

Term 1

Quick Revision Guide

Examination 2023-24

PHYSICS

Chapter -1 Motion in Two Dimensions

Slides 1-15

Chapter -2 Gravitation and Kepler's Laws

Slides 16-26

Chapter -3 Rotational Motion

Slides 27-48

Chapter – 4 Work and Energy

Slides 49 -

Number of MCQ عدد الأسئلة الموضوعية	15
Marks of MCQ درجة الأسئلة الموضوعية	4
Number of FRQ عدد الأسئلة المقالية	5
Marks per FRQ الدرجات للأسئلة المقالية	(5-10)
Type of All Questions نوع كافة الأسئلة	الأسئلة الموضوعية / MCQ
	الأسئلة المقالية / FRQ
Maximum Overall Grade الدرجة القصوى الممكنة	100
Exam Duration - مدة الامتحان	150 minutes
Mode of Implementation - طريقة التطبيق	SwiftAssess & Paper-Based
Calculator	Allowed
الآلة الحاسبة	مسموحة

LESSONS OVERVIEW

Chapter 1-Motion in two dimensions

Section 2:Circular motion

Chapter 2 -Gravitation

Section 1-Planetary motion and Gravitation

Section 2-Using the law of universal gravitation.

Chapter 3-Rotational motion

Section 1 -Describing Rotational Motion

Section 2-Rotational Dynamics

Section3-Equilibrium

Chapter 4-Work ,Energy and Machines

Section1-Work and Energy

LESSON 2

	1	Demonstrate that the velocity vector at any time is tangent to the circular path for an object in uniform circular motion.	figure 9	12
	2	Define the centripetal/central force.	as mentioned in the book question 18	13 15
	3	Relate the centripetal acceleration to the object's speed and the radius of the circular path ($a_c = v^2/r$).	questions 56,57	23
	17	Relate the centripetal acceleration and the speed of an object in uniform circular motion to its period of revolution and use this relation to find unknown parameters ($v = 2\pi r/T$, $a_c = 4\pi^2 r/T^2$).	example 3	14

Lesson-2

Circular motion

Uniform Circular Motion

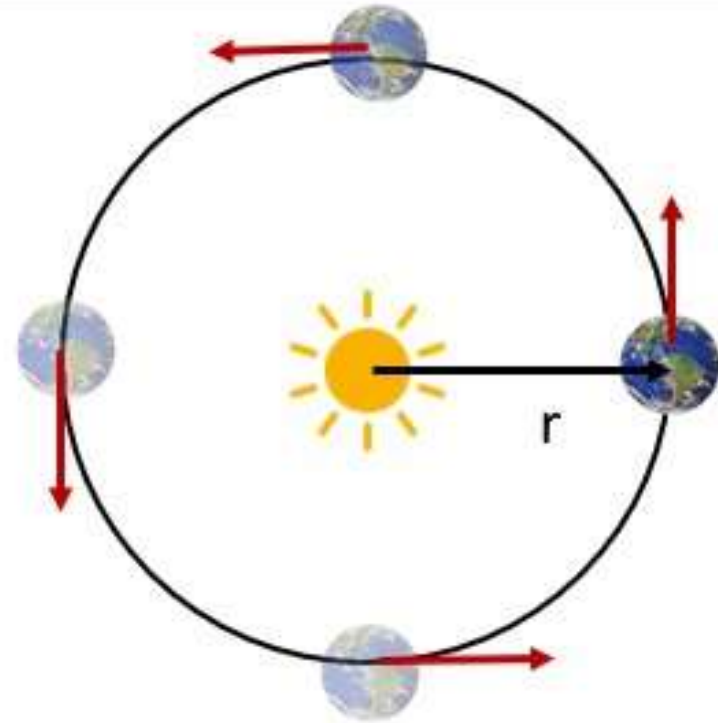
Movement of an object at **constant speed** around a circle with fixed axis is called uniform circular motion.

Example : Motion of Earth around Sun

Time Period (T)

Time taken to complete one revolution in uniform circular motion is called Time Period T

Example : Time Period of Earth around Sun is 365 days



$$\text{Speed of UCM, } v = \frac{2\pi r}{T}$$

$$\text{Avg. Velocity of UCM, } v = \frac{\text{displacement}}{\text{time}}$$

$$v = \frac{\Delta r}{\Delta t}$$

Velocity Vectors

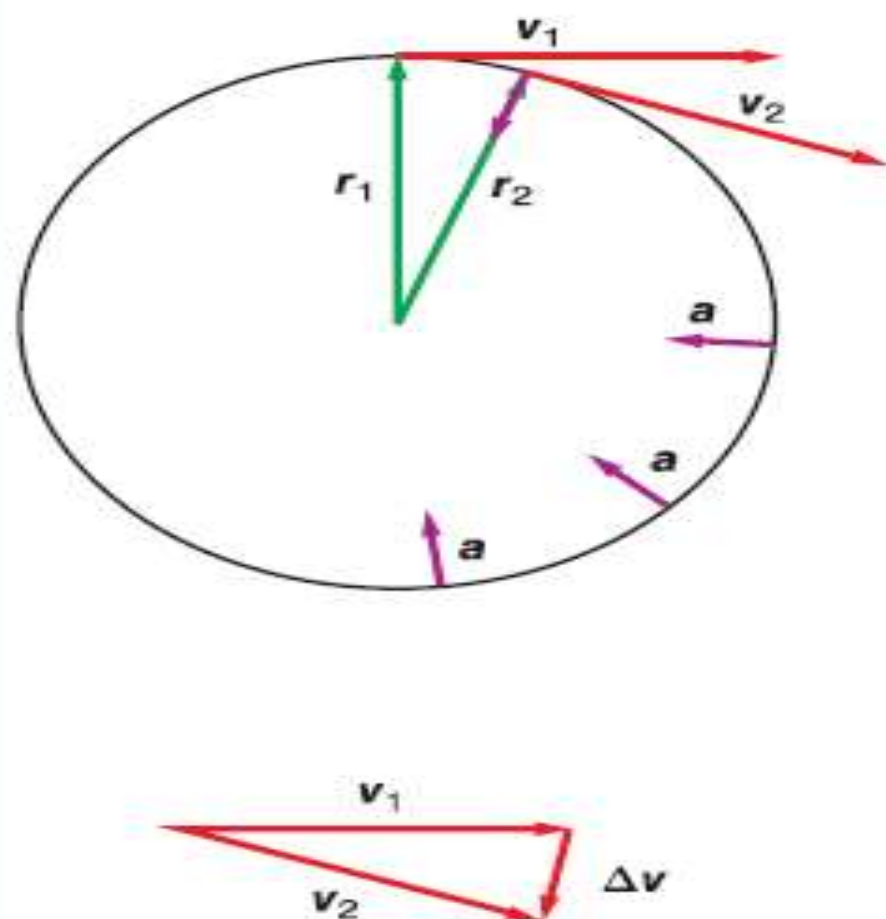
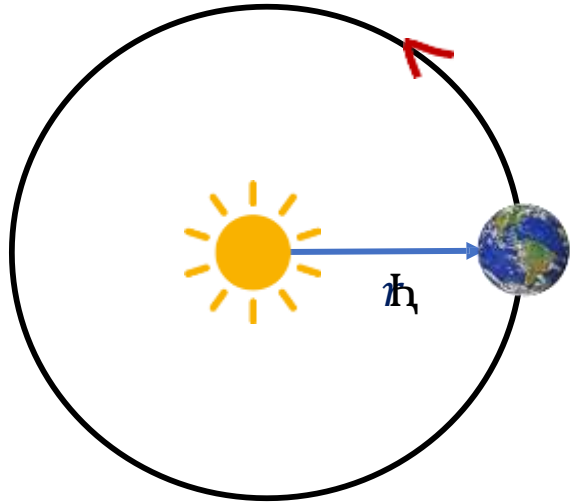


Figure 9 The acceleration of an object in uniform circular motion is the change in velocity divided by the time interval. The direction of centripetal acceleration is always toward the center of the circle.

- 3- The movement of an object at a **constant speed** around a **circular** radius is known as:
- a. uniform horizontal motion.
 - b. uniform vertical motion.
 - c. uniform linear motion.
 - d. uniform circular motion.

Speed of Uniform Circular Motion



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

v – speed of UCM
 r – radius of the orbit
 T – time period

Concept Question

1. A pilot circles above an airport in preparation for landing. It takes 10 minutes to complete circular revolution for a 5 km radius of the flight path. What is the plane's speed ?

Given,
 $T = 10 \text{ min} = 600 \text{ s}$
 $r = 5 \text{ km} = 5000 \text{ m}$

Plane's speed,
 $v = ?$

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

$$v = \frac{2 \times 3.14 \times 5000}{600}$$

$$v = 52.33 \text{ m/s}$$

2. A Hurricane wind has a speed of 18.17 m/s on its outer edge, which makes one rotation every day. What is the diameter of the hurricane ?

Given,
 $T = 1 \text{ day} = 24 \times 60 \times 60 = 86400 \text{ s}$
 $v = 18.17 \text{ m/s}$

Hurricane's radius,
 $r = ?$

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

$$r = \frac{vT}{2\pi} = \frac{18.17 \times 86400}{6.28}$$

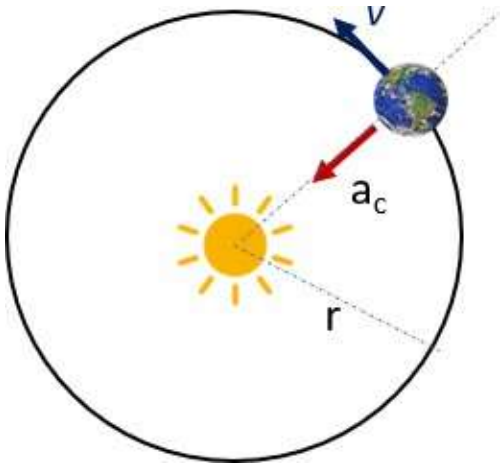
$$r = 249982 \text{ m} = 250 \text{ km}$$

$$d = 2r = 500 \text{ km}$$

Centripetal Acceleration (a_c)

The acceleration of an object in Uniform Circular Motion is called Centripetal Acceleration (a_c)

It points **to the center** of the circle.



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

a_c – centripetal acceleration
 v – speed of UCM
 r – radius of the orbit

Concept Question

1. A runner moving at a speed of 8.8 m/s rounds a bend with radius of 25 m. **What is the centripetal acceleration** of the runner?

Given,
 $v = 8.8 \text{ m/s}$
 $r = 25 \text{ m}$

Centripetal
acceleration,
 $a_c = ?$

$$a_c = \frac{v^2}{r} \quad a_c = \frac{8.82}{25}$$

$$a_c = 3.09 \text{ m/s}^2$$

2. An airplane travelling at 201 m/s makes a turn. **What is the smallest radius** of the circular path(in kilometers) the pilot can make and keep the centripetal acceleration under 5.0 m/s²?

Given,
 $v = 201 \text{ m/s}$
 $a_c = 5 \text{ m/s}^2$

Radius,
 $r = ?$

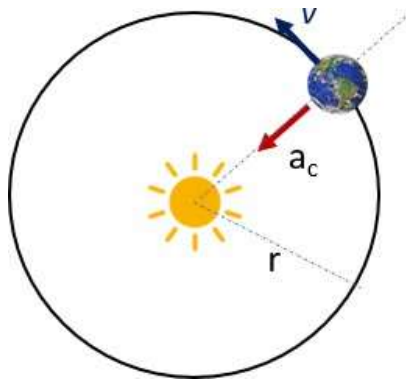
$$a_c = \frac{v^2}{r}$$

$$r = \frac{v^2}{a_c} = \frac{201^2}{5}$$

$$r = 8080 \text{ m} = 8.080 \text{ km}$$

Centripetal Acceleration (a_c) and Time period

- Time period is the time taken to make a complete circle (T)
- Centripetal acceleration decreases with increase in time period



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

a_c – centripetal acceleration

r – radius of the orbit

T – time period of orbit

EOT QUESTION 17

1. A 13 g rubber stopper is attached to 0.93 m string. The stopper is swung in a horizontal circle, making one revolution in 1.18 s. **What is the centripetal acceleration?**

Given,

$$T = 1.18 \text{ s}$$

$$r = 0.93 \text{ m}$$

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

$$a_c = \frac{4 \times 3.142 \times 0.93}{1.18^2}$$

Centripetal
acceleration,
 $a_c = ?$

$$a_c = 26 \text{ m/s}^2$$

2. A 16 g ball at the end of a 1.4 m string is swung in a horizontal circle. It revolves once every 1.09 s. **What is the centripetal acceleration?**

Given,

$$T = 1.09 \text{ s}$$

$$r = 1.4 \text{ m}$$

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

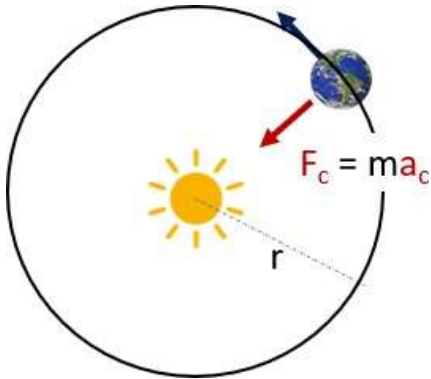
$$a_c = \frac{4 \times 3.142 \times 1.4}{1.09^2}$$

Centripetal acceleration,
 $a_c = ?$

$$a_c = 46 \text{ m/s}^2$$

Centripetal Force (F_c)

- Force required for on an object in Uniform Circular Motion is called Force(F_c)
- Centripetal Force **points to the center** of the circle.



$$F_c = ma_c$$

F_c – centripetal force

a_c – centripetal acceleration

m – mass of the object

Concept Question

1. A 13 g rubber stopper is attached to 0.93 m string. The stopper is swung in a horizontal circle, making one revolution in 1.18 s. **What is the centripetal force?**

Given,

$$T = 1.18 \text{ s}$$

$$r = 0.93 \text{ m}$$

$$m = 0.013 \text{ kg}$$

Centripetal

force,

$$F_c = ?$$

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

$$a_c = \frac{4 \times 3.142 \times 0.93}{1.18^2}$$

$$a_c = 26 \text{ m/s}^2$$

$$F_c = ma_c$$

$$F_c = 0.013 \times 26$$

$$F_c = 0.34 \text{ N}$$

2. A 16 g ball at the end of a 1.4 m string is swung in a horizontal circle. It revolves once every 1.09 s. **What is the string's tension?**

Given,

$$T = 1.18 \text{ s}$$

$$r = 0.93 \text{ m}$$

$$m = 0.016 \text{ kg}$$

Tension force provides
centripetal force,

$$T = F_c = ?$$

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

$$a_c = \frac{4 \times 3.142 \times 1.4}{1.09^2}$$

$$a_c = 46 \text{ m/s}^2$$

$$F_c = ma_c$$

$$F_c = 0.016 \times 46$$

$$F_c = 0.736 \text{ N}$$

Extra Questions

22. **Centripetal Force** The 40.0 g stone in **Figure 13** is whirled horizontally at a speed of 2.2 m/s. What is the tension in the string?

$$T = F_c$$

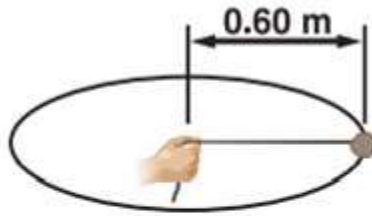


Figure 13

$$\begin{aligned} T &= ma_c \\ &= \frac{mv^2}{r} \\ &= \frac{0.040 \times 2.2^2}{0.60} \\ &= 0.322 \text{ N} \end{aligned}$$

$$\begin{aligned} m &= 40 \text{ g} = 0.040 \text{ kg} \\ v &= 2.2 \text{ m/s} \\ r &= 0.60 \text{ m} \end{aligned}$$

Page 14

14. A 45 kg merry-go-round worker stands on the ride's platform 6.3 m from the center, as shown in **Figure 11**. If her speed (v_{worker}) as she goes around the circle is 4.1 m/s, what is the force of friction (F_f) necessary to keep her from falling off the platform?

15. A 16 g ball at the end of a 1.4 m string is swung in a horizontal circle. It revolves once every 1.09 s. What is the magnitude of the string's tension?

$$T = F_c$$

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

$$F_f = F_c = ma_c$$

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

$$= \frac{45 \times 4.1^2}{6.3} = 120.07 \text{ N}$$

$$\begin{aligned} m &= 45 \text{ kg} \\ r &= 6.3 \text{ m} \\ v &= 4.1 \text{ m/s} \end{aligned}$$

EOT Questions

18. Uniform Circular Motion What is the direction of the force that acts on the clothes in the spin cycle of a top-load washing machine? What exerts the force?

ANS The force is toward the center of the tub.

The walls of the tub exert the force on the clothes. Of course, the whole point is that some of the water in the clothes goes out through holes in the wall of the tub rather than moving toward the center.

56. To obtain uniform circular motion, how must the net force that acts on a moving object depend on the speed of the object?

57. Suppose you whirl a yo-yo about your head in a horizontal circle.

- a. In what direction must a force act on the yo-yo?
- b. What exerts the force?
- c. If you let go of the string on the yo-yo, in which direction would the toy travel? Use Newton's laws in your answer.

56. Circular motion results when the direction of the force is constantly perpendicular to the instantaneous velocity of the object.

57. The force is along the string toward the center of the circle that the yo-yo follows. The string exerts the force.

Previous Questions

$$F_c = ma_c$$

17-A spider twirls a $(2.50 \times 10^{-2} \text{ kg})$ fly around in a circle with radius (0.18m) at the end of its web thread. If the velocity of the fly is (1.10 m/s) .

- Calculate the centripetal force acting on the fly.

Given,

$$v = 1.10 \text{ m/s}$$

$$r = 0.18 \text{ m}$$

$$m = 2.5 \times 10^{-2} \text{ kg}$$

Centripetal Force, $F_c = ?$

Centripetal
acceleration,

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

$$a_c = \frac{1.10^2}{0.18}$$

$$a_c = 6.72 \text{ m/s}^2$$

$$F_c = ma_c$$

$$F_c = 2.5 \times 10^{-2} \times 6.72$$

$$F_c = 0.168 \text{ N}$$

Centrifugal Force

Centrifugal force is the **fictitious, non-existent force** experienced by objects in circular motion

Examples :

When an car moves along a curve objects inside it is thrown outwards. This is due to centrifugal force



Lessons 1.1 and 1.2

MULTIPLE CHOICE

1. A 1.60-m-tall girl throws a football at an angle of 41.0° from the horizontal and at an initial speed of 9.40 m/s. What is the horizontal distance between the girl and the spot when the ball is again at the height above the ground from which the girl threw it?
 A. 4.55 m ☒ C. 8.90 m
 B. 5.90 m D. 10.5 m
2. A child is sitting on a merry-go-round 2.8 m from the center. If the tangential velocity of the ride is 0.89 m/s, what is the centripetal acceleration of the dragonfly?
☒ A. 0.11 m/s² C. 0.32 m/s²
 B. 0.28 m/s² D. 2.2 m/s²
3. The force exerted by a 2.0 m massless string on a 0.82 kg object being swung in a horizontal circle is 4.0 N. What is the tangential velocity of the object?
☒ A. 2.8 m/s C. 4.9 m/s
 B. 3.1 m/s D. 9.8 m/s
4. A 1000 kg car enters an 80.0 m-radius curve at 20.0 m/s. What centripetal force must be supplied by friction so the car does not skid?
 A. 5.0 N ☒ C. 5.0×10^3 N
 B. 2.5×10^2 N D. 1.0×10^3 N

A1. Initial Velocity in X, $v_{ix} = 9.4 \cos 41 = 7.09$ m/s

If projectile starts from ground, $x_i = 0$

To find horizontal distance, use equations of motion in X direction

$$x_f = x_i + v_i t + \frac{1}{2} a_x t^2$$

$$x_f = 0 + 7.09 \times t + \frac{1}{2} \times 0 \times t^2$$

$$x_f = 7.09 \times 1.26 = 8.92 \text{ m}$$

Time of flight,

$$t = \frac{2v_0 \sin \theta}{g}$$

$$t = \frac{2 \times 9.40 \sin(41)}{9.8}$$

$$t = 1.26 \text{ s}$$

A2. Given, Centripetal acceleration, $a_c = ?$

$$v = 8.8 \text{ m/s}$$

$$r = 25 \text{ m}$$

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

$$a_c = \frac{0.892}{2.8}$$

$$a_c = 0.28 \text{ m/s}^2$$

A3. Given, Centripetal Force, F_c

$$r = 2 \text{ m}$$

$$m = 0.82 \text{ kg}$$

$$F = 4 \text{ N}$$

$$v = ?$$

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

$$4 = \frac{0.82 \times v^2}{2}$$

$$v = 3.12 \text{ m/s}$$

A4. Given, Centripetal Force, F_c

$$r = 80 \text{ m}$$

$$m = 1000 \text{ kg}$$

$$v = 20 \text{ m/s}$$

$$F = ?$$

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

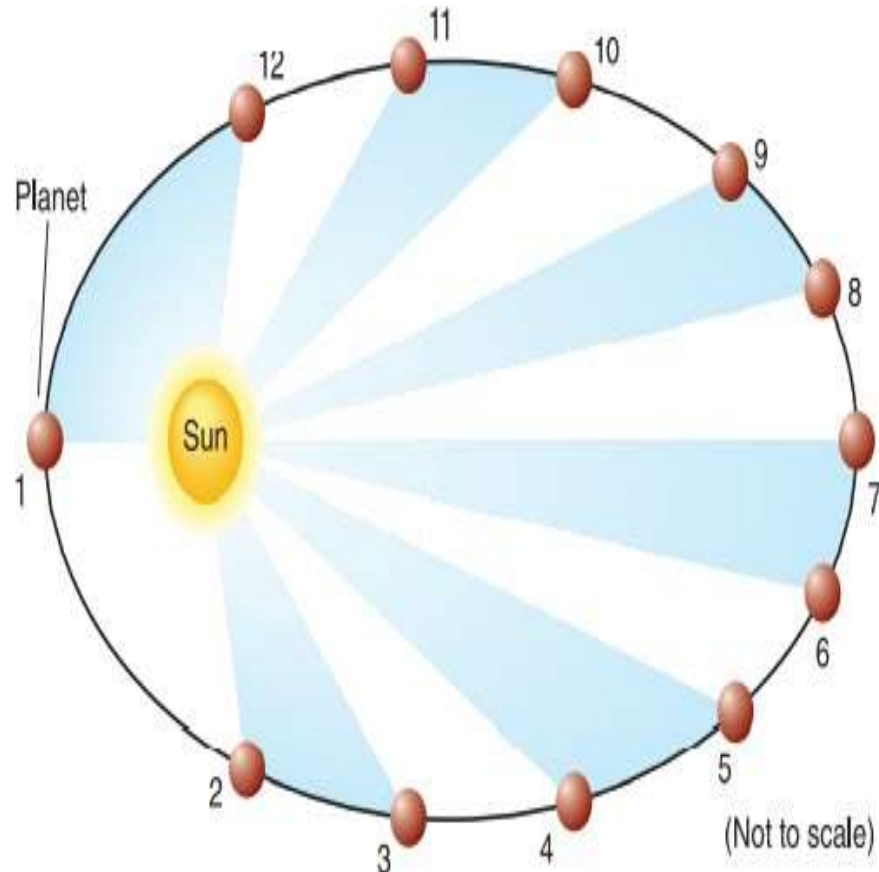
$$F_c = \frac{1000 \times 20^2}{80}$$

$$F_c = 5000 \text{ N}$$

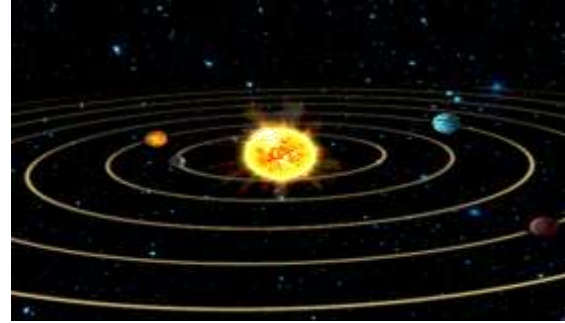
Gravitation

4	Explain Kepler's Third Law which states that the square of the ratio of the periods of any two planets revolving about the Sun is equal to the cube of the ratio of their average distances from the Sun and write it in equation form $((T_A/T_B)^2 = (r_A/r_B)^3)$.	as mentioned in the book question 33	32 48
5	Explain Kepler's Second Law which states that an imaginary line from the Sun to a planet sweeps out equal areas in equal time intervals.	as mentioned in the book	31
6	Justify Kepler's Third Law by using Newton's Second Law of motion and Newton's Law for universal gravitation.	as mentioned in the book	34
7	Apply the law of universal gravitation to calculate the gravitational force or other unknown parameters.	questions 38, 43	48

Gravitation



Kepler's Law of planetary motion



- **Kepler's First Law of Planetary Motion**
Paths of planets are ellipses with sun at one of focii.
- **Kepler's second law** : An imaginary line between the Sun and a planet defines equal areas in equal time intervals.

When planet is **close** ,it moves **fast**.

When planet is **far** ,it moves **slow**.

- **Kepler's third law** states that, **square of time** period of revolution of planet around sun is directly proportional to **cube of distance** to Sun

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

$$\frac{T_A^2}{T_B^2} = \frac{r_A^3}{r_B^3}$$

Previous Year Question

5- **Kepler's third** law states that

- a. the orbits of the planets are elliptical. 1st law
- b. the speed of a planet's orbit varies depending on which part of the ellipse it is occupying. 2nd law
- ✓ c. the square of the ratio of the periods of any two planets revolving around the Sun is equal to the cube of the ratio of their average distance from the Sun. 3rd law
- d. objects attract other objects with a force that is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them. Newton's universal law of gravitation

Text Book Problems

EXAMPLE 1

CALLISTO'S DISTANCE FROM JUPITER Galileo measured the orbital radii of Jupiter's moons using the diameter of Jupiter as a unit of measure. He found that Io, the closest moon to Jupiter, has a period of 1.8 days and is 4.2 units from the center of Jupiter. Callisto, the fourth moon from Jupiter, has a period of 16.7 days. Using the same units that Galileo used, predict Callisto's distance from Jupiter.

$$T_I = 1.8 \text{ days}$$

$$r_I = 4.2 \text{ units}$$

$$T_C = 16.7 \text{ days}$$

$$r_C = ?$$

$$\frac{T_A^2}{T_B^2} = \frac{r_A^3}{r_B^3}$$

$$\left(\frac{1.8}{16.7}\right)^2 = \left(\frac{4.2}{r_c}\right)^3$$

$$r_c^3 = \frac{74.08}{0.011}$$

$$0.011 = \frac{74.08}{r_c^3}$$

$$r_c = \sqrt[3]{\frac{74.08}{0.011}} = 18.88 \text{ units}$$

2. An asteroid revolves around the Sun with a mean orbital radius twice that of Earth's. Predict the period of the asteroid in Earth years.

$$T_{\text{earth}} = 1 \text{ year}$$

$$r_{\text{earth}} = r$$

$$T_{\text{asteroid}} = ?$$

$$r_{\text{asteroid}} = 2r$$

$$\left(\frac{1}{T}\right)^2 = \left(\frac{r}{2r}\right)^3$$

$$\left(\frac{1}{T}\right)^2 = \left(\frac{1}{2}\right)^3$$

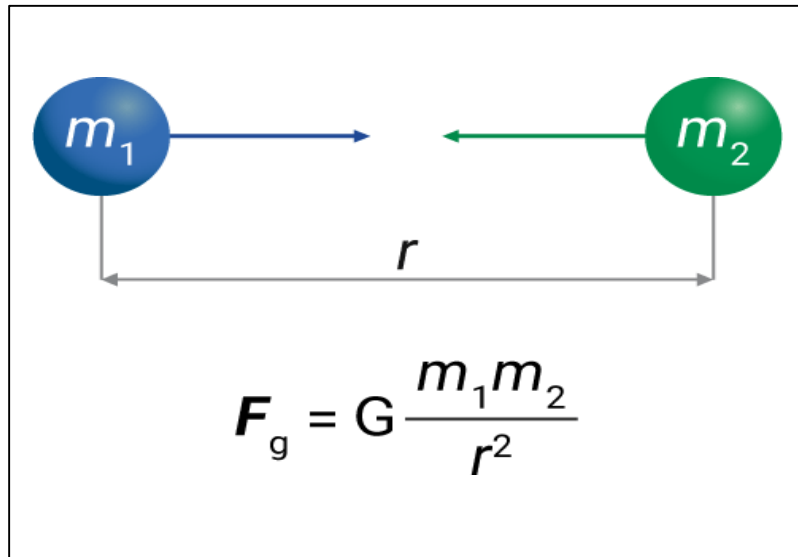
$$T^2 = 2^3$$

$$T = \sqrt[2]{2^3} = 8 \text{ years}$$

$$\frac{T_A^2}{T_B^2} = \frac{r_A^3}{r_B^3}$$

Newton's law of universal gravitation

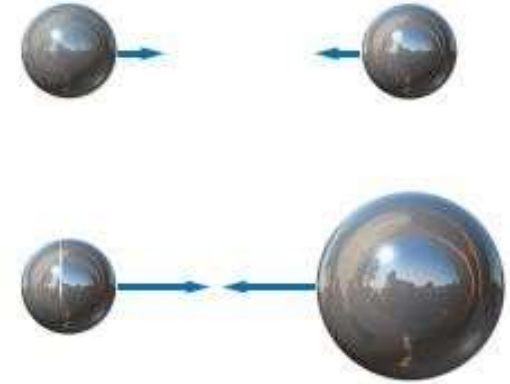
force (F_g) of attraction between objects is proportional to the product of their **masses (m)** and inversely proportional to the square of their **distance (r)**



G – Universal Gravitational Constant.

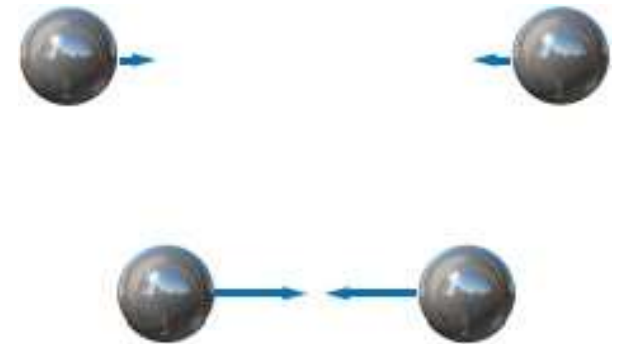
$$G = 6.674 \times 10^{-11} \text{ Nm}^2/\text{kg}^2.$$

Think !



More mass, more force

If mass doubles, force doubles

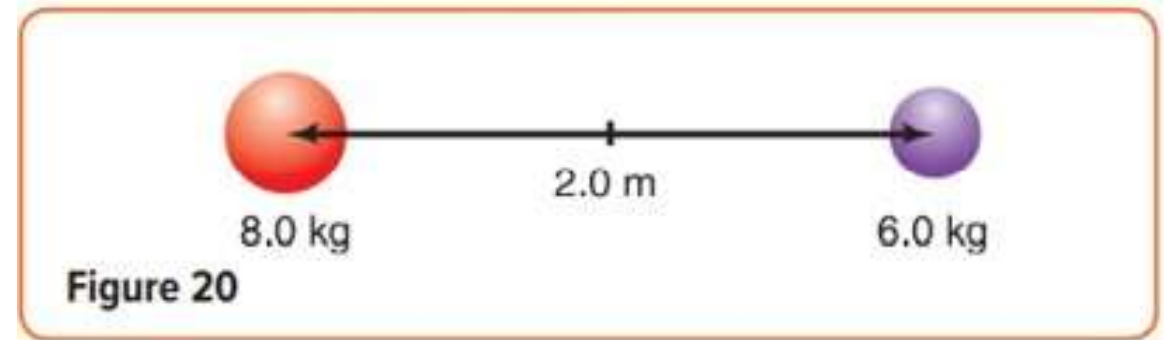


Less distance, more force

If distance becomes half, force becomes quadrupled (four times)

Text Book Problem

43. **BIG IDEA** The centers of two balls are 2.0 m apart, as shown in **Figure 20**. One ball has a mass of 8.0 kg. The other has a mass of 6.0 kg. What is the gravitational force between them?



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

$$F = \frac{6.67 \times 10^{-11} \times 8.0 \times 6.0}{2^2} = 8.004 \times 10^{-10} \text{ N}$$

Text Book Problems

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

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

40. Assume that your mass is 50.0 kg. Earth's mass is 5.97×10^{24} kg, and its radius is 6.38×10^6 m.

a. What is the force of gravitational attraction between you and Earth?

b. What is your weight?

41. A 1.0-kg mass weighs 9.8 N on Earth's surface, and the radius of Earth is roughly 6.4×10^6 m.

a. Calculate the mass of Earth.

b. Calculate the average density of Earth.

A 40. Given, $m_1 = 5.97 \times 10^{24}$ kg, $m_2 = 50$ kg
 $F = ?$, $r = 6.38 \times 10^6$ m

$$(a) F = \frac{6.67 \times 10^{-11} \times 5.97 \times 10^{24} \times 50}{(6.38 \times 10^6)^2}$$
$$= 489.13 \text{ N}$$

$$(b) W = mg = 50 \times 9.8 = 490 \text{ N}$$

A 41.

Given, $m_2 = 1$ kg, $F = 9.8$ N, $r = 6.4 \times 10^6$ m
 $m_1 = ?$

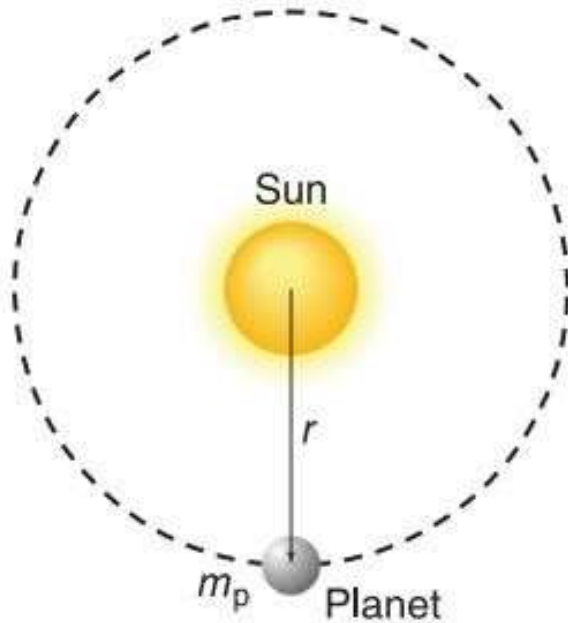
$$(a) 9.8 = \frac{6.67 \times 10^{-11} \times M \times 1}{(6.4 \times 10^6)^2}$$

$$M = \frac{9.8 \times (6.4 \times 10^6)^2}{(6.67 \times 10^{-11})}$$

$$M = 6.01 \times 10^{24} \text{ kg}$$

Universal Gravitation and Kepler's Third Law

Consider a planet orbiting Sun in a circle of radius r .



Time Period of a Satellite

$$T = 2\pi \sqrt{\frac{r^3}{Gm_s}}$$

Concept Question

1. Saturn's average distance from the Sun is 9.6 AU (or 1.43×10^{12} m). Calculate Saturn's orbital period. The mass of the Sun is 1.99×10^{30} kg, G is $6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$.

Given,

$$m_s = 1.99 \times 10^{30} \text{ kg}$$

$$r = 1.43 \times 10^{12} \text{ m}$$

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

$$T = ?$$

$$T =$$

$$2\pi \sqrt{\frac{(1.43 \times 10^{12})^3}{6.67 \times 10^{-11} \times 1.99 \times 10^{30}}}$$
$$T = 932125190 \text{ s}$$

Since, 1 year has $365 \times 24 \times 60 \times 60$ seconds

$$T = \frac{932125190}{365 \times 24 \times 60 \times 60} = 29.56 \text{ years}$$

Orbital Velocity

For a satellite of mass 'm' orbits around earth of mass m_e ,

Centripetal force = Gravitational force

$$F_c = F_g$$

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

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

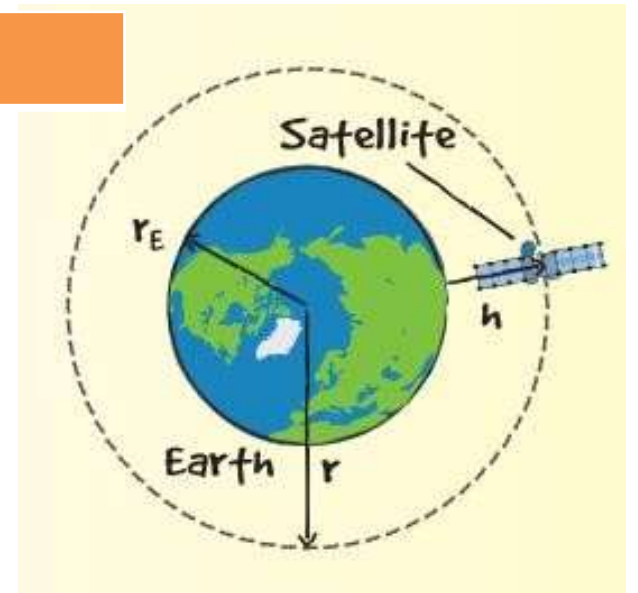
Where, v – velocity of satellite in an orbit

m_e – mass of earth

r – radius of orbit

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

EOT QUESTION 19



Example

Calculate the speed of a satellite orbiting 36,000 km above the surface of the Earth. The mass of the Earth = 5.97×10^{24} kg and its radius = 6.38×10^6 m .

Given,

$$h = 36000 \text{ km} = 3.6 \times 10^4 \text{ m} = 0.036 \times 10^6 \text{ m}$$

$$R = 6.38 \times 10^6 \text{ m}$$

$$r = R + h = 6.42 \times 10^6 \text{ m}$$

$$m_e = 5.97 \times 10^{24} \text{ kg}$$

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

$$v = \sqrt{\frac{Gm_e}{r}} = 7875.5 \text{ m/s} = 7.85 \text{ km/s}$$

Free Fall Acceleration

- Acceleration of an object due to gravitational pull of earth is called free fall acceleration

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

m_E - mass of earth
 r - distance from earth

- Free fall acceleration for earth is always 9.8 m/s^2 for all objects (do not depend on mass of object)

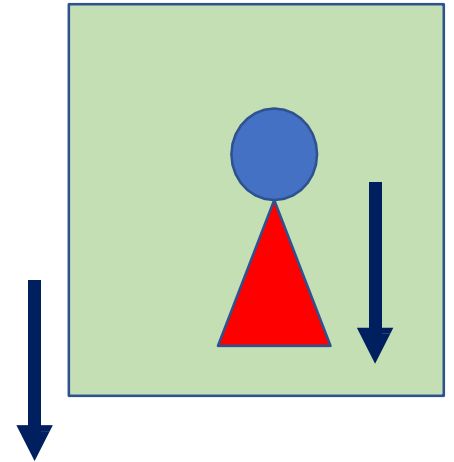
$$g = 9.8 \text{ m/s}^2$$

Weightlessness

Weightlessness occur when floor that supports you is under free fall.

This can be seen in

- in lifts
- In space stations
- In jet rides



Previous Year Question

4- The **acceleration** due to Earth's gravity is:

- ✓ a. 9.8 m/s^2
- b. 98 m/s^2
- c. 9.8 ft/s^2
- d. 9.8 mi/s^2



2nd Question

19- Mercury orbits the Sun with an orbital radius of $(5.8 \times 10^{10} \text{ m})$. Given that the mass of the Sun is $(2.0 \times 10^{30} \text{ kg})$, and the mass of Mercury is $(3.3 \times 10^{23} \text{ kg})$.

- Calculate the **period of Mercury's orbit**.

Given,

$$m_s = 2 \times 10^{30} \text{ kg}$$

$$r = 5.8 \times 10^{10} \text{ m}$$

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

$T = ?$

$$T = 2\pi \sqrt{\frac{(5.8 \times 10^{10})^3}{6.67 \times 10^{-11} \times 2 \times 10^{30}}}$$

$$T = 7594925 \text{ s} = 87.9 \text{ days}$$

$$T = 2\pi \sqrt{\frac{r^3}{Gm_s}}$$

- Calculate the **gravitational force between Mercury and the Sun**.

Given,

$$m_s = 2 \times 10^{30} \text{ kg}$$

$$m_m = 3.3 \times 10^{23} \text{ kg}$$

$$r = 5.8 \times 10^{10} \text{ m}$$

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

$$F = \frac{Gm_s m}{r^2}$$

$$F = 1.31 \times 10^{22} \text{ N}$$

$$F = \frac{Gm_s m}{r^2}$$

- Calculate the **orbital velocity of Mercury around the Sun**.

Given,

$$m_s = 2 \times 10^{30} \text{ kg}$$

$$r = 5.8 \times 10^{10} \text{ m}$$

$$G = 6.67 \times 10^{-11} \text{ Nm}^2/\text{kg}^2$$

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

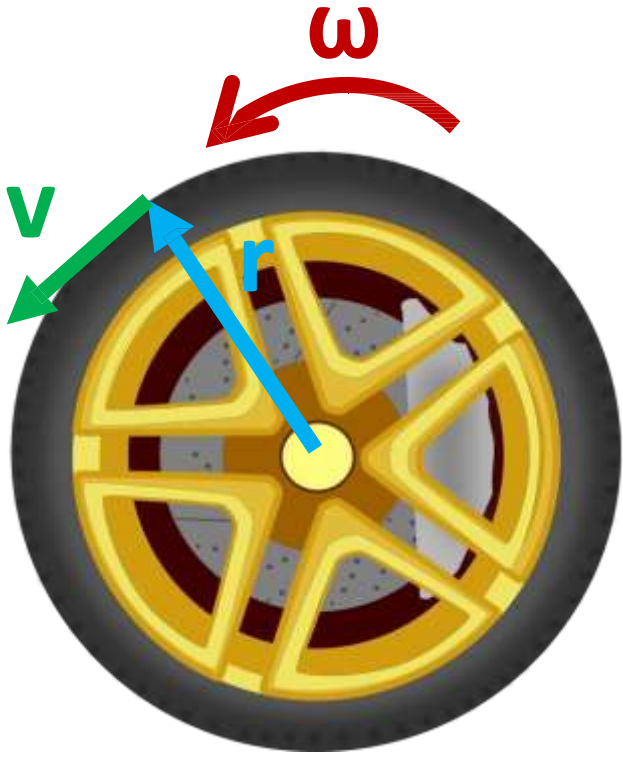
$$v = 47958 \text{ m/s} \quad v = 48 \text{ km/s}$$

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

Rotational Motion

8	Define a radian and convert degrees to radians and vice-versa	as mentioned in the book	57
9	Relate the linear velocity (v) to the angular velocity (ω) and the distance (r) from the axis of rotation	problem 4	59
10	Apply the relationship between average angular acceleration, change in angular velocity, and the time interval for that change	problem 2	59
11	Apply the relationship between angular displacement and the initial and final angular positions	problem 1	59
12	Define angular displacement	as mentioned in the book	56
13	Apply the relation ($\tau = Fr \sin \theta$) to calculate the magnitude of torque (τ) for a force of magnitude (F) where (r) is the distance from the axis of rotation to the point where the force is exerted, and θ is the angle between the force and the radius from the axis of rotation to the point where the force is applied	question 63	81

Rotational Motion



Angle of Rotation

To measure the angle of rotation we use two units

- **Degree :**
1 degree = $1/360$ of revolution a circle
- **Radian :**
1 radian = $1/2\pi$ of revolution of circle
- One complete revolution equals 360 degree
or 2π radian

$$360 \text{ degree} = 2\pi \text{ radian}$$

Previous Year Question 2019-20

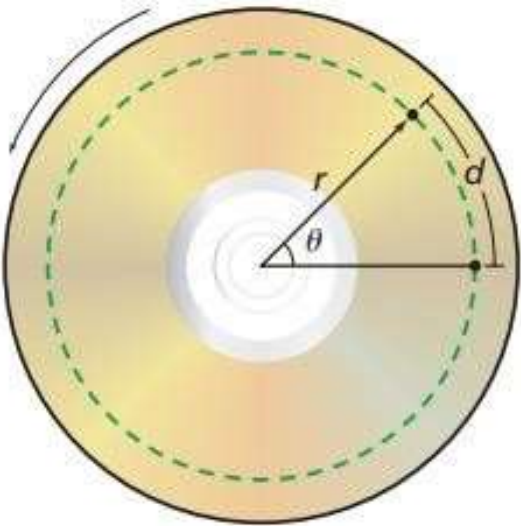
10- **A degree** is a unit of measurement equal to

- ✓ a. $1/360$ of a revolution
- b. $1/500$ of a revolution
- c. $1/(2\pi)$ of a revolution
- d. $1/4$ of a revolution

Angular displacement (θ)

- When an object rotates, change in angle of an object is called angular displacement

- It is denoted by θ *theta*

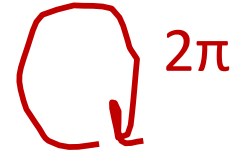


- Unit is **rad**

Concept Questions

What is the angular displacement of earth in 24 hour?

- (a) $\pi/2$ rad
- (b) π rad
- ☒ (c) 2π rad



If a wheel makes 50 rotations in 1 sec.

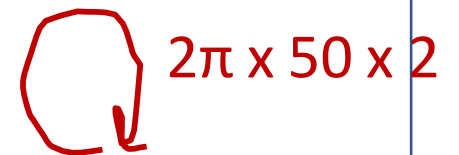
What is the angular displacement in **1 sec**?

- (a) 50π rad
- ☒ (b) 100π rad
- (c) 200π rad

If a wheel makes 50 rotations in 1 sec.

What is the angular displacement in **2 sec**?

- (a) 50π rad
- (b) 100π rad
- ☒ (c) 200π rad



EOT QUESTIONS

1. What is the angular displacement of each of the following hands of a clock in 1.00 h? State your answer in three significant digits.

- a. the second hand
- b. the minute hand
- c. the hour hand

1. What is the angular displacement of each of the following hands of a clock in 1 h? State your answer in three significant digits.

- a. the second hand

$$\begin{aligned}\Delta\theta &= (60)(-2\pi \text{ rad}) \\ &= -120\pi \text{ rad or } -377 \text{ rad}\end{aligned}$$

- b. the minute hand

$$\Delta\theta = -2\pi \text{ rad or } -6.28 \text{ rad}$$

- c. the hour hand

$$\begin{aligned}\Delta\theta &= \left(\frac{1}{12}\right)(-2\pi \text{ rad}) \\ &= -\frac{\pi}{6} \text{ rad or } 0.524 \text{ rad}\end{aligned}$$

2. A rotating toy above a crib makes one complete counterclockwise rotation in 1 min.

- a. What is its angular displacement in 3 min?
- b. What is the toy's angular velocity in rad/min?
- c. If the toy is turned off, does it have positive or negative angular acceleration? Explain.

$$\Delta\theta = 6 \times 2\pi \text{ rad}$$

$$2. \text{ a. } 6\pi \text{ rad}$$

$$\text{b. } 2\pi \text{ rad/min}$$

c. negative acceleration because the toy slows down until it stops moving

Angular velocity (ω)

- Angular velocity is how fast an object rotates.
- Angular velocity is the angular displacement divided by time

omega

$$\omega = \frac{\Delta}{\Delta t}$$

ω is angular velocity

$\Delta\theta$ is angular displacement

Δt is time interval

- Unit of angular velocity is rad/s

Concept Question



The tires of a car completes 200 rotations in 5 seconds.

(a) What is the angular displacement?

angular displacement for 1 rotation is 2π rad

angular displacement for 200 rotation,

$$\Delta\theta = 2\pi \text{ rad} \times 200 = 400\pi \text{ rad}$$

(b) What is the angular velocity (ω)?

$$\omega = \frac{\Delta}{\Delta t}$$

$$\omega = \frac{400\pi}{5} = 80\pi \text{ rad/s}$$

Angular acceleration (α)

Angular acceleration is the change in angular velocity divided by the time required

$$\text{alpha } \alpha = \frac{\Delta \omega}{\Delta t}$$

α is angular acceleration

$\Delta \omega$ is change in angular velocity

Δt is time interval

SI unit of angular acceleration is rad/s^2

Concept Question



The angular velocity of wheel of a tire changes from $10\pi \text{ rad/s}$ to $20\pi \text{ rad/s}$ in 2 sec .What is the angular acceleration?

Given,

Change in angular velocity,

$$\begin{aligned}\Delta \omega &= 20\pi - 10\pi \\ &= 10\pi \text{ rad/s}\end{aligned}$$

Time interval,

$$\Delta t = 2 \text{ sec}$$

Angular acceleration,

$$\alpha = \frac{\Delta \omega}{\Delta t} \qquad \alpha = \frac{10\pi}{2} = 5\pi \text{ rad/s}^2$$

Angular frequency

The number of complete revolution made by an object in 1 sec

$$f = \frac{\omega}{2\pi}$$

f is frequency

ω is angular velocity

Unit : Hertz (Hz)

Concept Question



The angular velocity of wheel of a tire is 20π rad/s. What is the angular frequency?

Given,

$$\omega = 20\pi \text{ rad/s}$$

$$f = \frac{\omega}{2\pi}$$

$$f = \frac{20\pi}{2\pi} = 10 \text{ Hz}$$

Table 1 Linear and Angular Measures

EOT 16A

Quantity	Linear	Angular	Relationship
displacement	x	θ	$x = r\theta$
velocity	v	ω	$v = r\omega$
acceleration	a	α	$a = r\alpha$

1. A Ferris wheel has a radius of 15 m. It makes **one rotation** in every 60 s.

(a) What is angular displacement in one rotation?

(b) What is angular velocity?

(c) **What is linear velocity** experienced by a person at a distance of 15 m from the center?

Given,

Wheel completes one rotation in 60 seconds (2π rad)

(a) Angular displacement = 2π rad

(b) Angular velocity , $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi \text{ rad}}{60 \text{ s}} = 0.104 \text{ rad/s}$

(c) linear velocity , $v = r\omega = 15 \times 0.104 = 1.56 \text{ m/s}$

2. A truck has **linear acceleration** of 1.85 m/s^2 and the wheels have an angular acceleration of 5.23 rad/s^2 ? What is the diameter of the wheels?

Linear acceleration, $a = 1.85 \text{ m/s}^2$

Angular acceleration, $\alpha = 5.23 \text{ rad/s}^2$

$$r = \frac{a}{\alpha} = \frac{1.85}{5.23}$$

$$r = 0.353 \text{ m}$$

$$d = 2r = 0.7074 \text{ m}$$

3. If a truck has a linear acceleration of 1.85 m/s^2 and the wheels have an angular acceleration of 5.23 rad/s^2 , what is the diameter of the wheels?
4. The truck in the previous problem is towing a trailer with wheels that have a diameter of 48 cm.
- How does the linear acceleration of the trailer compare with that of the truck?
 - How do the angular accelerations of the wheels of the trailer and the wheels of the truck compare?

$$r = \frac{a}{\alpha}$$

$$= \frac{1.85 \text{ m/s}^2}{5.23 \text{ rad/s}^2}$$

$$= 0.354 \text{ m}$$

Thus, the diameter is **0.707 m**.

- a. How does the linear acceleration of the trailer compare with that of the truck?

The changes in velocity are the same, so the linear accelerations are the same.

Because the radius of the wheel is reduced from 35.4 cm to 24 cm, the angular acceleration will be increased.

$$\alpha_1 = 5.23 \text{ rad/s}^2$$

$$\alpha_2 = \frac{a_2}{r} = \frac{1.85 \text{ m/s}^2}{0.24 \text{ m}}$$

$$= 7.7 \text{ rad/s}^2$$

11- Which of the following is a correct relationship between **linear displacement** and **angular displacement** ?

a. $v = d/t$

b. $a = r\alpha$

c. $v = r\omega$

☒ d. $d = r\theta$



12- The **angular acceleration** of an object , is given by:

a. $\omega = \Delta\theta/\Delta t$

☒ b. $\alpha = \Delta\omega/\Delta t$

c. $d = r\theta$

d. $v = r\omega$

14- according to the graph, what the **slope of the line** represents?

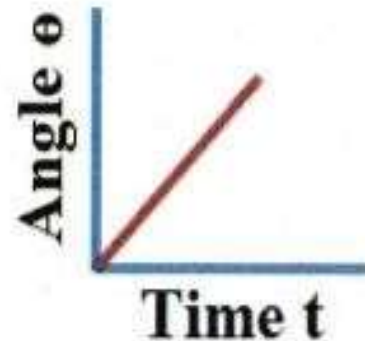
a. Angular acceleration

☒ b. Angular velocity

c. The moment of inertia

d. The torque

$$\frac{\theta}{t} = \omega$$



Practice Problems

1. What is the angular displacement for each of the following hands of a clock in 1.00 h

- (a) second hand
- (b) minute hand
- (c) hour hand

(a) Second hand completes 60 revolutions in 1 h,
(60 rev = 60 min = 1 hour)

angular displacement, $\theta = 60 \times 2\pi \text{ rad}$
 $= 120 \pi \text{ rad}$

(b) Minute hand completes 1 revolutions in 1 h,
angular displacement, $\theta = 1 \times 2\pi \text{ rad}$
 $= 2 \pi \text{ rad}$

(b) Hour hand completes 1/12 of revolutions in 1 h,
angular displacement, $\theta = 2\pi/12 \text{ rad} = \pi/6 \text{ rad}$

2. A rotating toy makes one complete counter clockwise rotation in 1 min.

- a) What is the angular displacement in 3 min.
- b) What is the angular velocity in radians/min

(a) Angular displacement for one complete rotation is ,

$$\theta = 1 \times 2\pi \text{ rad} = 2 \pi \text{ rad}$$

(b) Angular velocity in 1 minute,

$$\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi \text{ rad}}{1 \text{ min}} = 2\pi \text{ rad/min}$$

6. The Moon ($r = 1.74 \times 10^6 \text{ m}$) rotates once on its axis in 27.3 days.

- What is the period of rotation in seconds?
- What is the frequency of rotation in rad/s?
- A rock sits on the surface of the Moon's equator. What is the linear speed?

(a) Period of rotation in sec = $24 \times 60 \times 60 \text{ s} = 86400 \text{ s}$

(b) Angular frequency, $\omega = \frac{\Delta\theta}{\Delta t} = \frac{2\pi \text{ rad}}{86400 \text{ s}} = 7.26 \times 10^{-5} \text{ rad/s}$

(c) Linear velocity, $v = r \omega = \frac{2\pi \text{ rad}}{86400 \text{ s}} = 1.74 \times 10^6 \times 7.26 \times 10^{-5}$

$$v = 126.32 \text{ m/s}$$



Finding Net Torque

Figure 8 shows a practical application of increasing torque to make a task easier. For another example of torque, try the following investigation. Collect two pencils, some coins, and some transparent tape. Tape two identical coins to the ends of the pencil and balance it on the second pencil, as shown in Figure 9. Each coin exerts a torque that is equal to the distance from the balance point to the center of the coin (r) times its weight (F_g), as follows:

$$\tau = rF_g$$

But the torques are equal and opposite in direction. Thus, the net torque is zero:

$$\tau_1 - \tau_2 = 0$$

or

$$r_1 F_{g1} - r_2 F_{g2} = 0$$

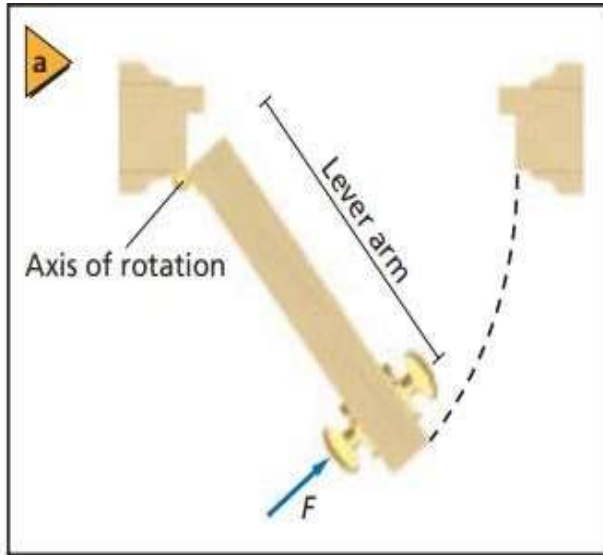
How can you make the pencil rotate? You could add a second coin on top of one of the two coins, thereby making the two forces different. You also could slide the balance point toward one end or the other of the pencil, thereby making the two lever arms of different length.



Figure 9 The torque exerted by the first coin ($F_{g1}r_1$) is equal and opposite in direction to the torque exerted by the second coin ($F_{g2}r_2$) when the pencil is balanced.

Lever Arm

Lever arm is the distance from the axis of rotation to the point where force is applied perpendicular to the radius.



$$l = r \sin \theta$$

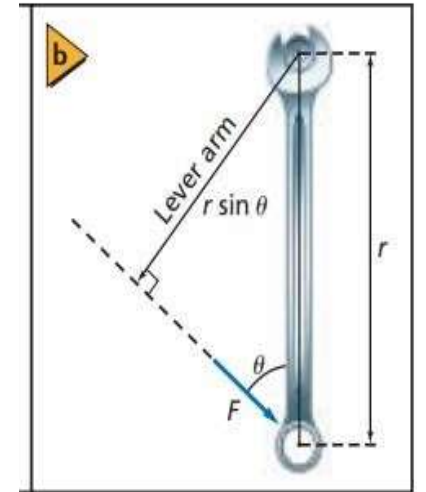
l – lever arm

r is the distance from the axis of rotation to the point where force is applied.

θ is the angle between F and r

EOT Q 18

A bolt on a car engine must be tightened with a torque of 35 N·m. You use a **25-cm-long wrench** and pull the end of the wrench at an **angle of 60.0°** to the handle of the wrench. **How long is the lever arm?**



Given,

$$r = 25 \text{ cm} = 0.25 \text{ m}$$

$$\theta = 60^\circ$$

Lever arm = ?

Lever arm ,

$$l = r \sin \theta = 0.25 \times \sin 60 = 0.22 \text{ m}$$

Torque

Torque produces rotational motion.

Torque is the product of force and the perpendicular lever arm

Torque = force x lever arm

$$T = Fr\sin\theta$$

SI Unit is Nm

Concept Problem

A bolt on a car engine must be tightened with a torque of 35 N·m. You use a 25-cm-long wrench and pull the end of the wrench at an angle of 60.0° to the handle of the wrench. **how much force** must you exert?

Given,

$$r = 25 \text{ cm} = 0.25 \text{ m}$$

$$\theta = 60^\circ$$

$$T = 35 \text{ Nm}$$

Force = ?

Torque,

$$T = Fr\sin\theta$$

$$35 = F \times 0.25 \times \sin 60$$

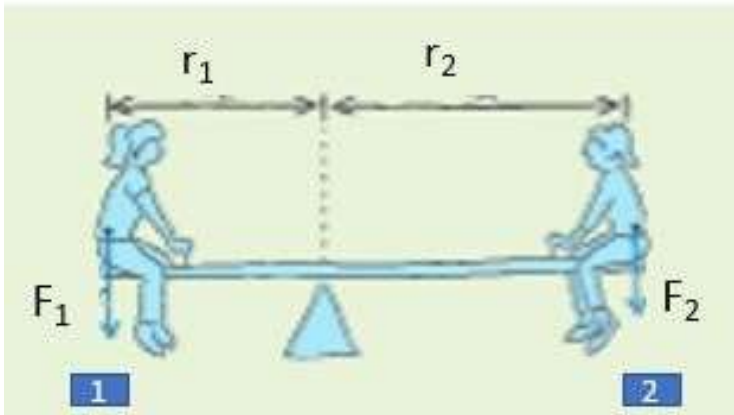
$$35 = F \times 0.22$$

$$F = \frac{35}{0.22} = 159 \text{ N}$$



Balancing of an Object

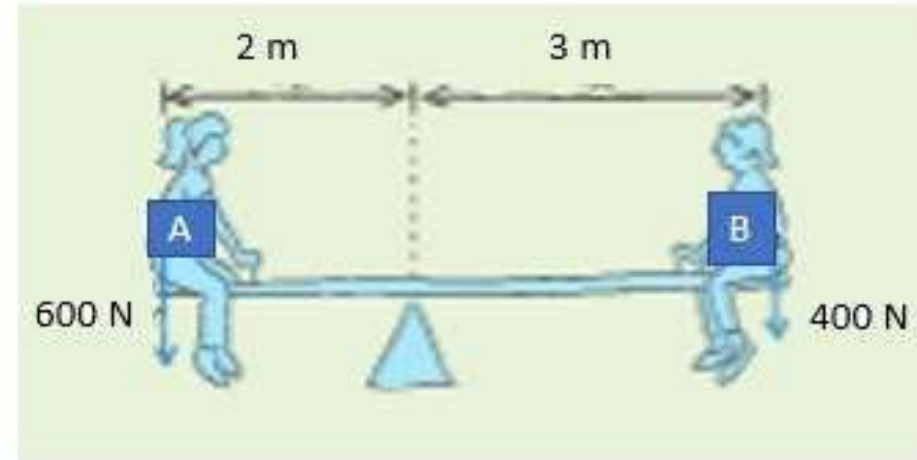
- When an object is balanced, the torques acting on both sides cancel each other.



- Anticlockwise torque = $F_1 r_1$
- Clockwise torque = $F_2 r_2$

Anticlockwise torque = clockwise torque

$$F_1 r_1 = F_2 r_2$$



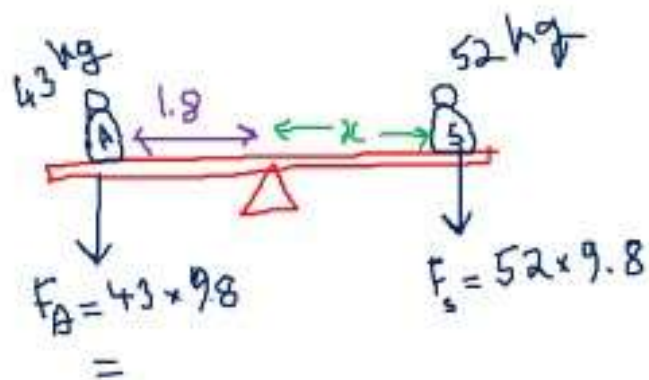
Q1. Observe the figure and answer the question.

- What is the torque acting at A?
- What is the torque acting at B?
- What is the net torque ?

A1. (a) Torque at A = $600 \times 2 = 1200$ Nm anticlockwise (+)
(b) Torque at A = $400 \times 3 = 1200$ Nm clockwise (-)
(c) Net Torque = $+1200 - 1200 = 0$ Nm

PRACTICE Problems

16. Ashok, whose mass is 43 kg, sits 1.8 m from a pivot at the center of a seesaw. Steve, whose mass is 52 kg, wants to seesaw with Ashok. How far from the center of the seesaw should Steve sit?



Let x is distance Steve sits from pivot

Since see-saw is balanced,
Anticlockwise moment = Clockwise moment

$$F_A \times 1.8 = F_S \times x$$

$$43 \times 9.8 \times 1.8 = 52 \times 9.8 \times x$$

$$x = \frac{43 \times 9.8 \times 1.8}{52 \times 9.8} = \underline{\underline{1.488 \text{ m}}}$$

Practice Problem

Kariann (56 kg) and Aysha (43 kg) want to balance on a 1.75-m-long seesaw. Where should they place the pivot point of the seesaw? Assume that the seesaw is massless

Given,

Mass of Kariann = 56 kg

Mass of Aysha = 43 kg

$r_K = ?$

Since the seesaw is balanced,

Anticlockwise torque = clockwise torque

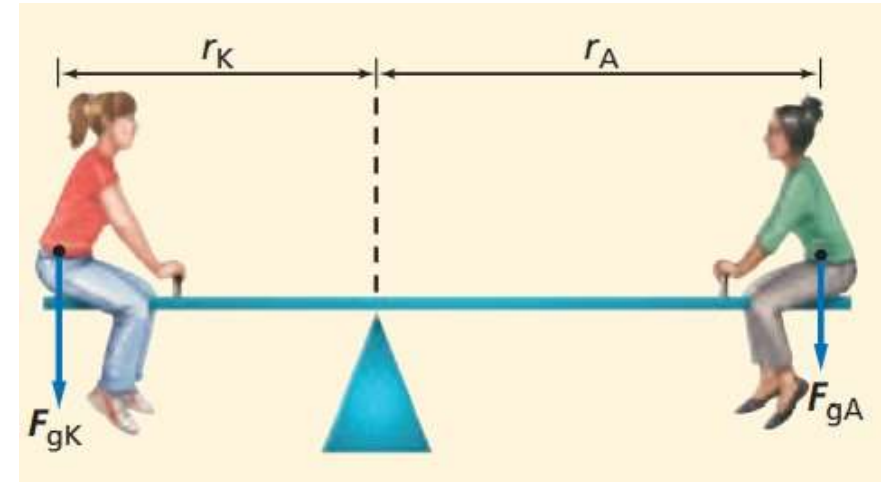
$$F_{gK} \times r_K = F_{gA} \times r_A$$

$$56 \times 9.8 \times r_K = 43 \times 9.8 \times (1.75 - r_K)$$

$$56 r_K = 43 (1.75 - r_K)$$

$$99 r_K = 75.5$$

$$r_K = 0.76 \text{ m}$$



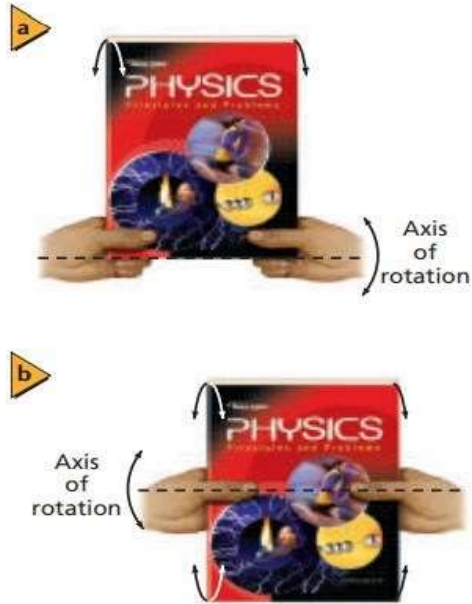
Let r_K is the distance to the pivot

Total length of seesaw is 1.75 m

$$r_A = 1.75 - r_K$$

Moment of Inertia (I)

Moment of Inertia is the resistance of rotation.



If mass is distributed

- near to the axis, it is easy to rotate
- far to the axis, it is hard to rotate

Moment of Inertia of a Point Mass $I = mr^2$

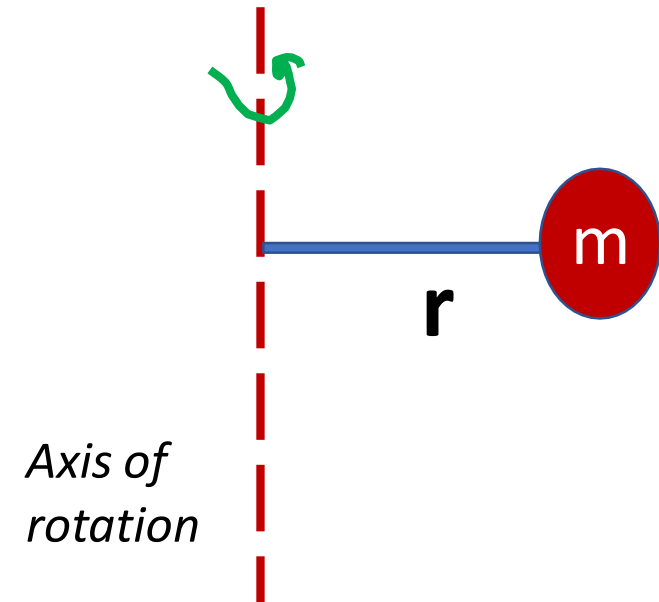
The moment of inertia of a point mass is equal to the mass of the object times the square of the object's distance from the axis of rotation.

$$I = mr^2$$

m - mass of the object

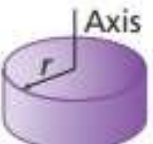
r - distance of the object from axis of rotation

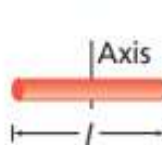
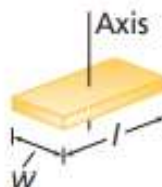
SI unit of moment of Inertia is kgm^2



PRACTICE Problems

Do It Yourself !

Object	Location of Axis	Diagram	Moment of Inertia
Thin hoop of radius r	Through central diameter		mr^2
Solid, uniform cylinder of radius r	Through center		$\frac{1}{2}mr^2$
Uniform sphere of radius r	Through center		$\frac{2}{5}mr^2$

Object	Location of Axis	Diagram	Moment of Inertia
Long, uniform rod of length l	Through center		$\frac{1}{12}ml^2$
Long, uniform rod of length l	Through end		$\frac{1}{3}ml^2$
Thin, rectangular plate of length l and width w	Through center		$\frac{1}{12}m(l^2 + w^2)$

1. Calculate the moments of inertia for each object below using the formulas in Table 2 . Each object has a radius of 2.0 m and a mass of 1.0 kg.

- a. a thin hoop b. a solid, uniform cylinder c. a solid, uniform sphere

$$\begin{aligned} \text{a) } I_{\text{loop}} &= mr^2 \\ &= 1 \times 2^2 = 4 \text{ kgm}^2 \end{aligned}$$

$$\begin{aligned} \text{b) } I_{\text{cylinder}} &= \frac{1}{2} mr^2 \\ &= \frac{1}{2} \times 1 \times 2^2 = 2 \text{ kgm}^2 \end{aligned}$$

$$\begin{aligned} \text{c) } I_{\text{sphere}} &= \frac{2}{5} mr^2 \\ &= \frac{2}{5} \times 1 \times 2^2 = 0.8 \text{ kgm}^2 \end{aligned}$$

20- Mohammad, whose weight is (270 N), sits (1.50 m) from the center of a seesaw. Salem, whose weight is (320 N).

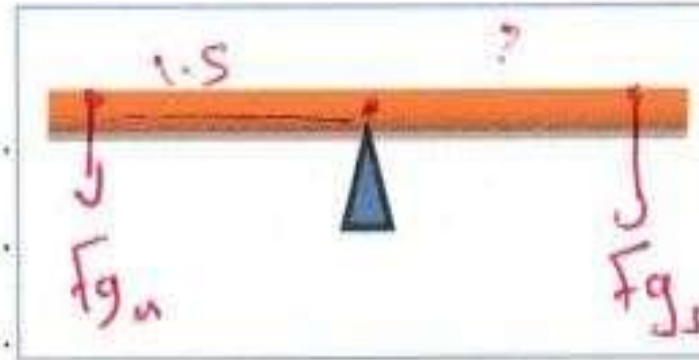
- Calculate the torque of Mohammad.

Given,

Force of gravity on Muhammed (F_{gm}) = 270 N

Distance of Muhammed to pivot (r_m) = 1.5 m

Torque of Muhammed (T_m) = $Fr = 270 \times 1.5 = 405 \text{ Nm}$



- Calculate how far from the center of the seesaw should Salem sit to balance Mohammad?

Given,

Force of gravity on Muhammed (F_{gm}) = 270 N

Force of gravity on Salem (F_{gs}) = 320 N

Since the seesaw is balanced,

Anticlockwise torque = clockwise torque

$$F_{gm} \times r_m = F_{gs} \times r_s$$

$$270 \times 1.5 = 320 \times r_s$$

$$r_s = \frac{320}{270 \times 1.5} = 0.79 \text{ m}$$

Chapter 4

Work and Energy

16.B Apply the relationship between a force F and the work done on a system by the force when the system undergoes a displacement d : $W = Fd \cos \theta$ where θ is the angle between the direction of the force and the direction of displacement

example 2

93



Work

Definition: Work is the transfer of energy that occurs when a force (F) is applied through a displacement (d).

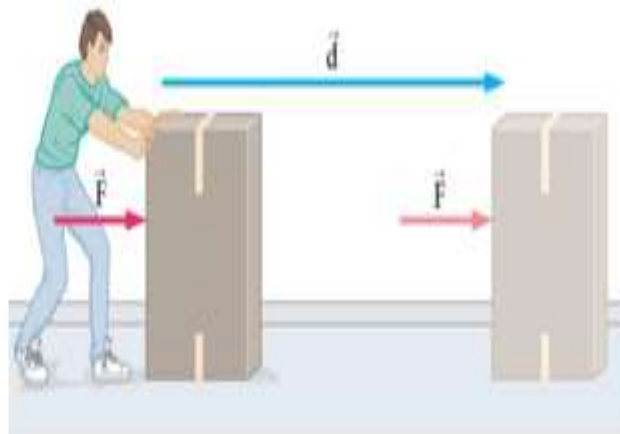
Work Done by a Constant Force
The definition of work, when the force is parallel to the displacement:

$$W = Fd$$

SI unit: newton-meter (N.m) = joule, J

Unit is the **Joule (J)** or the **Newton-Meter (N.m)**.

*Note Force x Displacement =
Newton x Meter = N.m

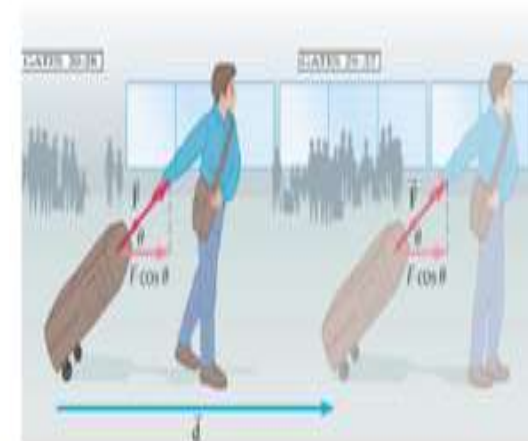


Work at an angle

Work Done by a Constant Force If the force is at an angle to the

When dealing with forces exerted at an angle, work can then be calculated as follows:

$$W = (F \cos \theta)d = Fd \cos \theta$$



WORK

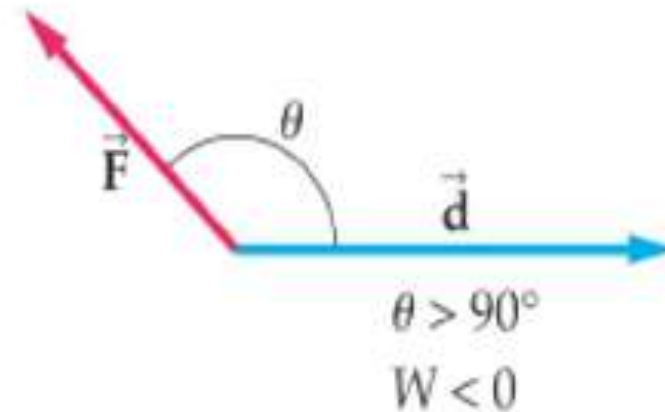
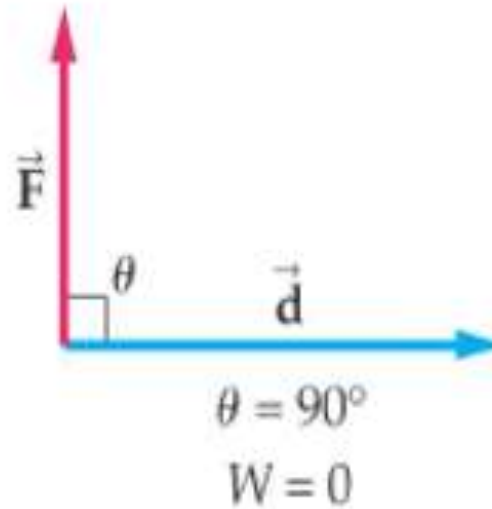
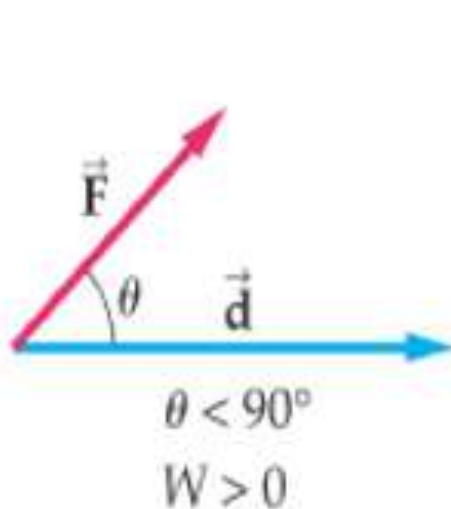
Work is equal to the product of the magnitude of the force and magnitude of displacement times the cosine of the angle between them.

$$W = Fd \cos \theta$$

Work at an angle

The work done may be positive, zero, or negative, depending on the angle between the force and the displacement.

Angle (θ)	$0 \leq \theta < 90$	$\theta = 90$	$90 < \theta \leq 180$
Cos (θ)	positive	ZERO	negative
Work	positive	ZERO	negative
Speed of Object	increases	constant speed	decreases





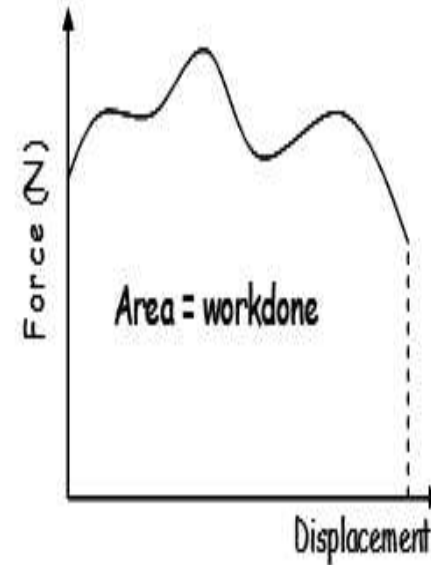
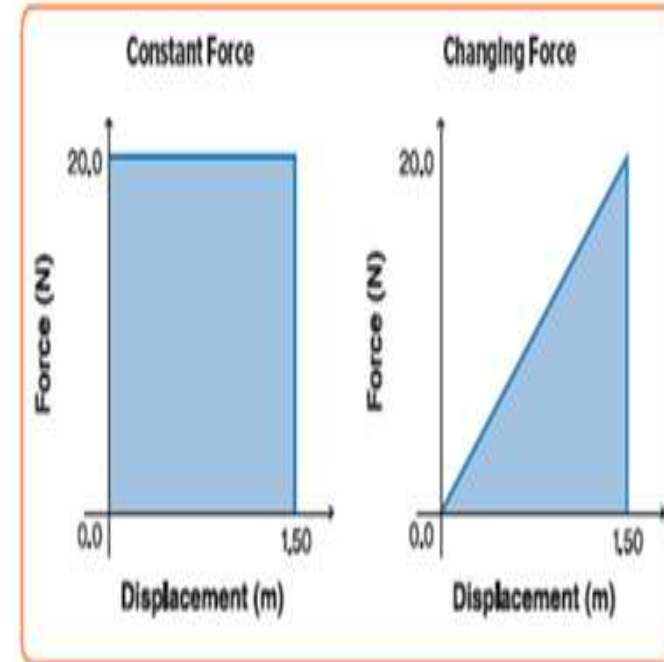
Total Work Done on a System

The **total work** done on a system is the sum of the work done by each body that exerts a force on the system.



Work done by a variable force

The area under a force-displacement graph is equal to the work.



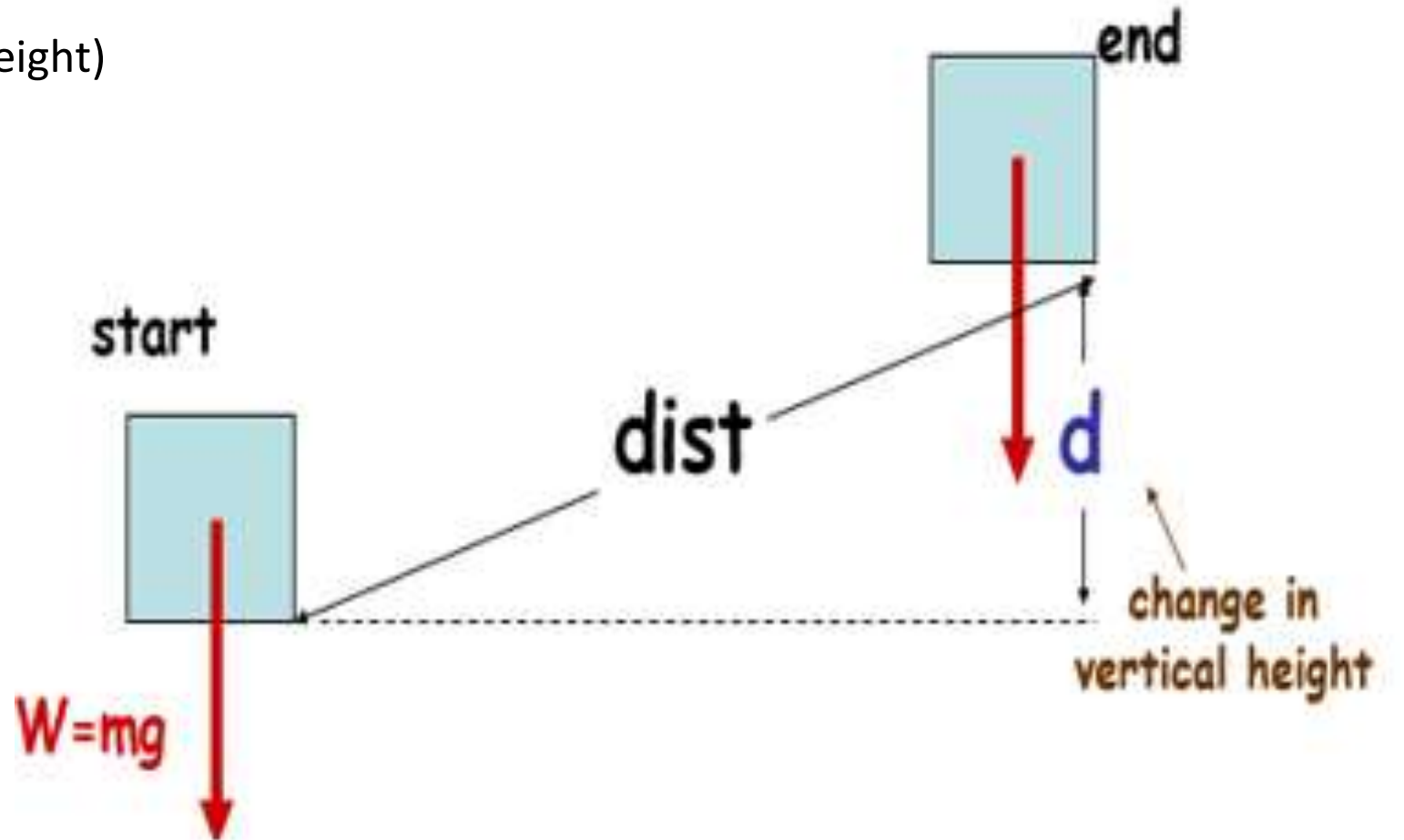
Work Done by Gravity

Work = Force x Displacement (or height)

$$W = F \times d$$

$$W = -mg \times h$$

$$W = -mgh$$



EXAMPLE Problem 2

ADDITIONAL PRACTICE

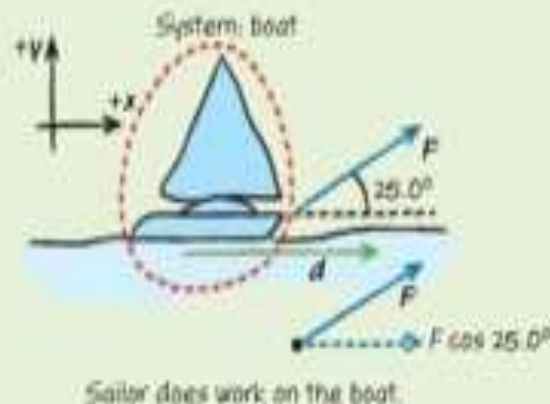
FORCE AND DISPLACEMENT AT AN ANGLE A sailor pulls a boat a distance of 30.0 m along a dock using a rope that makes a 25.0° angle with the horizontal. How much work does the rope do on the boat if its tension is 255 N?

1 ANALYZE AND SKETCH THE PROBLEM

- Identify the system and the force doing work on it.
- Establish coordinate axes.
- Sketch the situation showing the boat with initial conditions.
- Draw vectors showing the displacement, the force, and its component in the direction of the displacement.

Known
 $F = 255 \text{ N}$ $\theta = 25.0^\circ$
 $d = 30.0 \text{ m}$

Unknown
 $W = ?$



2 SOLVE FOR THE UNKNOWN

Use the definition of work.

$$W = Fd \cos \theta$$

$$= (255 \text{ N})(30.0 \text{ m})(\cos 25.0^\circ)$$

$$= 6.93 \times 10^3 \text{ J}$$

$$\text{Substitute } F = 255 \text{ N, } d = 30.0 \text{ m, } \theta = 25.0^\circ$$

3 EVALUATE THE ANSWER

- Are the units correct? Work is measured in joules.
- Does the sign make sense? The rope does work on the boat, which agrees with a positive sign for work.



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Practice Questions

Q1. Ahmed uses a force of 25 Newtons to lift his grocery bag while doing 50 Joules of work. How far did he lift the grocery bags?

Answer = 2 m

Q2. A baseball player does 1234 Joules of work when hitting a baseball into left field. Assuming the baseball landed 100 meters away from home plate, how much force did the player use to hit the ball?

Answer = 12.34 N

Q3. A force of 70 N acts on a 12 kg object at 60° to the horizontal and as a result, the object is displaced horizontally through a displacement of 23 m. Determine the work done on the object.

Answer = 805 J