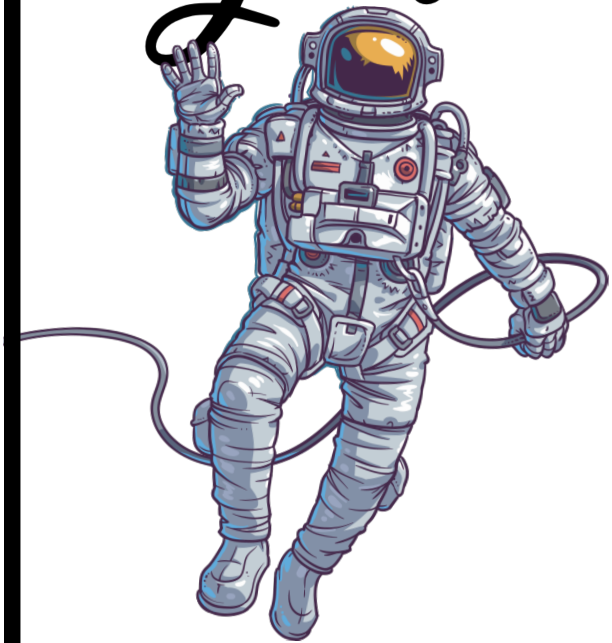
PHYSICS

Gravitation

To infinity and Beyond



Chapter 3

The will to win,
the desire to succeed,
the urge to reach
your full potential...
These are the keys
that will unlock
the door
to personal excellence.

DREAM BIG ... AIM HIGH ... NEVER GIVE UP ...

3.1 Newton's Universal Law Of Gravitation

A. Gravitational force

Newton's Universal Law of Gravitation
state that

Gravitational force, F is directly proportional to the product of mass of the object and inversely proportional to the square of the distance between them

FORMULA

$$F = \frac{Gm_1 m_2}{r^2}$$

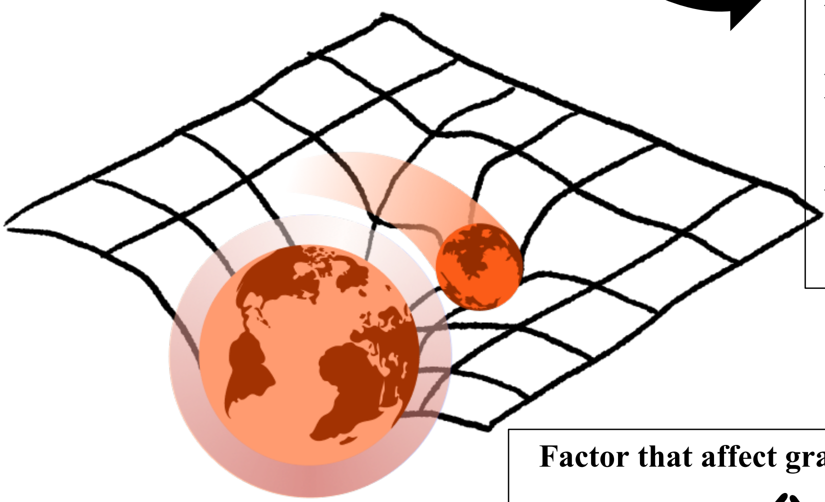
F = Gravitational force between two objects

G = Universal gravitational constant (6.67×10^{-11} N m^2 kg^{-2})

m_1 = mass of first object

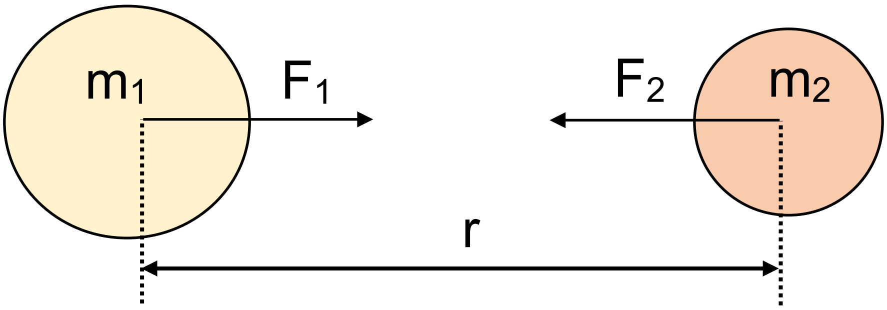
m_2 = mass of second object

r = distance between the center of two objects



Factor that affect gravitational force

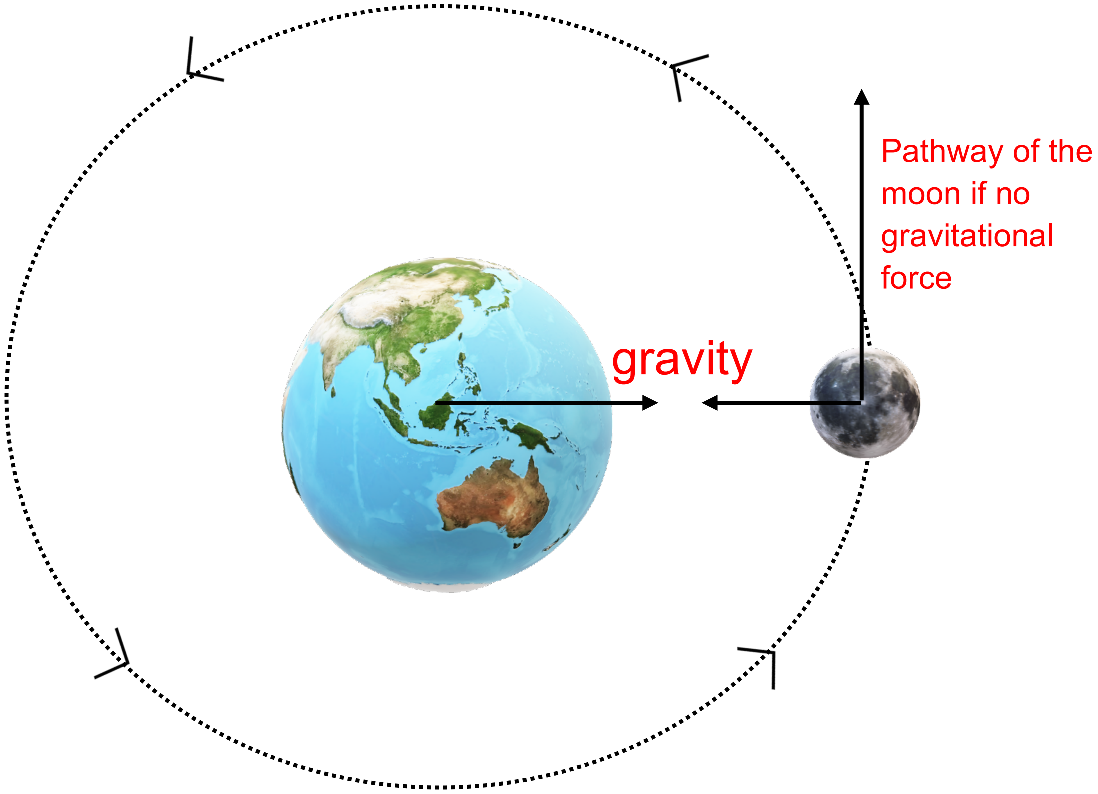
mass of object, m	distance between objects, r
Relationship mass, m ↑, gravitational force, F ↑	Relationship distance, r ↑, gravitational force, F ↓



$$F_1 = F_2$$

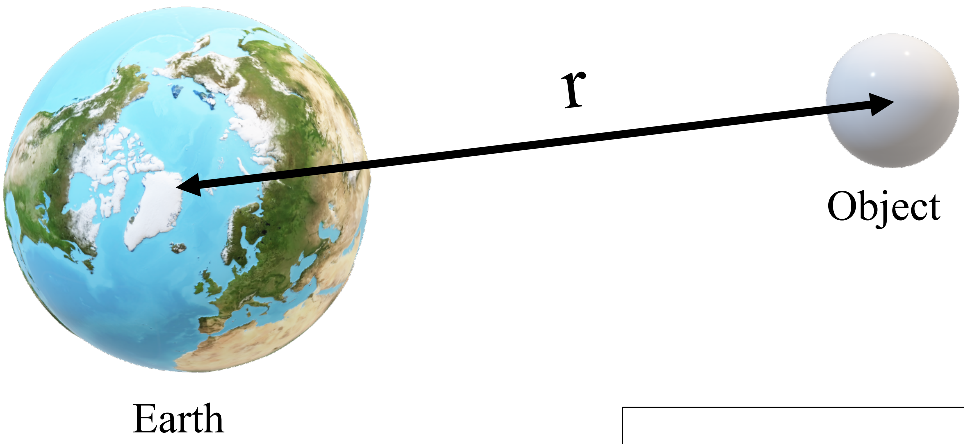
$$F = \frac{Gm_1 m_2}{r^2}$$

The moon can orbit around the Earth as there is **GRAVITATIONAL FORCE** between Moon and Earth



The planets can **orbit** around the Sun because of the **GRAVITATIONAL FORCE** imposed between the planets and the Sun.

B. Relationship gravitational acceleration, g, on the surface of the earth with the universal gravitational constant, g



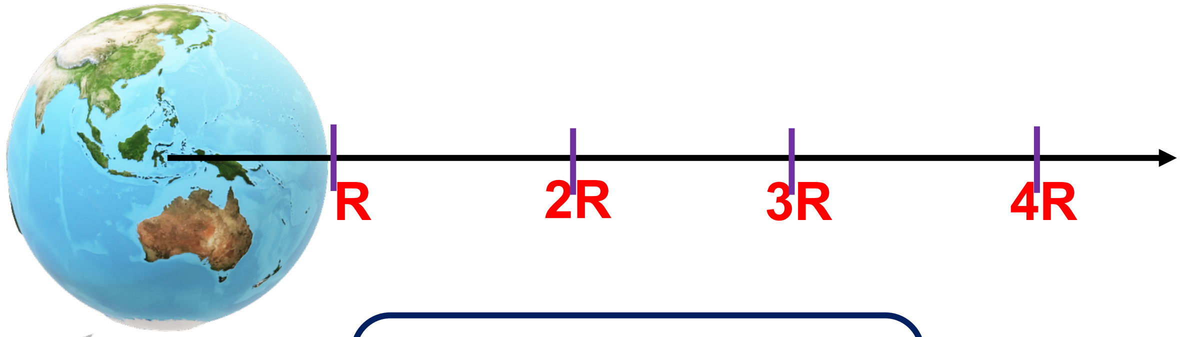
Newton's Second Law of Motion → $F = mg$ → (1)

Newton's Universal Law of Gravitation → $F = \dfrac{Gm\,M}{r^2}$ → (2)

(1) = (2) → $mg = \dfrac{Gm\,M}{r^2}$ → $g = \dfrac{GM}{r^2}$

Do not walk **PROUDLY** on the **EARTH**; your feet cannot tear apart the Earth nor are you as tall as mountains

Quran 17:37

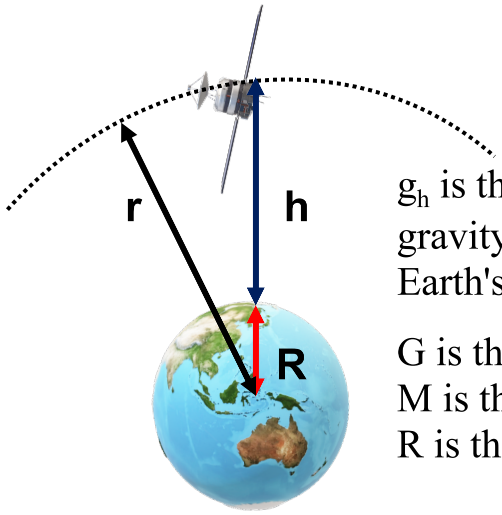


When R ↑ ∴ g ↓

Example:

Given that ;
Mass of the earth, M = 5.97×10^{24} kg
Radius of the earth, R = 6.37×10^{6} m
Gravitational constant, G = 6.67×10^{-11} N m^2 kg^{-2}

Distance from the centre of the Earth, r / m	Gravitational acceleration, g / ms^{-2}
R	$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{6} (5.97 \times 10^{24})}{(6.37 \times 10^{6})^2} = 9.8$
2R	$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{6} (5.97 \times 10^{24})}{2 \times (6.37 \times 10^{6})^2} = 4.9$
3R	$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{6} (5.97 \times 10^{24})}{3 \times (6.37 \times 10^{6})^2} = 3.3$
4R	$g = \frac{GM}{r^2} = \frac{6.67 \times 10^{6} (5.97 \times 10^{24})}{4 \times (6.37 \times 10^{6})^2} = 2.5$



g_h is the acceleration due to gravity at height, h from the Earth's surface

G is the Gravitational constant,
M is the mass of the Earth,
R is the radius of the Earth.

Example:

r = R + h

$$F = \frac{Gm\,M}{(R\ +\ h)^2} \quad \dots 1$$

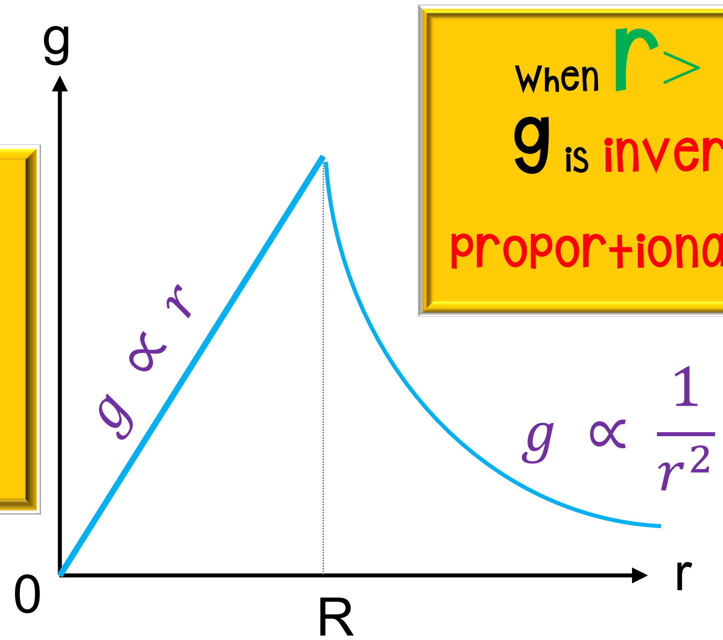
$$F\ =\ mg_h \quad \dots 2$$

equation 1 = equation 2

$$g_h = \frac{GM}{(R+h)^2}$$

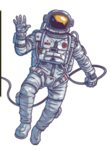
The **further** from the Earth's surface, the **smaller** is the gravitational acceleration, g.

When $r < R$
g is directly proportional to r

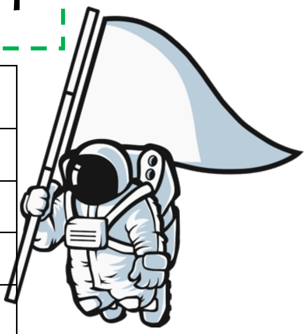


When $r > R$
g is inversely proportional to r^2

be amazing



Gravitational Acceleration of the planets in the Solar System



Planet	Mass, M /kg	Radius, R /m
Sun	1.99×10^{30}	6.96×10^{8}
Moon	7.35×10^{22}	1.74×10^{6}
Mars	6.42×10^{23}	3.40×10^{6}
Jupiter	1.90×10^{27}	6.99×10^{7}
Saturn	5.68×10^{26}	6.03×10^{7}

$$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(1.99 \times 10^{30})}{(6.96 \times 10^{8})^2} = 274 \text{ m s}^{-2}$$

Sun

$$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(7.35 \times 10^{22})}{(1.74 \times 10^{6})^2} = 1.62 \text{ m s}^{-2}$$

Moon

$$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(6.42 \times 10^{23})}{(3.40 \times 10^{6})^2} = 3.7 \text{ m s}^{-2}$$

Mars

$$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(1.90 \times 10^{27})}{(6.99 \times 10^{7})^2} = 25.94 \text{ m s}^{-2}$$

Jupiter

$$g = \frac{GM}{r^2} = \frac{(6.67 \times 10^{-11})(5.68 \times 10^{26})}{(6.03 \times 10^{7})^2} = 10.42 \text{ m s}^{-2}$$

Saturn

C. Centripetal force in the motion of satellites and planets system

Centripetal force

The force that act to an object in circular motion

FORMULA

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

F = Centripetal force

m = mass

v = linear speed

r = radius of the circle

Factor that affect Centripetal force

Factor	Relationship
Mass of object, m	$m\uparrow, F\uparrow$
Linear speed, v	$v\uparrow, F\uparrow$
Radius of the circle, r	$r\uparrow, F\downarrow$

Centripetal acceleration, a_c is the acceleration that directed towards the **centre** of the circle.

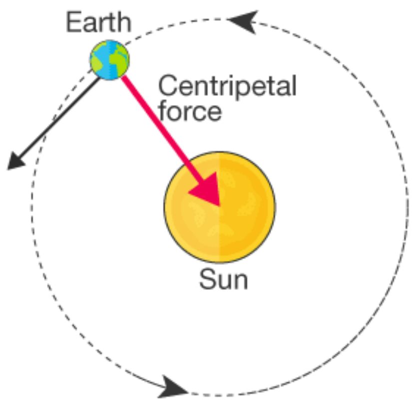
Force formula → $F = ma$ → (1)

Centripetal force formula → $F = \frac{mv^2}{r}$ → (2)

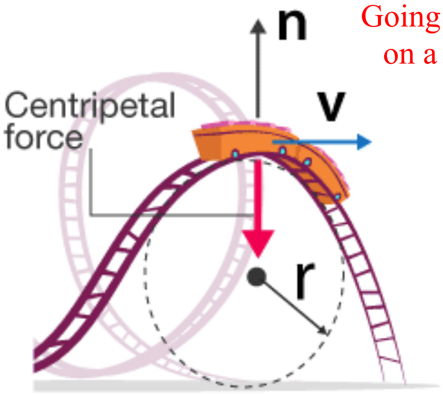
(1) = (2) → $ma = \frac{mv^2}{r}$ → $a = \frac{v^2}{r}$

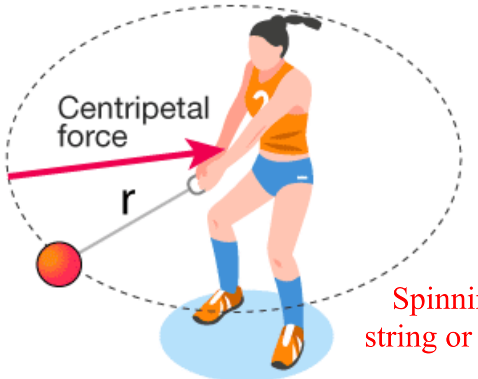
SITUATION:

Planets orbiting around the Sun

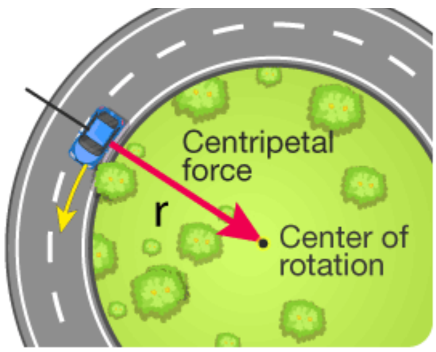


Going through a loop on a roller coaster



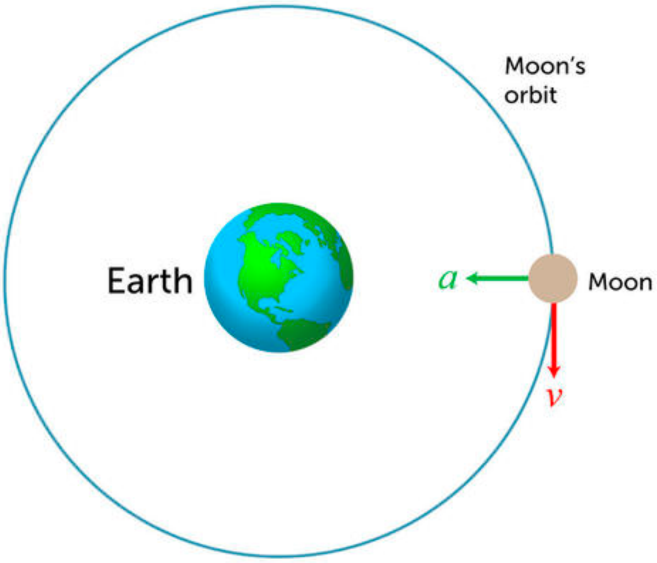


Spinning a ball on a string or twirling a lasso



Turning a car

D. Mass of the Earth and the Sun



Formula of Linear speed, V

Derive from formula of

Speed = $\frac{\text{Distance}}{\text{Time}}$

Distance = Distance travelled by a planet to make one complete orbit around the Earth

= Perimeter of orbit = $2\pi r$

Time = Period of revolution of the Moon around the Earth = T

Linear speed, $v = \frac{2\pi r}{T}$

#Refer Figure 3.20 in Text book

Newton's Universal Law of Gravitation → $F = \frac{GmM}{r^2}$ → (1)

Centripetal force formula → $F = \frac{mv^2}{r}$ → (2)

(1) = (2) → $\frac{GmM}{r^2} = \frac{mv^2}{r}$ → $\frac{GM}{r} = v^2$

replace v with $\frac{2\pi r}{T}$ → $\frac{GM}{r} = \left(\frac{2\pi r}{T}\right)^2$ → $M = \frac{4\pi^2 r^3}{GT^2}$

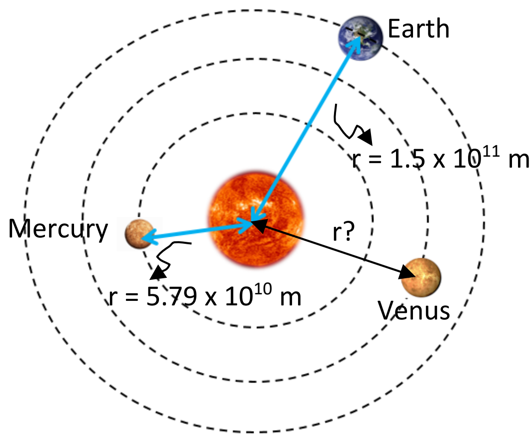
Where ;

r = **Radius of the orbit of any planet or satellite**

T = **Period of revolution**

Example:

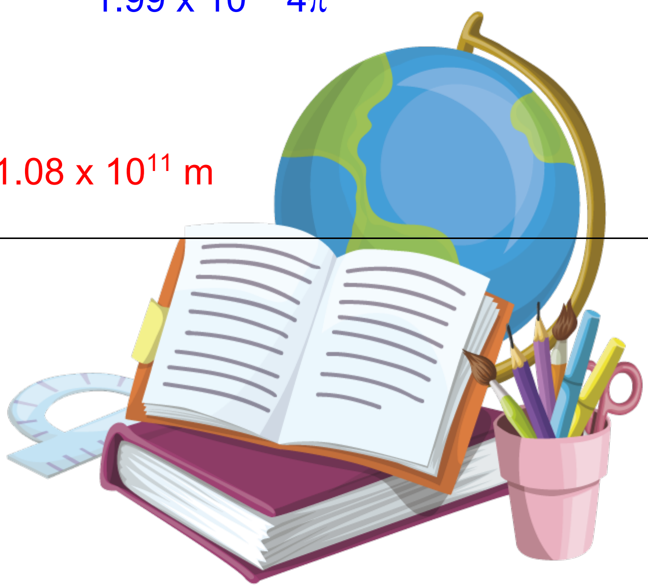
Diagram shows the Earth, planet Mercury and Venus revolving around the Sun.
[Mass of Sun = 1.99×10^{30} kg,
G = 6.67×10^{-11} N m^2 kg^{-2}]



Find:
(i) the period of revolution of Mercury

(ii) the radius of orbit of Venus.
(Period of revolution = 0.61 Earth's year)

(i)	(ii)
$M = \frac{4\pi^2 r^3}{GT^2}$ $1.99 \times 10^{30} = \frac{4\pi^2 r^3}{GT^2}$ $1.99 \times 10^{30} = \frac{4\pi^2 (5.79 \times 10^{10})^3}{6.67 \times 10^{-11} (T^2)}$ $T^2 = \frac{4\pi^2 (5.79 \times 10^{10})^3}{1.99 \times 10^{30} (6.67 \times 10^{-11})} = 7.96 \times 10^6$ s T = 0.24 years	Period of revolution = $0.61 \times 3.16 \times 10^7$ s = 1.93×10^7 s $M = \frac{4\pi^2 r^3}{GT^2}$ $1.99 \times 10^{30} = \frac{4\pi^2 r^3}{6.67 \times 10^{-11} (1.93 \times 10^7)^2}$ $r^3 = \frac{6.67 \times 10^{-11} (1.93 \times 10^7)^2}{1.99 \times 10^{30} \; 4\pi^2}$ $r = 1.08 \times 10^{11}$ m



FORMATIVE PRACTICE 3.1 (PAGE: 95 TEXT BOOK)

no 3.

A piece of space junk of mass 24 kg is at a distance of 7.00×10^6 m from the centre of the Earth. What is the gravitational force between the space junk and the Earth?
[$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2},
mass of the Earth = 5.97×10^{24} kg]

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

$$F = \frac{(6.67 \text{ x } 10^{-11})(24)(5.97 \text{ x } 10^{24})}{(7 \text{ x } 10^6)^2}$$

$$F = 195.03 \text{ N}$$

no 4.

A weather satellite orbits the Earth at a height of 560 km. What is the value of gravitational acceleration at the position of the satellite?
[$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2},
mass of the Earth = 5.97×10^{24} kg,
radius of the Earth = 6.37×10^6 m]

$r = R + h$
$= 560 \text{ x } 10^3 + 6.37 \text{ x } 10^6$
$= 6.93 \text{ x } 10^6$ m

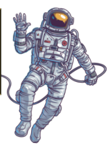
$$mg = \frac{GmM}{r^2}$$

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

$$g = \frac{(6.67 \text{ x } 10^{-11})(5.97 \text{ x } 10^{24})}{(6.93 \text{ x } 10^6)^2}$$

$$g = 8.292 \text{ ms}^{-2}$$

be amazing



no 5.

A man-made satellite of mass 400 kg orbits the Earth with a radius of 8.2×10^6 m. Linear speed of the satellite is 6.96×10^3 m s^{-1} . What is the centripetal force acting on the satellite?

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

$$F = \frac{(400)(6.96 \text{ x } 10^3)^2}{8.2 \text{ x } 10^6}$$

$$F = 2363 \text{ N}$$

no 6.

Figure 3.23 shows Mercury orbiting the Sun with a radius of 5.79×10^{10} m and a period of revolution of 7.57×10^6 s. Calculate the mass of the Sun.

$$M = \frac{4\pi^2 r^3}{GT^2}$$

$$M = \frac{4\pi^2 (5.79 \, x \, 10^{10})^3}{(6.67 \text{ x } 10^{-11})(7.57 \text{ x } 10^6)^2}$$

$$M = 2.005 \text{ x } 10^{30} \text{ kg}$$

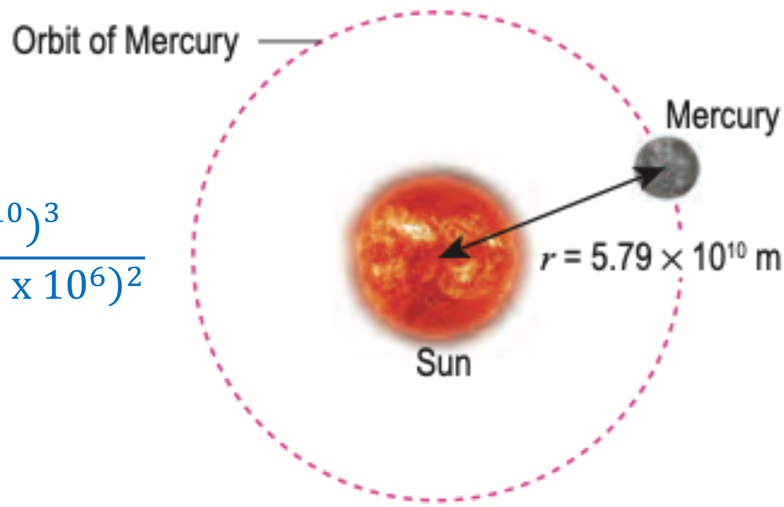


Figure 3.23

Time is **free**, but it's **priceless**.
You can't **own** it, but you can **use** it.
You can't **keep** it, but you can **spend** it.
Once you've **lost** it...
You **can never get it back**.

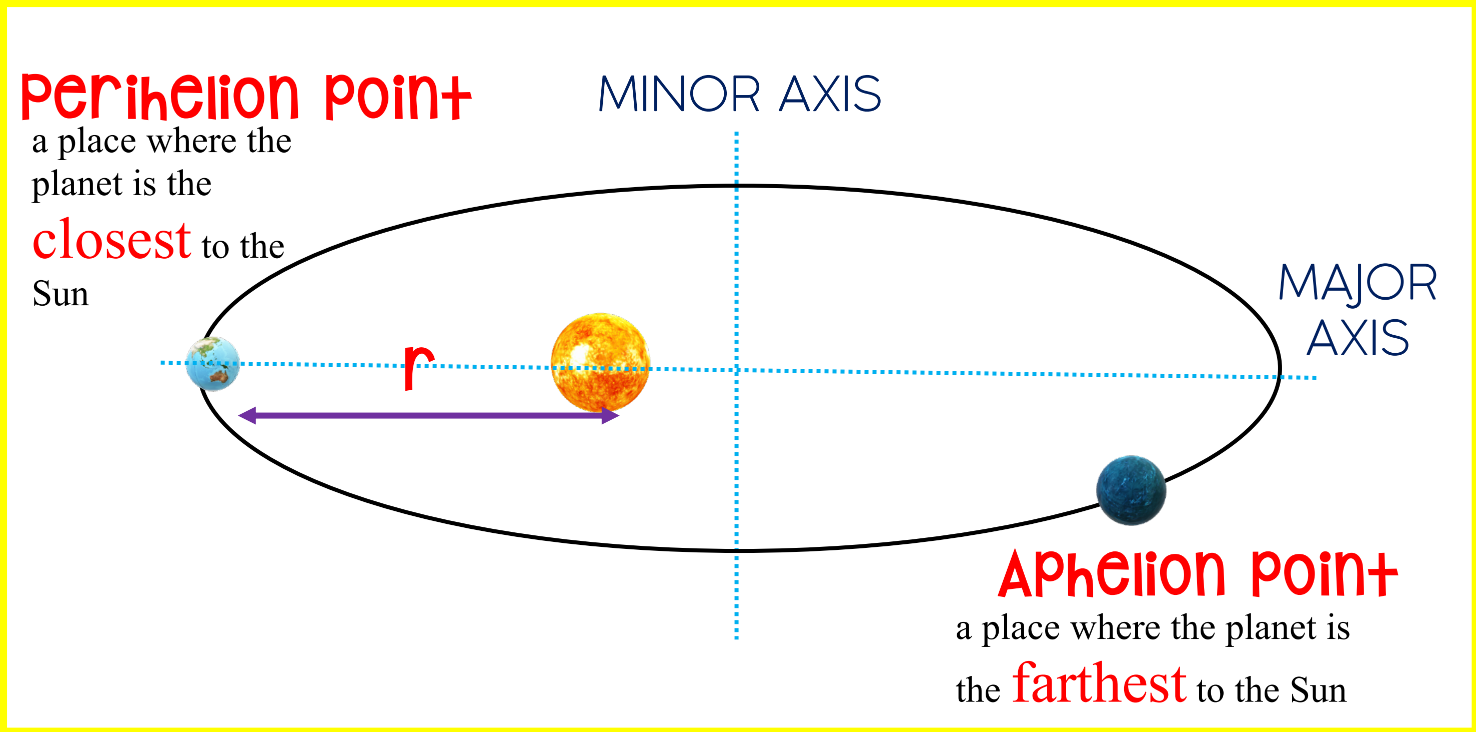
Harvey Mackay

3.2 KEPLER'S LAW

A. Explain Kepler's Law

KEPLER'S 1

All planets move in elliptical orbits with the sun at one focus



- The planet in Solar system have **elliptical** shaped orbits.
- The Sun always stays on a **focus of the ellipse**.
- The major axis is **longer** than the minor axis.
- Most orbit of planets in the Solar system have major axis and minor axis of almost at the **same** length.
- Planets can be assumed to make **circular** motion around the **Sun**.
- The **radius of orbit** = the average value of the distance between the planet and the Sun.

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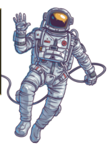
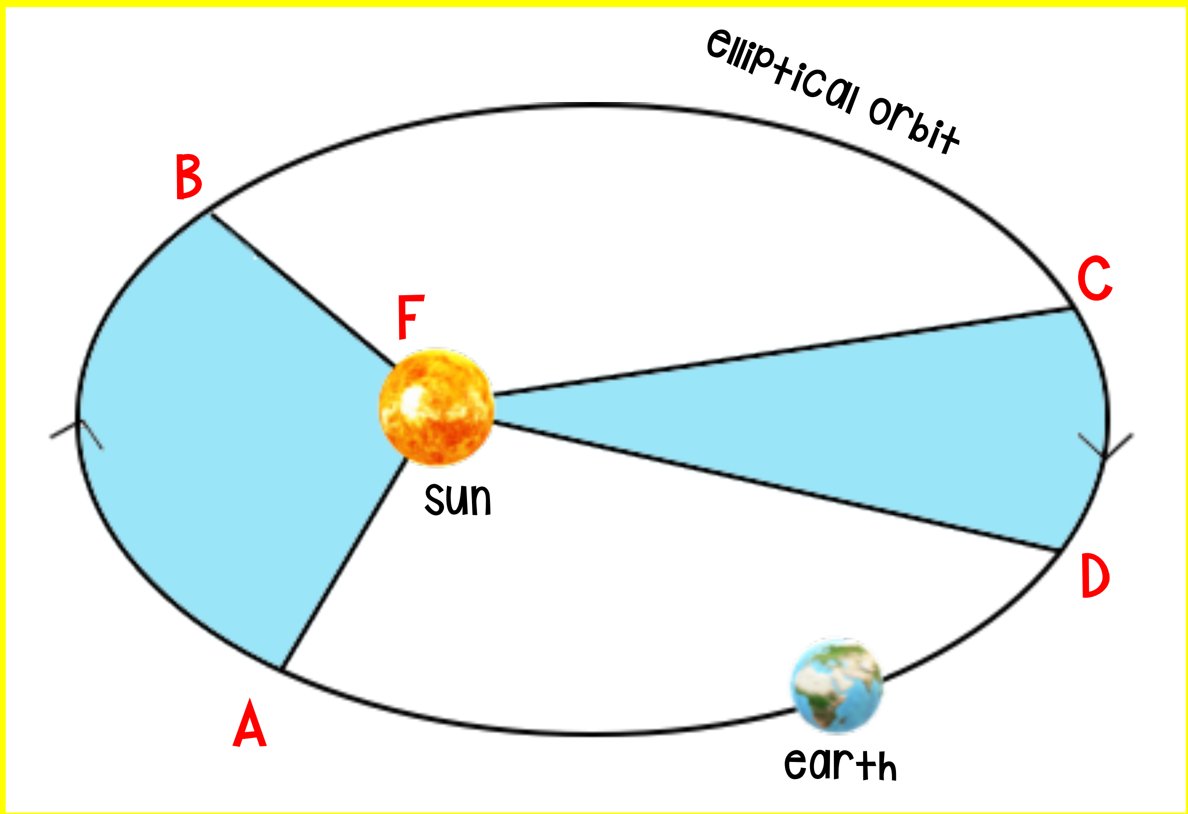


KEPLER'S 2

(Law of Areas)

A line that connects a planet to the sun sweeps out equal areas in equal times



time:		A to B	=	C to D
area:		AFB	=	CFD
distance:		AB	>	CD
linear speed:		A to B	>	C to D

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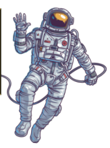


KEPLER'S 3

(Law of Period)

$$T^2 \propto r^3$$

The square of **period** of any planet is **proportional to the cube of the radius** of its orbit

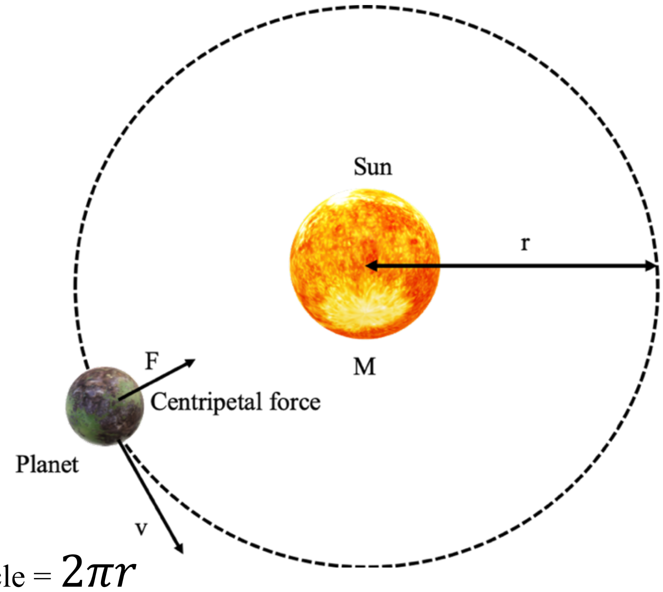
A planet which orbits with a **larger radius** has a **longer orbital period**

Mercury < Venus < Earth < Mars < Jupiter < Saturn < Uranus < Neptune

be amazing

B. Express Kepler's Third Law

M	Mass of the sun
m	Mass of the planet
v	Linear speed of the planet
r	Orbital radius
T	Period of the planet around the sun



Distance travelled by the planet in one complete circle = $2\pi r$

Linear speed of the planet, $v = \dfrac{2\pi r}{T}$

Gravitational force that acts on the planet → $F = \dfrac{Gm\,M}{r^2}$ → (1)

Centripetal force → $F = \dfrac{mv^2}{r}$ → (2)

(1) = (2) → $\dfrac{Gm\,M}{r^2} = \dfrac{mv^2}{r}$ → $\dfrac{GM}{r} = v^2$

replace v with $\dfrac{2\pi r}{T}$ → $\dfrac{GM}{r} = \left(\dfrac{2\pi r}{T}\right)^2$

Express T^2 as formula title → $T^2 = \dfrac{4\pi^2 r^3}{GM}$

From Kepler's Third Law

$$T^2 \propto r^3$$
$$T^2 = kr^3$$

k = constant

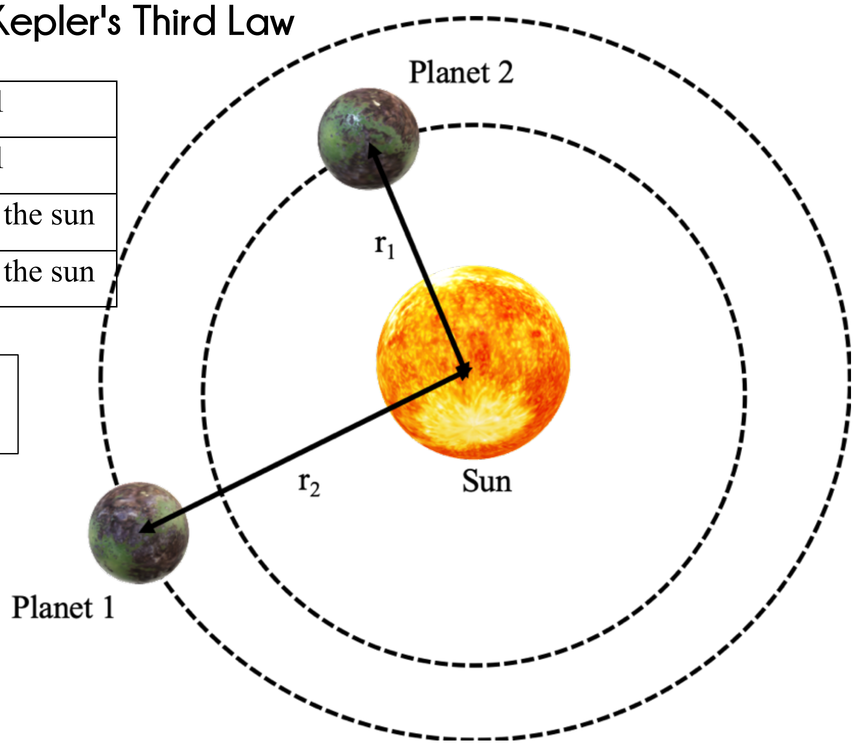
→ Compare with

$$T^2 = \left(\frac{4\pi^2}{GM}\right) r^3$$

so, k → $k = \dfrac{4\pi^2}{GM}$

C. Problem solving using Kepler's Third Law

r_1	Radius of the orbit planet 1
r_2	Radius of the orbit planet 1
T_1	Period of planet 1 orbiting the sun
T_2	Period of planet 1 orbiting the sun



From Kepler's Third Law, can be derived:

↓

$$\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$

1 For planet orbiting the sun,

- r is the distance between centre of the planet and centre of the sun

2 For satellite orbiting the earth,

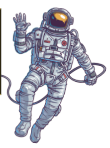
- r is the distance between centre of the earth and centre of the satellite
- r = R + h

R = radius of the earth = 6 370 km

h = height of satellite from the earth

A planet orbiting with a **BIGGER** radius of orbit has a **BIGGER** orbital period.

be amazing



FORMATIVE PRACTICE 3.2 (PAGE: 102 TEXT BOOK)

no 2. Figure 3.32 shows the orbit of a planet around the Sun. Compare the linear speed of the planet at positions *X*, *Y* and *Z*.

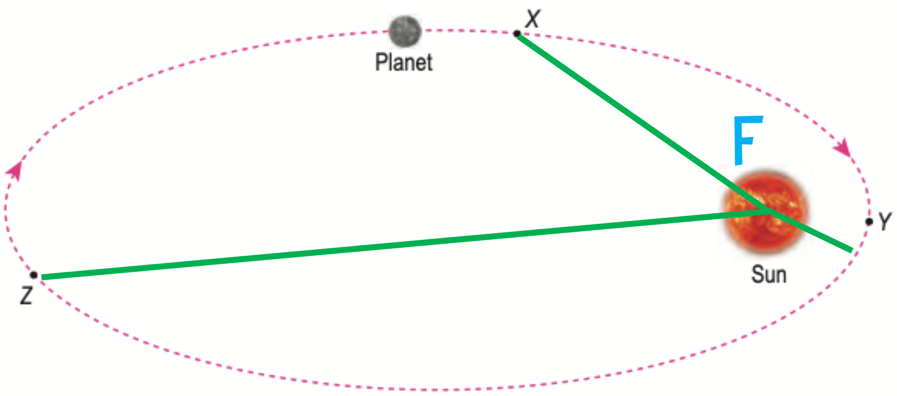


Figure 3.32

linear speed inversely proportional to r

r increase Linear speed decrease

AREA	: ZFX = XFY = YFZ
RADIUS (r)	: Z > X > Y
LINEAR SPEED	: Y > X > Z

no 3. At what height should a satellite be if the satellite is required to orbit the Earth in a period of 24 hours?
[Orbital period of the Moon = 27.3 days, radius of orbit of the Moon = 3.83×10^8 m]

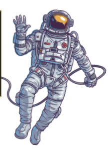
T_1 = 27.3 X 24
= 655.2 hours

$$\frac{T_1^2}{T_2^2} = \frac{r_1^3}{r_2^3}$$

$$\frac{(655.2)^2}{(24)^2} = \frac{(3.83\ x\ 10^8)^3}{(6.37\ x\ 10^6\ +\ h)^3}$$

$h = 3.6 \text{ x } 10^7$ m

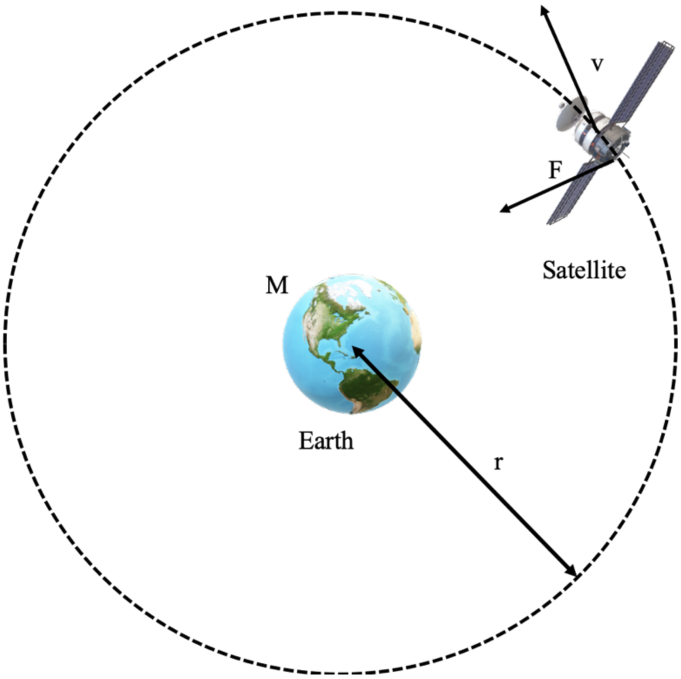
be amazing



3.3 MAN-MADE SATELLITE

A. Derived linear speed formula of a satellite

M	Mass of the earth
m	Mass of the satellite
v	Linear speed of the planet
r	Orbital radius



Gravitational force between satellite and the earth, F_1 → $$F_1 = \frac{Gm\,M}{r^2}$$

Centripetal force, F_2 → $$F_2 = \frac{mv^2}{r}$$

$F_1 = F_2$ →

$$\frac{Gm\,M}{r^2} = \frac{mv^2}{r}$$

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

$$v = \sqrt{\frac{GM}{r}}$$

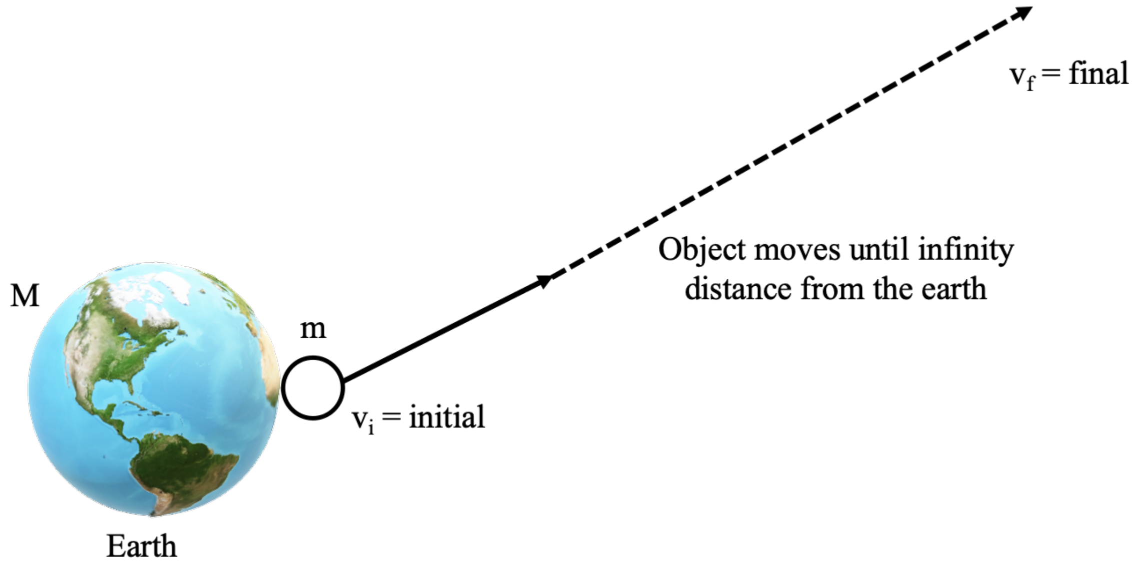
Important notes

1. Escape velocity, v of an object **does not** depend on the **mass of an object**, but it depends on

- ✓ mass of the Earth, M
- ✓ distance of object from the center of the Earth

2. The Earth has large mass, the escape velocity of an object from the Earth must be at high value which is 11 200 ms^{-1} or 40 300 km h^{-1}.

B. Escape velocity

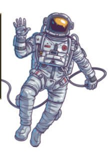


Escape velocity: **minimum velocity** required by an object on the Earth's surface to overcome the **gravitational force** and escape to outer space

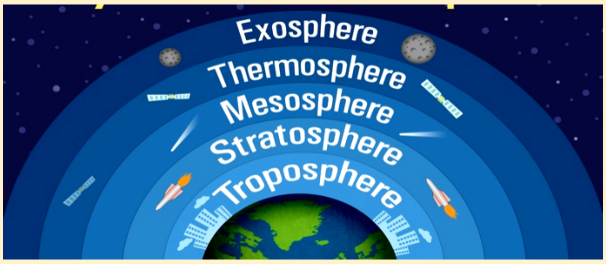
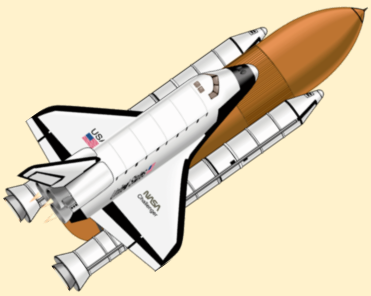
The escape velocity is achieved when the minimum kinetic energy supplied to the object **exceeds** the gravitational potential energy.

Gravitational potential energy = Minimum kinetic energy

$$v_{escape} = \sqrt{\frac{2GM}{R}}$$



The benefits and implication of Escape velocity

benefit and implication	explanation
Earth can maintain a layer of atmosphere around it. 	The linear speed of air molecules is 500 ms^{-1} which is lower than escape velocity of the Earth that is 11 200 ms^{-1}. Air cannot escape from the Earth into outer space
Commercial aircraft or fighter jet can fly high without escaping into outer space 	Commercial aircrafts or fighter jets has linear speed of 250 ms^{-1} while fighter jets has linear speed of up to 2 200 ms^{-1}. As both their linear speed is lower than escape velocity from the Earth, they can fly high without escaping into outer space.
Rocket can be launched at escape velocity to send spacecraft to outer space 	When a of rocket is supplied with large quantities of fuel to produce high thrust, the rocket can achieve escape velocity and enable to send the spacecraft to outer space.

HOW DO PLANETS LOSE THEIR ATMOSPHERES?

The **hotter** the atmosphere, the **more** molecule can escape.

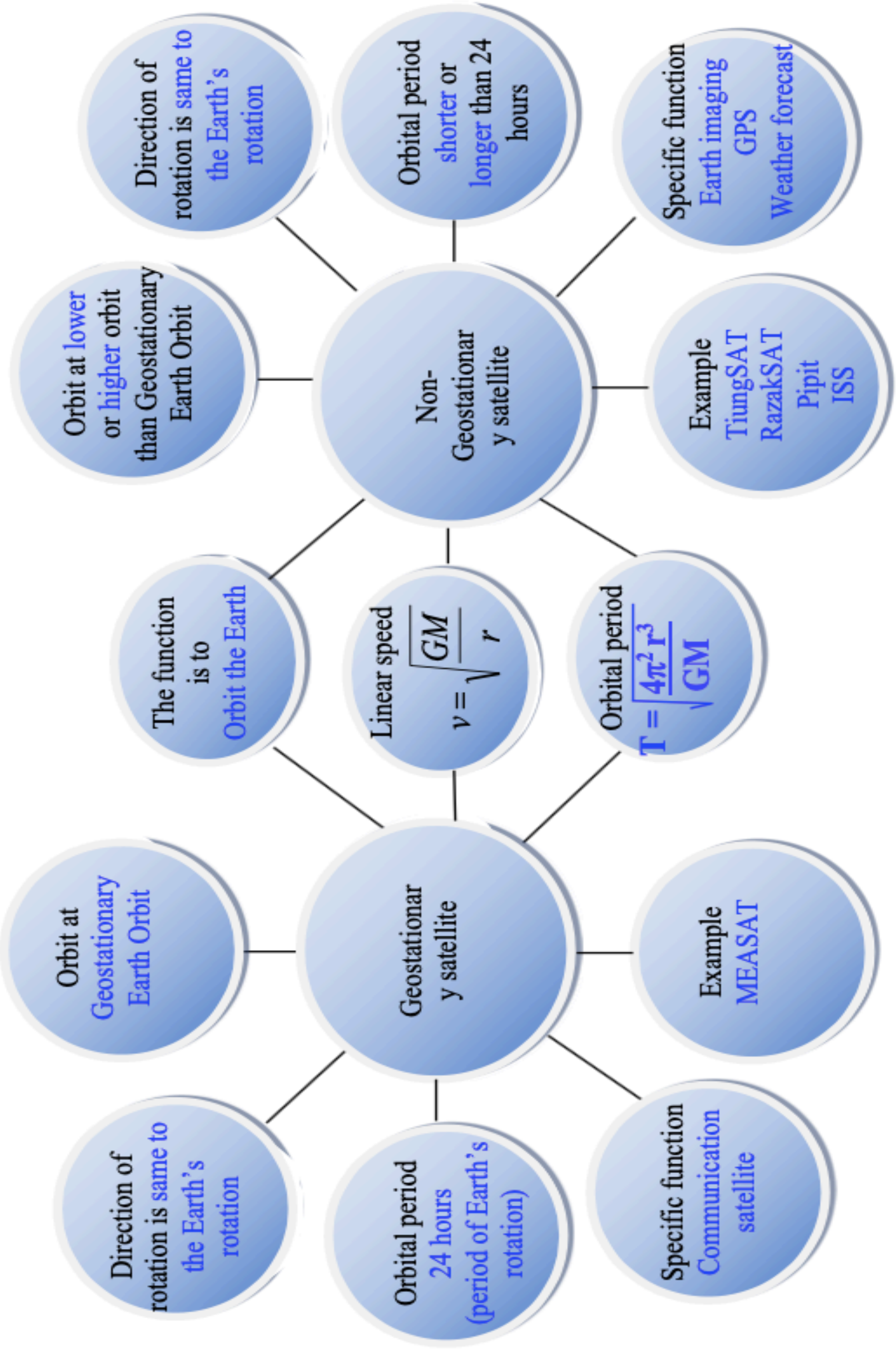
The **smaller** the object, the **lower** the gravity.

So, **escape velocity** is **lower** and it is **harder** to retain an atmosphere (esp.; Moon and Mercury)

The atmosphere loses to the outer space.

be amazing

Communicate on geostationary and non-geostationary satellites.



FORMATIVE PRACTICE 3.3
(PAGE: 110 TEXT BOOK)

no 2. What factors determine the linear speed of satellites orbiting the Earth?

$$v = \sqrt{\frac{GM}{r}}$$

mass of earth
orbital radius

no 3. State two factors which influence the value of escape velocity from a planet.

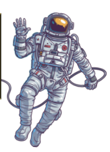
$$v_{escape} = \sqrt{\frac{2GM}{R}}$$

mass of planet
radius of planet

no 4. Discuss whether escape velocity from the Earth for spacecraft X of mass 1 500 kg is different from spacecraft Y of mass 2 000 kg.

Both X and Y spacecraft require the **same velocity**.

be amazing



no 5.

Proba-1 satellite orbits the Earth at a height of 700 km. What is the linear speed of this satellite?

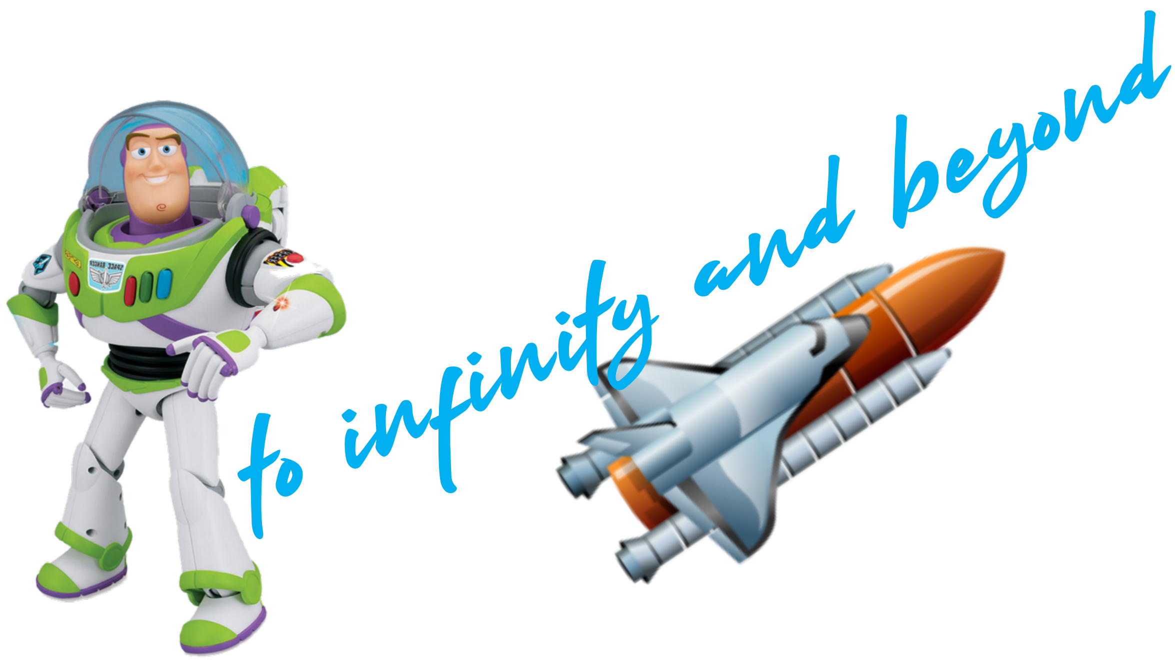
[G = 6.67×10^{-11} N m^2 kg^{-2},
mass of the Earth = 5.97×10^{24} kg,
radius of the Earth = 6.37×10^{6} m]

$$v = \sqrt{\frac{GM}{r}}$$

$$v = \sqrt{\frac{GM}{(R+h)}}$$

$$v = \sqrt{\frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24}}{(6.37 \times 10^{6} + 700 \times 10^{3})}}$$

$$v = 7.49 \times 10^{3} \text{ m s}^{-1}$$



EXERCISES:

1. PL3 (a) Communications satellites orbit the Earth at a height of 36 000 km.
How far is this from the centre of the Earth?
Given: Radius of the Earth = 6.4 x 10^6 m

r = 36 000 x 10^3 + 6.4 x 10^6
= 4.24 x 10^7 m

PL3 (b) If such a satellite has a mass of 250 kg, what is the force of attraction on it from the Earth?
Given: G = 6.67 x 10^{-11} N m^2 kg^{-2}
Mass of the Earth = 6.0 x 10^{24} kg

$$F = \frac{(6.67 \, x \, 10^{-11})(250)(6.0 \, x \, 10^{24})}{(4.24 \, x \, 10^{7})^2}$$

F = 55.65 N

2. PL3 Two spherical objects have masses of 200 kg and 500 kg. Their centres are separated by a distance of 25 m. Find the gravitational attraction between them.

Gravitational attraction = gravitational force

$$F = \frac{(6.67 \, x \, 10^{-11})(200)(500)}{(25)^2}$$

F = 1.0672 x 10^{-8} N

3. Diagram 1.1 shows an athlete spinning a 7 kg hammer in a sport.
Diagram 1.2 shows top view of the spinning.

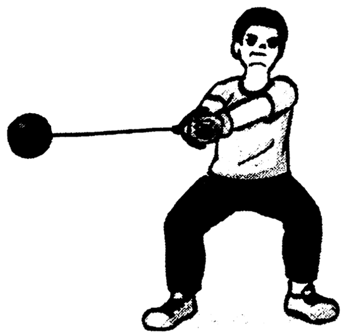


Diagram 1.1

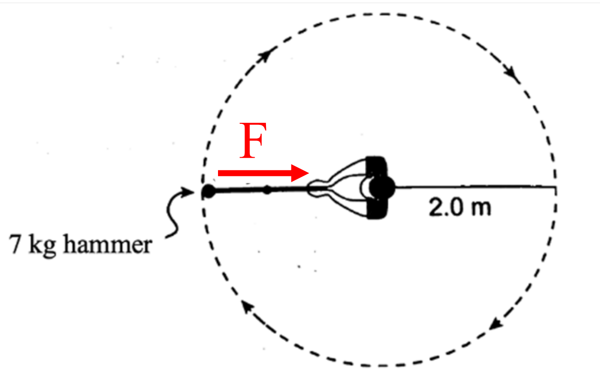


Diagram 1.2

(a) Based on Diagram 1.2,

PL1 (i) Name the force that make the hammer move in circle path.
Tick (√) the correct answer in the box provided.

Gravitational force		Centripetal force	√

[1 mark]

PL1 (ii) Mark on Diagram 1.2 the direction of force, F that stated in (a)(i).

[1 mark]

(b) If the hammer moves with constant velocity 25 ms^{-1}, calculate the force stated in (a)(i)
PL3 that acts on the hammer.

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

$$F = \frac{7(25)^2}{2}$$

= 21875.5 N

[2 marks]

(c) How does the movement of the hammer when the athlete release the string?
PL2 Move in straight line in direction of the tangent at point released

[1 mark]

TOTAL 5 marks

4. Diagram 2 shows an object A on the surface of the earth and object B at height h from the earth. R is the radius of earth, r is the distance of the object from the centre of the earth and

PL4 M is the mass of the earth.

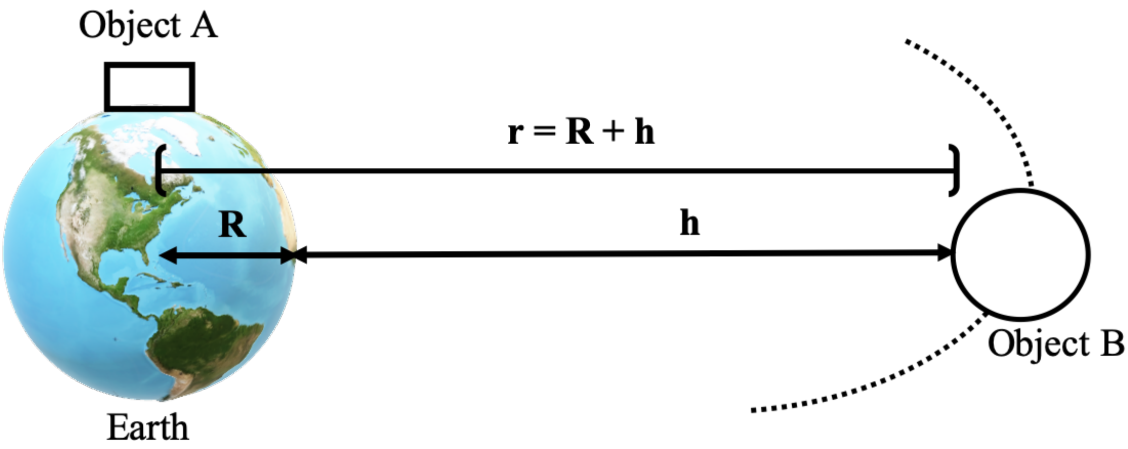


Diagram 2

(a) Based on the information above, derive the gravitational acceleration in terms of G, M, R and h for:

(i) Object A

r = R

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

[1 mark]

(ii) Object B

r = R + h

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

[2 marks]

(b) Given the mass of the earth 5.97 x 10^{24} kg, radius of earth is 6.37 x 10^{6} m, universal gravitational constant is 6.67 x 10^{-11} N m^2 kg^{-2}.

Calculate:

(i) the value of gravitational acceleration of object A

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

$$g = \frac{6.6 x \ 10^{-11} \ (5.97 x \ 10^{24})}{(6.37 x \ 10^{6})^2}$$

g = 9.81 N kg^{-1}

[2 marks]

(ii) the gravitational acceleration of object B at 345 km height from the surface of the earth.

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

$$g = \frac{6.6\ x\ 10^{-11}\ (5.97\ x\ 10^{24})}{(6.37\ x\ 10^{6}\ +\ 345\ x\ 10^{3})^2}$$

$g = 8.83\ N\ kg^{-1}$

[2 marks]

TOTAL 7 marks

5. Diagram 3 shows a satellite with mass 102 kg orbiting the earth at 3500 km height from the surface of the earth. Gravitational acceleration at the surface of the earth is 9.81 m s^{-2} and the radius of the earth is 6370 km.

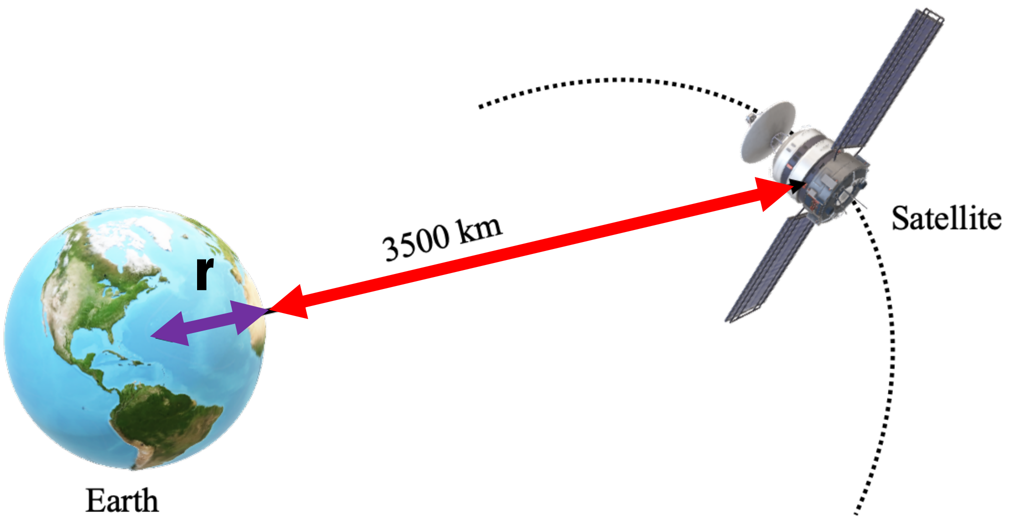


Diagram 3

(a) What is centripetal force?
PL1 A force that makes body to follow a circular path with direction always towards the center of curvature.

[1 mark]

(b) What is the orbital radius of the satellite?
PL2
r = 3 500 + 6 370
= 9 870 km

[1 mark]

(c) PL3 What is the gravitational acceleration at the position of the satellite?

- At the surface of earth

$g_b = 9.81 \text{ m s}^{-2}$

$$g_b = \frac{GM}{(6\ 370\ x\ 10^3)^2} \text{ .... } (1)$$

- At the surface of satellite

$$g_s = \frac{GM}{(9\ 870\ x\ 10^3)^2} \text{ .... } (2)$$

(1) = (2)

$g_s\,(9\ 870 \text{ x } 10^3)^2 = g_b\,(6\ 370 \text{ x } 10^3)^2$

$$g_s = \frac{9.81\ (6\ 370\ x\ 10^3)^2}{(9\ 870\ x\ 10^3)^2}$$

$= 4.086 \text{ m s}^{-2}$

[4 marks]

(d) PL2 What will happen to the gravitational acceleration if the height decrease? Give a reason.

Increases

Radius of the orbit decreases

[2 marks]

TOTAL 8 marks

6. Venus and Mars are planets in our Solar System. The acceleration due gravity and the escape velocity in both planets are different.
Given $G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}
Table 1 shows the mass and radius of both planets.

Planet	Mass, m (kg)	Radius, r (m)
Venus	4.87×10^{24}	6.05×10^{6}
Mars	6.42×10^{23}	3.40×10^{6}

Table 1

(a) Calculate:

PL3 (i) Acceleration due to gravity at Venus and Mars

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

Venus: $g = \frac{(6.67 \times 10^{-11})(4.87 \times 10^{24})}{(6.05 \times 10^{6})^2} = 8.87$ m s^{-2}

Mars: $g = \frac{(6.67 \times 10^{-11})(6.42 \times 10^{23})}{(3.40 \times 10^{6})^2} = 3.70$ m s^{-2}

[4 marks]

PL3 (ii) Escape velocity at Venus and Mars

$$v_{escape} = \sqrt{\frac{2GM}{R}}$$

Escape velocity at Venus = $\sqrt{\frac{2(6.67 \times 10^{-11})(4.87 \times 10^{24})}{6.05 \times 10^{6}}} = 1.04 \times 10^4$ m s^{-1}

Escape velocity at Mars = $\sqrt{\frac{2(6.67 \times 10^{-11})(6.42 \times 10^{23})}{3.40 \times 10^{6}}} = 5.02 \times 10^3$ m s^{-1}

[4 marks]

(b) Compare the value of acceleration due to gravity and escape velocity for both planets
PL2 The value of acceleration due to gravity and escape velocity at Mars $<$ at Venus

[1 mark]

(c) Explain your answer in 6(b)
PL2 Mars have smaller mass

[1 mark]

TOTAL 10 marks

7. A satellite is orbiting the earth at height 250 km from the surface of the earth. the mass of the satellite is 100 kg and the radius of the earth is 6.4×10^3 km.

(a) PL1 What is the radius of the satellite?

r = 250 + 6 400 = 6 650 km

[1 mark]

(b) PL2 What is the gravity of the satellite if the gravity at the surface of the earth is 10 N kg^{-1}? Give a reason.

Decrease

$g \propto \frac{1}{r^2}$ on the surface of the earth

[2 marks]

(c) PL3 What is the force acting on the satellite while orbiting the earth in a certain orbit and what is the value?

Centripetal force = Weight of the satellite

= mg = 100 x 10 = 1 000 N

[2 marks]

(d) PL3 What is the linear speed of the satellite?

Centripetal force = Weight of the satellite

$$\frac{mv^2}{R} = mg$$

$$v = \sqrt{gR} = \sqrt{10\ (6\ 650)} = 257.88 \text{ m s}^{-1}$$

[2 marks]

TOTAL 7 marks

8. State the difference between Geostationary and Non-geostationary satellites.
PL4

Satellite Geostationary	**Satellite Non-geostationary**
A satellite that moves around the earth at certain height (**Geostationary Earth Orbit**)	A satellite that moves around the earth at **changing orbit height**
Orbit period = 24 hours same with earth	Orbit period can be more than or less 24 hours
Direction of rotation = Direction of rotation of the earth	Direction of rotation $\neq$ Direction of rotation of the earth
Always seen to be stationary by an observer at the surface of the earth	Always seen to be changing position by an observer at the surface of the earth
Its orbit always above the Earth Equator	Its orbit must not always above the Earth Equator
It is used to communication throughout the whole world	It is used to get the information for weather broadcasting, GPS and imaging the earth surface

[10 marks]

9. PL5 You are an engineer whom is assigned to determine which satellite that can be used as GOES 'Geostationary Environment Satellite'. By using your knowledge on the characteristic of Geostationary satellite, choose the most suitable satellite to be used as GOES. Give justification for your choice.

Satellite	Direction of satellite rotation	Orbit period	Position of the satellite
A	In the opposite direction of the Earth orbit	24 hours	Orbiting from pole to pole
B	In the direction of the Earth orbit	24 hours	Orbiting above the Equator
C	In the opposite direction of the Earth orbit	12 hours	Orbiting from pole to pole
D	In the direction of the Earth orbit	12 hours	Orbiting above the Equator

Characteristic	Reason
In the direction of the Earth orbit	Satellite will always at the same position as observer by an observer on the surface of the earth
Orbit period = more	same with the period of the earth rotation
Orbiting above the Equator	The position allows the satellite to observe weather and other phenomenon that vary on short time scale
Choose B	In the direction of the Earth orbit Orbit period = 24 hours Orbiting above the Equator

[8 marks]

PL2 State one other use of Geostationary satellite. Give one example of the satellite stated.

Used in telecommunication.

MEASAT

[2 marks]

TOTAL 10 marks

Learn from yesterday
Live for today
Hope for tomorrow

The important thing is not to stop questioning

Training our mind to think
because

The Imagination Is More Than Knowledge

3.1 NEWTON'S UNIVERSAL LAW OF GRAVITATION

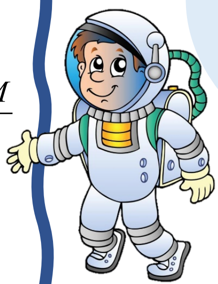
Physics Enrichment

Gravitational force, $F = \frac{Gm_1 m_2}{r^2}$

Gravitational acceleration, $g = \frac{GM}{r^2}$

Centripetal force, $F = \frac{mv^2}{r}$

Centripetal acceleration, $a = \frac{v^2}{r}$



ANSWER

SKILL: CALCULATION

1 Diagram 1 shows Ali stands 4.5 m away from his cat. The mass of Ali and the mass of the cat is 52 kg and 4.0 kg respectively. Calculate the attraction force between Ali and his cat.

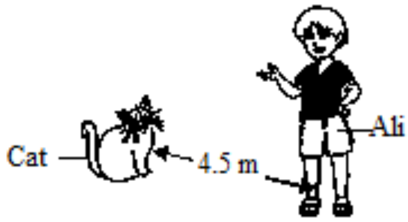


Diagram 1

Calculate the gravitational force between Ali and his cat.

$m_1 = 52$ kg
$m_2 = 4$ kg
$r = 4.5$ m
$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

$$F = \frac{G m_1 m_2}{r^2}$$

$$= \frac{6.67 \times 10^{-11} \times 52 \times 4}{(4.5)^2}$$ √1

= 6.85×10^{-10} N √2 with unit

[2 marks]

2 A satellite of mass 650 kg orbit about the Earth at an altitude of 350 km above Earth'. Calculate the force of attraction between the satellite and the Earth.
[G = 6.67×10^{-11} N m^2 kg^{-2}, radius of the Earth, R = 6 400 km , mass of the Earth, M = 5.97×10^{24} kg]

$m_1 = 650$ kg
$m_2 = 5.97 \times 10^{24}$ kg
$r = (6\,400 + 350) \times 10^3$ m
$G = 6.67 \times 10^{-11}$ N m^2 kg^{-2}

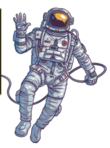
$$F = \frac{G m_1 m_2}{r^2}$$

$$= \frac{6.67 \times 10^{-11} \times 650 \times 5.97 \times 10^{24}}{[(6400 + 350) \times 10^3]^2}$$ √1

= 5.68×10^3 N √2 with unit

[2 marks]

be amazing



3 A coin of mass 0.0025 kg placed 0.3 m from the center of a rotating, horizontal turntable with speed 0.5 m s^{-1}. Calculate

(a) the centripetal force needed to keep it moving in the circle

m = 0.0025 kg
v = 0.5 ms^{-1}
r = 0.3 m

$$F = \frac{mv^2}{r} = \frac{0.0025x(0.5)^2}{0.3} = 2.08x10^{-3}\ N$$

√1 √2 with unit

[2 marks]

(b) the centripetal acceleration.

$$a = \frac{v^2}{r} = \frac{(0.5)^2}{0.3} = 0.83\ m\ s^{-2}$$

√1 √2 with unit

[2 marks]

4 The frictional force between the wheels and the surface of the road is 6 480 N , when the car moves in a roundabout of radius 50 m. The mass of the car is 1000 kg. Calculate the linear speed of the car.

m = 1000 kg
F = 6 480 N
r = 50 m

$$v = \sqrt{\frac{Fr}{m}} = \sqrt{\frac{6480\ x50}{1000}} = 18\ m\ s^{-1}$$

√1 √2 with unit

[2 marks]

5 A bucket is tied to a string and spun in a horizontal circle with speed 20 m s^{-1} produced a tension 450 N in the string. Calculate the tension in the string when the speed of bucket is 30 m s^{-1}.

F_1 = 450 N
v_1 = 20 ms^{-1}
v_2 =30 ms^{-1}

$$\frac{F_1}{v_1^2} = \frac{F_2}{v_2^2}$$

$$\frac{450}{20^2} = \frac{F_2}{30^2}$$

√1

F_2 = 1012.5 N √2 with unit

[2 marks]

6 Diagram 2 shows a wall clock. The length of the minute hand is 0.2 m and has mass of 0.15 kg.

Diagram 2

Calculate,

(a) The linear speed of the minute hand of the clock.

> **Formula of Linear speed, v**
>
> Derive from formula of
>
> Speed = $\frac{\text{Distance}}{\text{Time}}$
>
> Distance = Distance travelled by a planet to make one complete orbit around the Earth
> = Perimeter of orbit = $2\pi r$
>
> Time (T) = Period of revolution of the Moon around the Earth
>
> Linear speed, $v = \frac{2\pi r}{T}$
>
> *#Refer Figure 3.20 in Text book*

√1

$$v = \frac{2\pi r}{T} = \frac{2\pi(0.2)}{60} = 0.021\ \text{m s}^{-1}$$

√2 with unit

[2 marks]

(b) The centripetal force and centripetal acceleration experinces by the minute hand of the clock.

√1

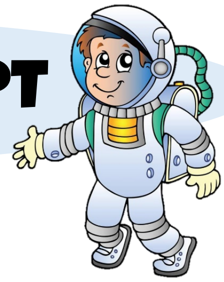
$$F = \frac{mv^2}{r} = \frac{(0.15)(0.021)^2}{0.2} = 0.00033\ \text{N}$$

√2 with unit

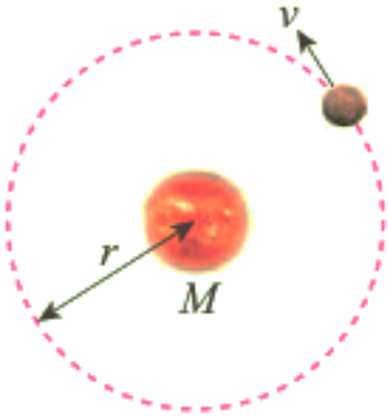
$$a = \frac{v^2}{r} = \frac{(0.021)^2}{0.2} = 0.0022\ \text{ms}^{-2}$$

√3 with unit

[3 marks]



1. Diagram 1 shows planet Mars orbits the Sun in a circular motion with orbital period, *T*.



m = Mass of the Mars
M = Mass of the Sun
r = radius of orbit of Mars
v = linear speed of Mars

Diagram 1

(a) For planet Mars, write the formula for:

(i) gravitational force in terms of *m*, *M* and *r*

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

(ii) centripetal force in terms of *m*, *v* and *r*

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

(iii) linear speed in terms of *r* and *T*

$$v = \frac{2\pi r}{T}$$

(b) Derive an expression for the mass of the Sun in terms of *r* and *T* by using the three formulae in (a).

Newton's Universal Law of Gravitation → $F = \frac{GmM}{r^2}$ → (1)

Centripetal force formula → $F = \frac{mv^2}{r}$ → (2)

(1) = (2) → $\frac{GmM}{r^2} = \frac{mv^2}{r}$ → $\frac{GM}{r} = v^2$

replace v with $\frac{2\pi r}{T}$ → $\frac{GM}{r} = \left(\frac{2\pi r}{T}\right)^2$ → $M = \frac{4\pi^2 r^3}{GT^2}$

Where ;

r = **Radius of the orbit of any planet or satellite**

T = **Period of revolution**

(c) Radius of orbit of Mars is $r = 2.28 \times 10^{11}$ m and its orbital period is $T = 687$ days.
Calculate the mass of the Sun.

1 day = 24 hours
1 hour = 3600 s
∴ T = 687 days = (687 x 24 x 3600)s

$$M = \frac{4\pi^2 (2.28 \times 10^{11})^3}{(6.67 \times 10^{-11})(687 \times 24 \times 3600)^2}$$

$M = 1.99 \times 10^{30}$ kg

2. A satellite orbits the Earth with radius, r and orbital period, T.

(a) Write down the linear speed of the satellite in terms of r and T.

$$v = \frac{2\pi r}{T}$$

(b) Use other suitable formulae to establish the formula for linear speed of the satellite in terms of r and M. M is the mass of the Earth.

Gravitational force between satellite and the earth, F_1 → $F_1 = \frac{GmM}{r^2}$

Centripetal force, F_2 → $F_2 = \frac{mv^2}{r}$

$F_1 = F_2$ →

$$\frac{GmM}{r^2} = \frac{mv^2}{r}$$

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

$$v = \sqrt{\frac{GM}{r}}$$

(c) Why does the linear speed of a satellite orbiting the Earth not depend on the mass of the satellite?

- Satellites fall freely around the Earth with a central acceleration = acceleration of gravity = $a = \frac{v^2}{r}$
- acceleration of gravity does not depend on the mass of the object

I'M NOT HERE TO BE AVERAGE I'M HERE TO BE AWESOME

be amazing