300kg satellite, for launch in 2009, would provide Nigeria with valuable geographically referenced high-resolution satellite imaging for applications in mapping, water resources management, agricultural land use, population estimation, health hazard monitoring and disaster mitigation and management. SSTL will develop NIGERIASAT-2 based upon its new generation of high-resolution Earth observation satellites.

Figure 3.16 Artificial satellite orbiting the Earth

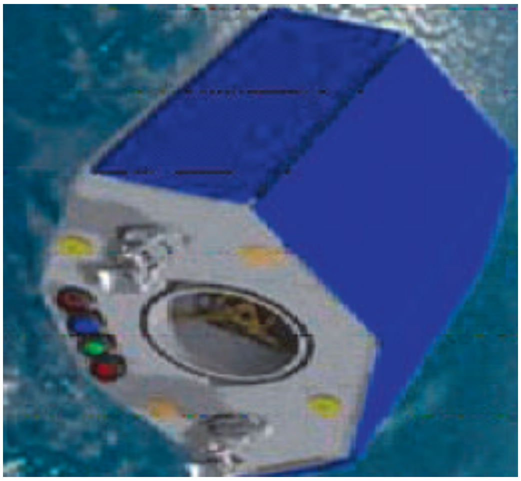


Figure 3.17 NigeriaSat-2 Earth observing satellite

Summary

1.The planetary system consists of the Sun, nine planets and their satellites, comets and other objects that move round the Sun.

2.The planets in our solar system are Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

3.A natural satellite is a natural body in space that orbits a larger body or moon orbiting another body.

4.An artificial satellite is a device or any object purposely placed into orbit around Earth, another planet or the Sun by man.

5.Geostationary orbit is an orbit that keeps the satellite over the same spot above Earthâ€™s surface.

6.A rocket or a rocket vehicle is a missile or aircraft.

7.Staging is dropping off unnecessary parts of the rocket to reduce weight.

Questions

1.What is meant by solar system? Name the objects that make our solar system.

2.Differentiate between terrestrial and jovian planets. Name the nine planets in the order of their distances from the Sun.

3.What is meant by dwarf planets? Explain why Pluto is not considered as a planet.

4.State Keplerâ€™s laws of planetary motion.

5.Differentiate between natural and artificial satellites. Give two examples of each.

6.Explain what is meant by geostationary orbit.

7. (a) What is a rocket?

   (b) State two components, two propellants and two forces, which act on a rocket.

   (c) Explain how rockets work.

   (d) Mention three applications of a rocket.

8.Explain the term â€˜stagingâ€™ as applied to rockets. Give two advantages of staging in rocket lunching.

9.Give the full meaning of NASRDA.

10.State three applications each of NigeriaSat-1 and NigeriaSat-2.

Past Questions

1. A body is launched from the earthâ€™s surface, radius R, so that it just escapes from the gravitational influence of the earth. If the gravitational constant is G and the mass of the earth is *M,* what is the escape velocity of the body?

A. $\frac{\sqrt{2GM}}{R}$ D. $\sqrt{2GMR}$

B. $\frac{\sqrt{2GM}}{R}$ D. $\frac{R}{2GM}$

C. $\sqrt{\frac{2G}{MR}}$

NECO

2. A satellite is in a parking orbit if its period is
   A. equal to the period of the earth.
   B. less than the period of the earth.
   C. the square of the period of the earth.
   D. more than the period of the earth.

JAMB

3. Two spheres of masses 100 kg and 90 kg respectively have their centres separated by a distance of 1.0 m. Calculate the magnitude of the force of attraction between them. {G = 6.67 Ã— 10^{-11} N m^2 kg^{-2}.}
   A. 6.70 Ã— 10^{-11} N.
   B. 6.70 Ã— 10^{-10} N.
   C. 6.03 Ã— 10^{-10} N.
   D. 6.003 Ã— 10^{-7} N.

WASSCE

4. The magnitude of the gravitational attraction between the earth and a particle is 40N. If the mass of the particle is 4 kg, calculate the magnitude of the gravitational field intensity of the earth on the particle.
   A. 10.0 N kg^{-1}.
   B. 12.6 N kg^{-1}.
   C. 25.0 N kg^{-1}.
   D. 160.0 N kg^{-1}.

WASSCE

5. The force of attraction between the earth and a body of mass, *m,* situated in the earthâ€™s gravitational field is **F.** The magnitude of the gravitational field intensity experienced by the body is given by the expression.
   A. **F**m.
   B. $\frac{F}{m}$

C. $\frac{F}{m}$

D. $\mathbf{F}^2$m.

WASSCE

6. What is the escape velocity of a satellite launched from the earthâ€™s surface? {Take the g as 10 $ms^{-2}$and the radius of the earth as 6.4 Ã— 10^6 m}

   A. 7.80 Ã— 10^3 m s^{-1}.

   B. 1.13 Ã— 10^4 m s^{-1}.

   C. 3.56 Ã— 10^7 m s^{-1}.

   D. 6.00 Ã— 10^7 m s^{-1}.

   E. 1.20 Ã— 10^8 m s^{-1}.

NECO

7. If **m** is the mass of an object on the surface of the earth, **g** the acceleration due to gravity, **G** the gravitational constant and **R** the radius of the Earth, the mass **M** of the Earth is

   A. $\frac{gmR^2}{G}$

   B. $\frac{gR^2}{G}$

   C. $\frac{G}{gmR^2}$

   D. $\frac{G}{gR^2}$

WASSCE

8. The gravitational potential energy of a body of mass 5kg, situated at a point within the Earthâ€™s gravitational field is 3.25 Ã— 10^8J. Calculate the magnitude of the escape velocity of the body.

   A. 5.50 Ã— 104 ms^{-1}.

   B. 1.14 Ã— 104 ms^{-1}.

   C. 6.25 Ã— 103 ms^{-1}.

   D. 3.60 Ã— 103 ms^{-1}.

WASSCE

9. A missile weighing 40N on the Earthâ€™s surface is shot into the atmosphere to an altitude of 6.40 Ã— 10^6 m. Taking the Earth as a sphere of radius 6.40 Ã— 10^6 m

and assuming the inverse-square law of universal gravitation, what would be the weight of the missile at that altitude?

A. 10.0N

B. 200N

C. 400N

D. 800N

E. 1600N

WAEC

10. What is the gravitational potential due to a point mass **m** at a distance **r** from it? {G = gravitational constant}

A. $-\frac{Gm^2}{r^2}$ D. $-\frac{Gm}{r}$

B $-\frac{Gm^2}{r}$ E. $-\frac{G^2m^2}{r}$

C. $-\frac{m^2}{Gr^2}$

WAEC

11. (a) (i) State in words, Newtonâ€™s law of universal gravitation.

(ii) Explain acceleration of free fall due to gravity.

(b) The magnitudes of the force of attraction between two particles of masses M and m separated by a distance d is F_1. When the distance of separation is $\frac{d}{2}$, the magnitude of the force is F_2 . Given that the universal gravitational constant is G, obtain expression for:

(i) *F1*

(ii) the ratio of $\frac{F_2}{F_1}$

(c) A body of mass m is projected from the surface of the Earth with a velocity v. If the mass and mean radius of the earth are M *and* R respectively, write down an expression for the:

(i) gravitational potential energy of the body at a distance r from the centre of the earth;

(ii) initial kinetic energy acquired by the body.

(d) (i) Show that the magnitude V of the velocity with which the body in (c) above would escape from the earthâ€™s field is given by $v = \sqrt{2gR}$

(ii) Calculate V give n that the mean radius of the ea{g = 9.8 m s^{-2}}

WASSCE