Class Notes	
Class : IX	**Topics:** **(Gravitation)** **In- text and Exercise Q & A**
Subject: Physics	**Prepared by:** Arindam Pramanik

In – Text Questions:

Gravitation Exercise 134

1. State the universal law of gravitation

The universal law of gravitation states that every object in the universe attracts every other object with a force called the gravitational force. The gravitational force acting between two objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.
Consider two objects of masses m_1 and m_2 and let the distance between their centres be r. The gravitational force of attraction (F) acting between them is given by the universal law of gravitation as:

2. Write the formula to find the magnitude of the gravitational force between the earth and an object on the surface of the earth.

Let M be the mass of the Earth and m be the mass of an object on its surface. If R is the radius of the Earth, then according to the universal law of gravitation, the gravitational force (F) acting between the Earth and the object is given by the relation:

Gravitation Exercise 136

1. What do you mean by free fall?
Gravity of the Earth attracts every object towards its centre. When an object is released from a height such that it falls towards the surface of the Earth under the influence of gravitational force alone, the motion of the object is called free fall.

2. What do you mean by acceleration due to gravity?
During free fall of an object towards the earth, the magnitude of velocity of the falling object goes on increasing. This changing velocity produces acceleration in the object. This acceleration is known as acceleration due to gravity (g). Its value is given by 9.8 m/s^2.

Gravitation Exercise 138

1. What are the differences between the mass of an object and its weight?

See Gravitation III content for the answer.

2. Why is the weight of an object on the moon is 1/6th its weight on the earth?

Let M_E be the mass of the Earth and m be the mass of an object on the surface of the Earth. Let R_E be the radius of the Earth. According to the universal law of gravitation, weight W_E of the object on the surface of the Earth is given by,

$$W_E = \frac{GM_E m}{R_E^2}$$

Let M_M and R_M be the mass and radius of the Moon. Then, according to the universal law of gravitation, weight W_M of the same object on the surface of the Moon is given by:

$$W_M = \frac{GM_M m}{R_M^2}$$

$$\frac{W_M}{W_E} = \frac{M_M R_E^2}{M_E R_M^2}$$

Therefore, weight of an object on the moon is $1/6^{th}$ of its weight on the Earth.

Exercise Questions:

Gravitation Exercise 143

1. How does the force of gravitation between two objects change when the distance between them is reduced to half?

According to the universal law of gravitation, gravitational force (F) acting between two objects is inversely proportional to the square of the distance (r) between them, i.e.

$$F \propto \frac{1}{r^2}$$

If distance r becomes $r/2$, then the gravitational force will be proportional to $\frac{1}{\left(\frac{r}{2}\right)^2} = \frac{4}{r^2}$

Hence, if the distance is reduced to half, then the gravitational force would become four times.

2. Gravitational force acts on all objects in proportion to their masses. Why then, a heavy object does not fall faster than a light object?

It is true that gravitational force acts on all objects in proportion to their masses. But a heavy object does not fall faster than a light object. This is because of the reason that

$$\text{Acceleration} = \frac{\text{Force}}{\text{Mass}}$$

As Force ∝ Mass, therefore, acceleration is constant for a body of any mass.

3. What is the magnitude of the gravitational force between the earth and a 1 kg object on its surface? (Mass of the earth is 6×10^{24} kg and radius of the earth is 6.4×10^6 m).

According to the universal law of gravitation, gravitational force between two objects of masses M and m at a distance r from each other is given by:

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

Let mass of Earth be represented by $M = 6 \times 10^{24}$ kg
Let mass of the object be represented by m = 1 kg
Universal gravitational constant, $G = 6.7 \times 10^{-11}$ Nm^2 kg^{-2}
Since the object is on the surface of the Earth, r = radius of the Earth (R)
$r = R = 6.4 \times 10^6$ m

Gravitational force, $F = \frac{GMm}{R^2}$

$$\frac{6.7 \times 10^{-11} \times 6 \times 10^{24} \times 1}{(6.4 \times 10^{6})^2} = 9.8\ N$$

4. The earth and the moon are attracted to each other by gravitational force. Does the earth attract the moon with a force that is greater or smaller or the same as the force with which the moon attracts the earth? Why?

The Earth attracts the Moon with a force which is same as the force with which the moon attracts the Earth because according to Newton's third law of motion, force of action and reaction are always equal and opposite. So, the force of attraction of Earth on Moon is equal and opposite to the force of attraction of Moon on Earth.

5. If the moon attracts the earth, why does the earth not move towards the moon?

The Earth and the Moon experience equal gravitational forces from each other. However, the mass of the Earth is much larger than the mass of the Moon. Hence, it accelerates at a rate much lesser than the acceleration rate of the Moon towards the Earth. For this reason, we do not see the Earth moving towards the Moon.

Gravitation Exercise 144

6. What happens to the force between two objects, if

(i) the mass of one object is doubled?

(ii) the distance between the objects is doubled and tripled?

(iii) the masses of both objects are doubled?

According to the universal law of gravitation, the force of gravitation between two objects is given by:

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

(i) F is directly proportional to the product of masses of the objects. If the mass of one object is doubled, then the gravitational force will also get doubled.
(ii) F is inversely proportional to the square of the distance between the objects. If the distance is doubled, then the gravitational force becomes one-fourth of its original value.
Similarly, if the distance is tripled, then the gravitational force becomes one-ninth of its original value.
(iii) F is directly proportional to the product of masses of the objects. If the masses of both the objects are doubled, then the gravitational force becomes four times the original value.

7. What is the importance of universal law of gravitation?

The universal law of gravitation is important because it accounts for the force that binds us to the Earth, motion of planets around the Sun, motion of the Moon and other artificial satellites around the Earth, tides due to the Moon and the Sun and many other phenomena.

8. What is the acceleration of free fall?

When objects fall towards the Earth under the effect of gravitational force alone, then they are said to be in free fall. This force produces a uniform acceleration in the objects, which is called acceleration of free fall or acceleration due to gravity. Its value is 9.8 m/s^2.

9. What do we call the gravitational force between the Earth and an object?

Gravitational force between the Earth and an object is known as Earth's gravity or weight of the object.

10. Amit buys few grams of gold at the poles as per the instruction of one of his friends. He hands over the same when he meets him at the equator. Will the friend agree with the weight of gold bought? If not, why? [*Hint*: The value of *g* is greater at the poles than at the equator].

Weight of a body on the earth is given by:

$W = m\,g$

Where,

m = Mass of the body

g = Acceleration due to gravity

The value of g is greater at poles than at the equator. Therefore, the same mass of gold weighs lesser at the equator than at the poles. Hence, Amit's friend will not agree with the weight of the gold bought.

11. Why will a sheet of paper fall slower than one that is crumpled into a ball?

A sheet of paper has more surface area than a crumpled ball of paper. So, the resistance offered by air to a sheet of paper falling through it is more than the resistance offered to a falling crumpled ball of paper. This decreases the speed of the sheet of paper and hence it falls slower than the crumpled ball.

12. Gravitational force on the surface of the moon is only $\frac{1}{6}$ as strong as gravitational force on the Earth. What is the weight in Newton of a 10 kg object on the moon and on the Earth?

Weight = Mass × Acceleration

Acceleration due to gravity on earth, $g_e = 9.8\ m/s^2$

Therefore, weight of a 10 kg object on the Earth = 10 × 9.8 = 98 N

Acceleration due to gravity on Moon, $g_m = \frac{1}{6} \times g_e = \frac{9.8}{6}\ m/s^2$

Therefore, weight of the same object on the Moon = $10 \times \frac{9.8}{6} = 16.3\ N$

13. A ball is thrown vertically upwards with a velocity of 49 m/s. Calculate

(i) The maximum height to which it rises.

(ii) The total time it takes to return to the surface of the earth.

(i) For the upward motion of the ball, we use the equation:

$v^2 - u^2 = 2\,g\,h$

where,

u = Initial velocity of the ball = 49 m/s (Given)

v = Final velocity of the ball = 0 (At the highest point)

h = Maximum height attained by the ball

g = Acceleration due to gravity = -9.8 m/s^2 (Ball goes up)

Putting the values, we get

$0 - (49)^2 = 2 \times (-9.8) \times h$

$h = \frac{49 \times 49}{2 \times 9.8} = 122.5\ m$

(ii) Let t be the time taken by the ball to reach the height 122.5 m, then to calculate t we use the following equation of motion:

v = u + g t

Putting the values, we get

0 = 49 + (-9.8) × t

0 = 49 - 9.8 t

49 = 9.8 t

$t = \frac{49}{9.8} = 5\ s$

But, Time of ascent = Time of descent

Therefore, the total time taken by the ball to return = 5 + 5 = 10 s

14. A stone is released from the top of a tower of height 19.6 m. Calculate its final velocity just before touching the ground.

Initial velocity of the stone, u = 0

Final velocity of the stone, v =?

Height of the tower, h = 19.6 m

Acceleration due to gravity, g = 9.8 ms^{-2}

For a freely falling body:

$v^2 - u^2 = 2\ g\ h$

$v^2 - 0^2 = 2 \times 9.8 \times 19.6$

$v^2 = 19.6 \times 19.6 = (19.6)^2$

$v^2 = 384.16$

$v = \sqrt{384.16}$

v = 19.6 ms^{-1}

Hence, the velocity of the stone just before touching the ground is 19.6 ms^{-1}.

15. A stone is thrown vertically upward with an initial velocity of 40 m/s. Taking g = 10 m/s^2, find the maximum height reached by the stone. What is the net displacement and the total distance covered by the stone?

Given:

Initial velocity of the stone, u = 40 m/s

Final velocity of the stone, v = 0 (At the highest point)

Maximum height reached by the stone, h =?

Acceleration due to gravity, g = -10 ms^{-2} (Stone goes up)

Using the equation of motion:

$v^2 - u^2 = 2\ g\ h$

$0 - (40)^2 = 2 \times (-10) \times h$

0 - 1600 = - 20 h

-1600 = -20 h

1600 = 20 h

$\frac{1600}{20} = h$

$\therefore h = 80\ m$

Thus, total distance covered by the stone during its upward and downward journey = 80 + 80 = 160 m

Net displacement of the stone during its upward and downward journey = 0 (since final position coincides with the initial position)

16. Calculate the force of gravitation between the earth and the Sun, given that the mass of the earth = 6 × 10^{24} kg and of the Sun = 2 × 10^{30} kg. The average distance between the two is 1.5 × 10^{11} m.

According to the universal law of gravitation, the force of attraction between the Earth and the Sun is given by:

$$F = \frac{GM_{Sun}M_{Earth}}{R^2}$$

Where,
M_{Sun} = Mass of the Sun = 2 × 10^{30} kg
M_{Earth} = Mass of the Earth = 6 × 10^{24} kg
R = Average distance between the Earth and the Sun = 1.5 × 10^{11} m
G = Universal gravitational constant = 6.7 × 10^{-11} $Nm^2 kg^{-2}$
Substituting the values, we get

$$F = \frac{6.7 \times 10^{-11} \times 2 \times 10^{30} \times 6 \times 10^{24}}{(1.5 \times 10^{11})^2} = 3.57 \times 10^{22}\ N$$

17. A stone is allowed to fall from the top of a tower 100 m high and at the same time another stone is projected vertically upwards from the ground with a velocity of 25 m/s. Calculate when and where the two stones will meet.

Let the two stones meet after a time t.
(i) For the stone dropped from the top of the tower:
Initial velocity, u = 0
Let the displacement of the stone in time t from the top of the tower be s.
Acceleration due to gravity, g = 9.8 ms^{-2}
From the equation of motion,

$$s = ut + \frac{1}{2}gt^2$$

$$s = 0 \times t + \frac{1}{2} \times 9.8 \times t^2$$

$$\therefore s = 4.9\,t^2 \qquad \text{... (1)}$$

(ii) For the stone thrown upwards:
Initial velocity, u = 25 ms^{-1}
Let the displacement of the stone from the ground in time t be s'.
Acceleration due to gravity, g = -9.8 ms^{-2}
From the equation of motion,

$$s' = ut + \frac{1}{2}gt^2$$

$$s' = 25 \times t - \frac{1}{2} \times 9.8 \times t^2$$

$$\therefore s' = 25\,t - 4.9\,t^2 \qquad \text{... (2)}$$

The combined displacement (s + s') of both the stones at the meeting point is equal to the height of the tower 100 m.

From eqs. (1) and (2), we get,
$s + s' = 4.9\,t^2 + 25\,t - 4.9\,t^2$
$100 = 25\,t$

$$t = \frac{100}{25} = 4 \text{ sec}$$

In 4 s, the falling stone has covered a distance given by equation (1) as
$s = 4.9\ t^2 = 4.9 \times (4)^2 = 78.4$ m
Therefore, the stones will meet after 4 s at a height (100 - 78.4) = 21.6 m from the ground.

18. A ball thrown up vertically returns to the thrower after 6 s. find

(a) The velocity with which it was thrown up,

(b) The maximum height it reaches, and

(c) Its position after 4 s.

(a) Time of ascent is equal to the time of descent.
The ball takes a total of 6 s for its upward and downward journey.
Hence, it has taken 3 s to attain the maximum height.
Let the initial velocity of the ball be u.
Final velocity of the ball at the maximum height, v = 0
Acceleration due to gravity, $g = -9.8\ ms^{-2}$
From the equation of motion, v = u + gt, we get,
$0 = u + (-9.8) \times 3$
$0 = u - 29.4$
$u = 29.4\ ms^{-1}$
Hence, the ball was thrown upwards with a velocity of $29.4\ ms^{-1}$.

(b) Let the maximum height attained by the ball be h.
Initial velocity during the upward journey, $u = 29.4\ ms^{-1}$
Final velocity, v = 0
Acceleration due to gravity, $g = -9.8\ m\ s^{-2}$
From the equation of motion, $s = ut + \frac{1}{2}gt^2$

$$h = 29.4 \times 3 + \frac{1}{2} \times (-9.8) \times (3)^2$$

h = 44.1 m

(c) Ball attains the maximum height after 3 s. After attaining this height, it will start falling downwards.

In this case,

Initial velocity, u = 0

Position of the ball after 4 s of the throw is given by its position during the downward journey in 4 s - 3 s = 1 s.

From the equation of motion, $s = ut + \frac{1}{2}gt^2$ we get,

$$s = 0 \times 1 + \frac{1}{2} \times 9.8 \times (1)^2$$

$$s = 0 + \frac{1}{2} \times 9.8$$

$$s = \frac{9.8}{2}$$

$$\therefore s = 4.9 \text{ m}$$

Total height = 44.1 m

This means that the ball is 39.2 m (44.1 m - 4.9 m) above the ground after 4 seconds.

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