Gravitation - Lesson 1
A Brief History

4th Century BC, Greece

The first description of bodies falling downwards towards the centre was related to their nature was documented by the Greek philosopher Aristotle. This nature of objects getting attracted was due to their gravitas or heaviness.

3rd Century BC, Greece

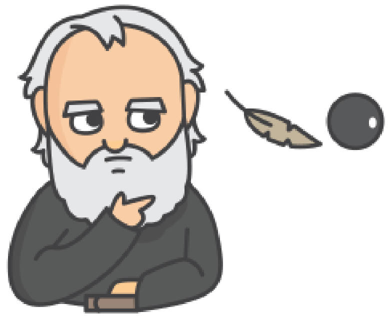
Archimedes discovered the centre of mass of a triangle and postulated the centre of mass of 2 equal weighing objects.

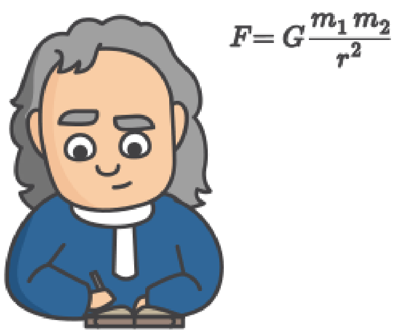
7th century AD, India

Brahmagupta called this invisible force of attraction *"gurutvaakarshan"*.

1589 - 1592 AD, Italy

Galileo Galilei showed that gravitational acceleration is the same for all falling objects. In short, all objects would fall at the same rate, if not for air resistance. He did that by dropping balls from the leaning Tower of Pisa.



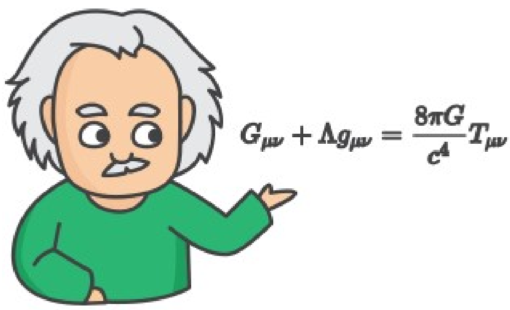


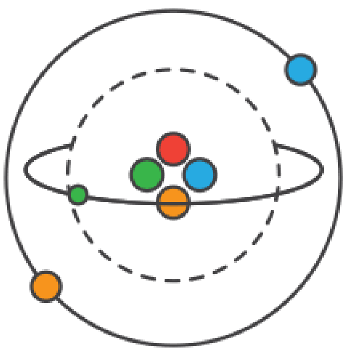
1687 AD, England

Sir Isaac Newton derived the Universal Law of Gravitation in "Principia".

1915 AD, Germany

Albert Einstien used the equivalence principle to develop the General Theory of Relativity, which remains the most extraordinary feat of human thinking about nature as summarised by Max Born.





Unknown, Unknown

Integration of Quantum Mechanics and General Relativity to form the Theory of Everything.

Note to Teacher

The text is aims to inform the vibrant and active history of gravitation. Although, the events listed here are limited, the teacher can give information about other important scientists such as Nicolaus Copernicus or Tycho Brahe. This lesson is inted to give an overvie of the past and can be used as a great tool to instill enthusiasm in the students.

Gravitation - Lesson 2
Introduction

Gravitational force is one of the four major forces (the other forces are Electromagnetic force, weak nuclear force and strong nuclear force). **It is particularly responsible for the invisible attraction among entities that have a property called mass.**

A brief description of the other three forces:

- **Electromagnetic force** explains the world of electricity and magnetism. Even though, the formula for gravity and electromagnetism is uncannily similar, the force of attraction/repulsion under simlar physical conditions is about 10^{36} times stronger than that of gravity.
- **Strong force** is the incredible force that holds the protons inside a neucleus. It is enormous in magnitude, but acts over a very small distance (about 10^{-15} m). It's strength is approximately 10^{38} times stronger than the force of gravity under similar circumstances. *Yeah!* It's that "strong".
- **Weak force** is responsible for radioactive decay. While, the effective range for this force is the least among all (about 10^{-18} m), it is about 10^{25} times stronger than the force of gravity under similar circumstances.

Although, gravity is the weakest force among all, it manages to keep massive planets revolve in an orbit. How? How does this mysterious force enables the formation of orbits? To understand the formation of orbits, we need to understand the independence of horizontal and vertical velocity.

You should, now, be able to answer the following questions:

1. Is gravitational force attractive or repulsive?
2. Define gravitational force?
3. What particular property should an object have so that gravitational force can act upon it?

Conclusion

Gravitational force is the force that pulls together massive entities. It is also the weakest force among the four fundamental forces.

Note to Teacher

The text is intended to give students a feel about all the forces present in nature. As gravitational force is the focus here, the text tries to draw comparison between all the other forces to the gravitational force. The lesson also aims to introduce few major questions that will increase the inquisitiveness of the reader.

Student Worksheet

1. Can gravitational force be repulsive?
2. List all the fundamental forces present in nature?
3. Which is the strongest force in nature?

Gravitation - Lesson 3
Independence of Horizontal and Vertical Velocity

We have all played with stones, and we throw them up in the air for fun. We know that the stone falls back to the surface of the earth. We have also seen how the stone, when thrown forward, falls back after covering some horizontal distance, i.e., the stone goes ahead and also falls. Now, there is a fact hidden in these two scenarios, the amount by which the stone falls is the same in both the cases or specifically, if you used the same initial conditions (namely, the initial vertical velocity) in throwing both the objects, it would hit the surface of the earth at the same time.

If you throw a stone up vertically and it takes 10 seconds to fall, if you threw the same stone at an angle with the same vertical velocity, it will also take 10 seconds to hit the surface of the earth. The only difference is that you can catch the stone wherever you were standing when you threw the stone in the first case, but in the second case, you need to run forward to at least have a chance of catching it. We can reverse this fact and say that a stone will fall a constant distance (we will calculate this later) in constant period of time, no matter how it is thrown!

You should, now, be able to answer the following questions:

1. Consider a scenario where two marbles hit the ground at the same time, falling from the same height. Also, they started to fall at the same instance. If the first marble started with a vertical velocity of 2 $m\ s^{-1}$ and a horizontal velocity of 0 $m\ s^{-1}$, what was the vertical velocity of the second marble, given that its horizontal velocity was 2 $m\ s^{-1}$?
2. In the above scenario, the first marble fell 20 m in the first 2 s. How much distance did the second marble cover in its first 2 s of fall?

Conclusion

Objects will fall at the same rate if the initial vertical velocity is kept the same.

Note to Teacher

This lesson tries to throw light on the fact that horizontal and vertical velocity of an object are never ineter-related, they are always independent. And this is case in the whole universe, it dosen't, in any way, conform only to earth. Although, this is non-trivial and may not be a part of the syllabus, it helps to understand the way components of velocity work. This will set the tone for the upcoming lessons.

Student Worksheet

1. Under what condition will two objects hit the surface at the same time?
2. If we add a horzontal velocity, i.e., if we throw the object forward, will the above be true?
3. What can you say about the vertical distance travelled by them at each instance of time?

Gravitation - Lesson 4
Formation of Orbits

Let’s for a moment put our thinking hats on and think that we have infinite energy and we can throw it at any distance we want to. Let’s go up on the terrace of a multi-storey building and start throwing stones (imaginary ones, or else it will get dangerous!). So whenever we throw a stone, remember that it will fall about a constant in 1 second. So when we throw a stone horizontally, it covers some horizontal distance (depending on the strength of the throw) but covers the same vertical distance (i.e., the building’s height) vertically every time. Therefore, when you start increasing the strength of the throw, the stone goes farther and farther from you but falls the same amount, the height of the building, every time. But, as soon as we reach the realms of superman’s throwing capacities, we need to keep in mind that the earth is round, and at some point, we will throw the stone with such a strength that it will fall greater than the height of the building as the earth’s surface curves. So, the stone is trying to fall to the surface from the stone’s perspective, but the earth’s surface keeps on curving, and the stone takes longer to fall. And, in fact, we will find a sweet point, when the earth curves the same amount, the stone falls, and in this bizarre case, the stone never touches the ground but is continuously "falling". Man, it would be damn difficult being this stone, it’s like trying to reach a delicious fruit, but it is just out of our reach.

You should, now, be able to answer the following questions:

1. What would happen if we did the same activity as above, but the earth was flat?
2. In the fourth animation, why does the stone take longer time to fall?
3. Would we observe the same for any object like a paper ball or a table tennis ball? Does this experiment hold true for all types of objects? Give it a thought.

Conclusion

Orbits are formed when an object attains a perfect velocity such that the amount by which the earth curves is the same amount by which the object "falls".

Note to Teacher

The text aims to give a visual narrative for gravitation and the formation of orbits. Along with the animation, it provides an experimental insight on the formation of orbits. It tries to relate the simple concept of falling with the formation of orbits, eventhough falling is not scientifically correct. The goal is to understand the consequences of gravitation before jumping into the mathematical modelling for the same. Just as falling is a consequence of gravity, so is formation of orbits, but the relation betweem them is not straight-forward. Here the text tries to connect the two.

Student Worksheet

1. How much distance is the stone falling during the initial phase of the imaginary activity?
2. Is there any scenario where the stone travels more than the building's height?
3. Under what condition does the stone travels more than the building's height?

Gravitation - Lesson 5
Centripetal Force

So, if we think about it, the moon is continuously *"falling"* towards the earth. The earth, along with other planets, is continuously *"falling"* towards the Sun and this, so called *"fall"*, is due to the gravitational force. *"Falling"* is not scientifically accurate, in reality things are pulled towards the centre. **A force that keeps an object in a circular motion by pulling it towards the centre is known as centripetal force.** This is why the moon is orbiting the earth, the earth, along with other planets, is orbiting the Sun and this very force is also responsible for the falling of objects on the ground when thrown up. This force is provided by the earth to the moon making it constantly revolve around the earth and not flying off on a tangent! The same is true for the Sun and Earth system.

What happens if there is no centripetal force?

You should, now, be able to answer the following questions:

1. What is centripetal force?
2. Is it the same force that we experience when a vehicle takes a turn?

3. Give some real-world examples where we see centripetal force in action?
4. Is gravitational force a type of centripetal force?

Conclusion

Centripetal force is a centre-pulling force that acts on objects when moving in a circular motion. Gravitational force is a type of centripetal force.

Note to Teacher

The goal of the text is to introduce centripetal force and its importance. It is important to realise that gravitational force is a centripetal force and subsequntly the word "falling" is a consequense of this centripetal force.

Student Worksheet

1. The force that acts towards a point (central) is also known as ________________.
2. What force causes an apple to fall?
3. Is the moon also orbiting the earth due to the same force?
4. What is the name of the centripetal force exerted by all objects which has mass?

Gravitation - Lesson 6
What happens if there is no Centripetal Force?

In the absence of this centripetal force, which we call gravitational force, planets will not conform to orbits, nor will matter form spherical blobs called planets. If we switch off gravity, the earth will continue to move but in a straight line. It is the same effect when we tie a string to a stone and rotate it above our head, like a helicopter. If the string breaks, it will set off in a straight line which is the tangent to the circle of revolution. This happens because the force applied is suddenly removed, and there is no force to bend the stone towards the centre. This force is essential for the occurence of nature as we see and observe it.

Apart from this, there are various phenomena that occur due to gravity, such as the occurrence of high and low tides and the fact that we are always stuck to the earth’s surface.

You should, now, be able to answer the following questions:

1. In the absence of centripetal force, if an object goes off in the tangential direction. What is the angle between the line showing the direction of centripetal force and the line showing the direction of motion?

2. What if instead of switching of the gravitational force, we gradually increase it. How would the motion look?

Conclusion

In the absence of centripetal force, the object in circular motion will fly off in a straight line which is the tangent at that point.

Note to Teacher

THaving introduced centripetal force in the previous lesson, the purpose of the lesson is to give the reader an understanding about the absence of centipetal force. It enforces the importance of it as well. The text relates the whirling of stone to centripetal force, an important comparision. The goal here is to understand that any object under the influence of centripetal force will travel in a straight line when the centripetal force is switched off suddenly.

Student Worksheet

1. Absence of centripetal force will enable the object to move in a
   (a) spiral
   (b) circle
   (c) straight line
   (d) zigzag path
2. The above path also forms a ________________ to the circle.
3. Why is the above path a stratight line?

Gravitation - Lesson 7
The Barycentre

Incidentally, an object falling towards the earth also accelerates the earth towards it (according to Newton's third law of motion). Still, the magnitude of the acceleration is so small that it does not affect anything whatsoever. The same holds true for the Sun. The earth does accelerate the Sun towards it, but it is negligible. However, when the small, negligible force of all the planets (thrown in the asteroid belt as well) is combined, the Sun does start to revolve around a point, and this point, known as the barycenter, is the centre of our solar system, not the Sun. Everything in our solar system revolves around this point, including the Sun. Formally barycentre is defined as the central point around which two or more bodies revolve.

You should, now, be able to answer the following questions:

1. Does a small object falling towards the earth makes it accelerate?
2. What is the centre of our solar system?

Conclusion

The Barycentre is the central point around which two or more bodies revolve.

Note to Teacher

This lesson aims to throw light on the fact that every body, no matter how massive it is, does experience an equal an opposite force as stated in Newton's third law. The goal is to realise that the sun itself reveloves around a point and this is true for all solar systems present in the unvierse. The text intends to create intriguing thoughts in the reader's mind.

Student Worksheet

1. If an object falling towards the earth also accelerates the earth towards it. Why don't we feel the acceleration?
2. Does the moon, really, revolve around the earth?

Gravitation - Lesson 8
Experiments on Centripetal Force

1. **Centripetal Force**

    (i) Take a piece of thread.

    (ii) Tie a small stone at one end. Hold the other end of the thread and whirl it round, as shown in Figure.

    (iii) Note the motion of the stone.

    (iv) Release the thread.

    (v) Again, note the direction of motion of the stone.

2. **Artificial Gravity**

    (i) Take a pneumatic piston and attach a ball to one end and an electric motor to another.

    (ii) Start the motor and see the ball increase its distance from the centre as the speed of rotation is increased.

3. **Marble Gravitron**

   (i) Take a marble and place it inside a wine glass.
   (ii) Swiftly whirl the wine glass so that the marble starts rolling.
   (iii) Whirl it fast enough, and you can invert the glass without letting the marble fall.

Note to Teacher

The aim of the experiments is to understand centripetal force in a more practical manner. This will give a break from the myrad theoretical reading and create curiosity about the application of the previously studied lessons.

Gravitation - Lesson 9
Mathematical Formulation of Gravity

In the summer of 1687, Newton published “Principia Mathematica”, which also described the mathematics of gravity among many other groundbreakings and astonishing mathematical works. He describes the **Universal law of gravitation** as follows:

Every object in the universe attracts every other object with a force that is:

1. Directly proportional to the product of their masses, and
2. Inversely proportional to the square of the distance between them.

This statement can be simply divided into two parts to make it easier to write the mathematical form.

Consider two bodies, A and B, of mass M and m respectively, then by the first part of the law, the force of gravity.

$$F \propto Mm \tag{1}$$

And assuming that they are separated by a distance, r, then

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

Combining both the bits gives,

$$F \propto \frac{Mm}{r^2} \tag{3}$$

A constant is introduced to remove the proportionality. It's called the **"Universal Gravitational Constant"**, G, whose SI Units is $N\,m^2\,kg^{-2}$. The value of G is $6.673 \times 10^{-11}\,N\,m^2\,kg^{-2}$.

So the final equation is,

$$F = G\,\frac{Mm}{r^2} \tag{4}$$

Let us look at a few examples:

1. **Example 1:** At some point of the year, Jupiter is about $5.8 \times 10^{11}\,m$ away from earth. Calculate the gravitational force between the two. Given that the mass of Jupiter is $1.9 \times 10^{27}\,kg$, the mass of the Earth is $6 \times 10^{24}\,kg$, and the universal gravitational constant is $6.67 \times 10^{-11}\,N\,m^2\,kg^{-2}$

   Answer
   The mass of the earth, $M = 6 \times 10^{24}\,kg$,
   The mass of Jupiter, $m = 1.9 \times 10^{27}\,kg$,
   The distance between the earth and Jupiter, $r = 5.8 \times 10^{11}\,m$
   From Eq. (4), the gravitational force between the two is,

   $$\begin{aligned} F &= G\,\frac{Mm}{r^2} \\ &= (6.67 \times 10^{-11}\,N\,m^2\,kg^{-2}) \times \frac{(6 \times 10^{24}\,kg)(1.9 \times 10^{27}\,kg)}{(5.8 \times 10^{11})^2} \\ &= 2.26 \times 10^{18}\,N \end{aligned}$$

   Thus, the gravitational force between Earth and Jupiter is $2.26 \times 10^{18}\,N$.

2. **NCERT Example:** The mass of the earth is $6 \times 10^{24}\,kg$ and that of the moon is $7.4 \times 10^{22}\,kg$. If the distance between the earth and the moon is $3.84 \times 10^5\,km$, calculate the force exerted by the earth on the moon. (Take $G = 6.67 \times 10^{-11}\,N\,m^2\,kg^{-2}$)

Answer

The mass of the earth, $M = 6 \times 10^{24}\ kg$,
The mass of moon, $m = 7.4 \times 10^{22}\ kg$,
The distance between the earth and the moon,

$$
\begin{aligned}
d &= 3.84 \times 10^5\ km \\
&= 3.84 \times 10^5 1000\ m \\
&= 3.84 \times 10^8\ m \\
G &= 6.7 \times 10^{-11}\ N\,m^2\,kg^{-2}
\end{aligned}
$$

From Eq. (4), the force exerted by the earth on the moon is,

$$
\begin{aligned}
F &= G\frac{Mm}{d^2} \\
&= \frac{(6.7 10^{-11} N\,m^2\,kg^{-2}) \times (6 \times 10^{24}\ kg) \times (7.4 \times 10^{22}\ \ kg)}{(3.84 10^8\ \ m)^2} \\
&= 2.02 10^{20}\ \ N
\end{aligned}
$$

Thus, the force exerted by the earth on the moon is $2.02 \times 10^{20}\ N$.

You should, now, be able to answer the following questions:

1. What is the universal law of Gravitation?
2. Write down the formula for the force of gravitation between two objects?
3. Consider the gravitational force between two objects of the same mass to be F. If the mass of one object is reduced by half, the gravitational force between them
   (a) Halved
   (b) Doubled
   (c) Tripled
   (d) Quadrupled
4. If the distance between them is reduced by half, keeping their masses equal, the gravitational force between them is
   (a) Halved
   (b) Doubled
   (c) Tripled
   (d) Quadrupled

Conclusion

Universal Law of Gravitation states that every object in the universe attracts every other object with a force that is directly proportional to the product of their masses, and inversely proportional to the square of the distance between them.

Note to Teacher

Having introduced centripetal force in the previous lesson, the purpose of the lesson is to give the reader an understanding about the absence of centipetal force. It enforces the importance of it as well. The text relates the whirling of stone to centripetal force, an important comparision. The goal here is to understand that any object under the influence of centripetal force will travel in a straight line when the centripetal force is switched off suddenly.

Student Worksheet

1. Gravitational force always acts along the ________________.
2. Gravitational force is directly proportional to ________________.
3. Gravitational force is inversely proportional to ________________.
4. What is the SI units of the universal gravitational constant?
5. What is the value of the universal gravitational constant?

Gravitation - Lesson 10

How was the Universal Gravitation Constant Determined?

Sir Henry Cavendish first discovered the Gravitational constant in a famous experiment named *"Weighing the world"* in 1797, more than 100 years later than Newton's law of gravitation. In this experiment, he stuck two steel balls of equal mass to a rigid rod, and he hung the centre of the rod. He connected the other end of the rod to a torsional spring and measured the rotational force experienced by the two balls. Two massive lead balls were fixed at a distance from the steel balls. The lead balls attracted the steel balls, and the rigid rod rotated. Hence, the reading of the force was measured. In this experiment, he measured F, and both the masses were known as well as the distance between them. The only unknown was the Gravitational constant, which was calculated using the above values. The reason this experiment was named "Weighing the world" because by knowing the gravitational constant, one could measure the mass of the earth.

You should, now, be able to answer the following questions:

1. Who discovered the value for the universal gravitational constant?

2. Calculate the universal gravitational constant, G, from the experimental results as given below:
   Mass of the lead ball, M = 160 kg,
   Mass of the steel ball, m = 1 kg,
   Distance between the lead and the steel ball, r = 0.225 m,
   Force experienced by the lead ball, $F = 2.1 \times 10^{-7}$ N

Conclusion

Universal Gravitational Constant was measured in 1797 by Sir Henry Cavendish using an apparatus which could measure the force between two solid lead and steel balls kept at a distance.

Note to Teacher

The goal of the text is to introduce Sir Henry Cavendish and his famous experiment. This lesson tries to illustrate different parts of the experiment that led to the discovery.

Student Worksheet

1. How was the force measured in the above experiment?
2. Why was the experiment named "Weighing the world"?

Gravitation - Lesson 11
A Little Help from Kepler

Johannes Kepler was a very talented astronomer and a mathematician. He lived in the 17th Century and is regarded as one of the key personalities to bring the scientific revolution to its peak. In 1602, Kepler was trying to calculate the position of the earth in its orbit and in turn stumbled on the fact that **"The radius vector describes equal areas in equal times."**, which, incidentally, became his second law.

In 1605, when sifting through the data collected by Tycho Brahe (another great scientist) on the orbit of Mars, he found that the orbit would perfectly fit an ellipse. Hence, he published the first law as **"Planets move in ellipses with the Sun at one focus".**

And in May 1618, he found the third law, which ultimately led Newton to form the Universal law of gravitation, which goes like **"The squares of the periodic times are to each other as the cubes of the mean distances".**

But how did these help Newton formulate his law? Suppose we step into Newton's shoes for a moment. In that case, we can think that by Kepler's first law, **"The orbit of a planet is an ellipse with the Sun at one of the foci"**, we can assume that the orbit is circular as a circle is a special type of ellipse with both its foci coinciding at the centre. In this exceptional case, the planet of mass M is going around the Sun at velocity v, and the radius is r.

The centripetal force experienced by the planet is:

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

As mass is a constant, we can write the above as:

$$F_c \propto \frac{v^2}{r}$$

As the motion of the planet is periodic, let us assume the period to be T, which means the planet takes T amount of time to complete one revolution around the Sun.
Then the velocity of the planet is given by

$$velocity = \frac{Distance}{Time}$$

In T amount of time, the distance covered by the planet is the circumference of the circle of revolution which is $2\pi r$. Therefore,

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

Substituting this in F_c gives,

$$F_c \propto \frac{r}{T^2}$$

which can also be written as,

$$F_c \propto \frac{r^3}{T^2} \times \frac{1}{r^2}$$

By Kepler's III law,

$$\frac{r^3}{T^2} = constant$$

which implies,

$$F_c \propto \frac{1}{r^2} = constant$$

This is how Newton arrived at the famous inverse square relationship for the universal law of gravitation.

You should, now, be able to answer the following questions:

1. What is the shape of the orbit under the influence of the gravitational force?

2. State three Kepler's laws of planetary motion?

Conclusion

Kepler's laws of planetary motion:

1. Planets move in ellipses with the Sun at one focus.
2. The radius vector describes equal areas in equal times.
3. The squares of the periodic times are to each other as the cubes of the mean distances.

Note to Teacher

The text intends to explain the three laws of planetary motion by Kepler and its importance. It is important to realise that these laws helped Newton to discover the universal law of gravitation. The text tries to explain the route that Newton might have taken to react that conclusion. This lesson gives an insight into the great minds of Newton and Kepler.

Student Worksheet

1. State the second law of planetary motion?
2. Describe its consequnece? *Hint:* Think about speed

Gravitation - Lesson 12
Experiments on Freefall

1. **Freefalling Stone**

   (i) Take a stone.

   (ii) Throw it upwards.

   (iii) It reaches a certain height, and then it starts falling.

2. **Falling Paper And Stone**

   (i) Take a sheet of paper and a stone. Drop them simultaneously from the first floor of a building. Observe whether both of them reach the ground simultaneously.

   (ii) We see that paper reaches the ground a little later than the stone. This happens because of air resistance. The air offers resistance due to friction to the motion of the falling objects. The resistance offered by air to the paper is more than the resistance offered to the stone. If we do the experiment in a glass jar from which air has been sucked out, the paper and the stone would fall at the same rate.

3. **Freefalling Coins**

(i) Take a square bell jar and evacuate it.
(ii) Hold two iron coins (or any iron metal) of different weight and size with an electro-magnet.
(iii) As you switch off the magnet, let them fall on two switches, lighting two bulbs of different colours.
(iv) They should glow at the same instant.
(v) Do the experiment with air, and they should fall at different rates due to air drag.

4. **Forceless Water Bottle**

(i) Take a water bottle and punch a few holes in it at the bottom.
(ii) Fill it with water and let it out the holes.
(iii) Leave the bottle from a height and see the water does not come out during free fall. Gravity doesn't work under freefall, which means while freefalling, you'll feel the same weightlessness as you'd fell in outer space in the absence of gravity. This consequence led to Einstein's formulation of general relativity.

Note to Teacher

The goal of the experiments is to introduce the concept of freefall. This does not explain freefall, but lays out its consequences. Most of these can be done at home or can be demonstrated to get more clarity.

Gravitation - Lesson 13
Understanding Freefall

What happens when you let go of a stone from a multi-storey building? It just falls. Why does it fall? Simple, because the earth's gravity is pulling the object towards the centre. More precisely, due to the earth's gravitational force, the object is pulled. But a simple consequence of force acting on an object is to change its velocity (either magnitude or direction). And therefore, the object does accelerate, and this acceleration is called the acceleration due to gravity, g. An interesting fact about this effect is that It does not depend on mass, as the force of gravity is proportional to the mass of the object. Still, the reaction of any object under the influence of a force is also proportional to its mass. Hence, the acceleration under gravity is independent of the mass of the object. Mathematically speaking,

$$Force = m \times a$$

$$Force(Gravity) = G\,\frac{Mm}{r^2}$$

When an object falls, the objects experiences an accelration given by,

$$ma = G\,\frac{Mm}{r^2}$$

$$a = G\,\frac{M}{r^2} = g$$

This has units of $m\ s^{-2}$.

The above also shows that the acceleration due to gravity is independent of the mass and constant *(but not quite!)*. This fact was tested by Galileo Galilei, as stated earlier in the chapter. This means that any two objects will fall at the same time when left from the same height (in the absence of air resistance). We can find the value of 'g' by using the data already available,

Universal Gravitation Constant, $G = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$,
Mass of the Earth, $M = 6 \times 10^{24}\ kg$, and
The radius of the earth, $r = 6.4 \times 10^6\ m$

Substituing this in the above equation,

$$ma = G\,\frac{Mm}{r^2}$$

$$g = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}\ \frac{6 \times 10^{24}\ kg}{(6.4 \times 10^6\ m)^2} = 9.8\ m\ s^{-2}$$

Sidenote: If we closely look at the above equation ($g = .../r^2$), it is an inverse function of radius from the centre. Therefore, g reduces as altitude increases, and it is also greater at the equator than at the poles, as the earth is not a perfect sphere and instead a sphere with a flattened top and bottom. But for the most part, this deviation is minimal and often neglected. For simplicity, we will assume that the acceleration due to gravity is a constant on the earth.

If that's the case, the trajectory of any object under gravitational acceleration can be figured out by equations of motion in a straight line. These are the set of 3 equations that were derived in the earlier chapters, to refresh,

Final velocity, v, of an object starting with an initial velocity, uu, after a time, t, is

$$v = u + at$$

If the distance, s, is to found after this elapsed time, t, then

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

Final velocity, v, of an object starting with an initial velocity, u, after covering a distance, s, is

$$v^2 = u^2 + 2as$$

Note: If acceleration is opposing the trajectory of motion, we will assign a -ve sign to it to show that it decreases the velocity rather than adding to it.

Let us look at a few examples:

1. **Example 1:** A ball is thrown upwards with an initial velocity of 2 $m\ s^{-1}$. Calculate the maximum height reached. Take g = 10 $m\ s^{-2}$.

   Answer
   Initial velocity, u = 2 $m\ s^{-1}$,
   At the maximum height, the object will stop.
   Hence, Final velocity, v = 0 $m\ s^{-1}$,
   As acceleration due to gravity is acting opposite to the direction of motion.
   Hence, $g = -10\ m\ s^{-2}$.

   Maximum height is the distance travelled by the ball.
   We know that,

$$
\begin{aligned}
v^2 &= u^2 + 2\,a\,s \\
0 &= (2)^2 + 2 \times (-10\ m\ s^{-2}) \times s \\
-4 &= -20 \times s \\
s &= 0.2\ m
\end{aligned}
$$

2. **Example 2:** A ball is dropped from a height of 20 m. Calculate the velocity with which it hits the ground. Take g = 10 $m\ s^{-2}$.

   Answer
   Initial velocity, u = 0 $m\ s^{-1}$,
   Distance, s = 20 m,
   As acceleration due to gravity is acting along to the direction of motion.
   Hence, g = 10 $m\ s^{-2}$.

   We know that,

$$
\begin{aligned}
v^2 &= u^2 + 2\,a\,s \\
v^2 &= (0)^2 + 2 \times (10\ m\ s^{-2}) \times 20 \\
v^2 &= 20 \times 20 \\
v &= \sqrt{400}\ m \\
v &= 20\ m\ s^{-1}
\end{aligned}
$$

3. **Example 3:** A ball is dropped from a certain height takes 5 s to hit the ground. Calculate the velocity of the ball when it hits the surface. Take g = 10 $m\ s^{-2}$.

Answer
Initial velocity, $u = 0\ m\ s^{-1}$,
As acceleration due to gravity is acting along to the direction of motion.
Hence, $g = 10\ m\ s^{-2}$.
Time taken, $t = 5\ s$

We know that,

$$v = u + a\,t$$
$$v = 0 + (10\ m\ s^{-2}) \times 5$$
$$v = 50\ m\ s^{-1}$$

4. **Example 4:** A ball is thrown down with an initial velocity of $10\ m\ s^{-1}$ and it takes 20 seconds to hit the ground. Calculate the distance travelled by the ball. Take $g = 10\ m\ s^{-2}$.

Answer
Initial velocity, $u = 10\ m\ s^{-1}$,
As acceleration due to gravity is acting along to the direction of motion.
Hence, $g = 10\ m\ s^{-2}$.
Time taken, $t = 20\ s$

We know that,

$$s = ut + \frac{1}{2}\,a\,t^2$$
$$s = 10\ m\ s^{-1} \times 20\ s + \frac{1}{2} \times 10\ m\ s^{-2} \times (20\ s)^2$$
$$s = 2200\ m$$

5. **NCERT Example:** A car falls off a ledge and drops to the ground in $0.5\ s$. Let $g = 10\ m\ s^{-2}$ (for simplifying the calculations).

(i) What is its speed on striking the ground?
(ii) What is its average speed during the $0.5\ s$?
(iii) How high is the ledge from the ground?

Answer
Time taken, $t = \frac{1}{2}\ s$
Initial velocity, $u = 0\ m\ s^{-1}$,
As acceleration due to gravity is acting along to the direction of motion.

Hence, g = 10 $m\ s^{-2}$.
Acceleration of the car, a = +10 $m\ s^{-2}$ (downward)

(i) speed,

$$\begin{aligned} v &= at \\ &= 10\ m\ s^{-2} \times 0.5\ s \\ &= 5\ m\ s^{-1} \end{aligned}$$

(ii) average speed,

$$\begin{aligned} &= \frac{u+v}{2} \\ &= \frac{(0\ m\ s^{-1} + 5\ m\ s^{-1})}{2} \\ &= 2.5\ m\ s^{-1} \end{aligned}$$

(iii) distance travelled,

$$\begin{aligned} s &= \frac{1}{2}\ a\ t^2 \\ &= \frac{1}{2} \times 10\ m\ s^{-2} \times (0.5\ s)^2 \\ &= \frac{1}{2} \times 10\ m\ s^{-2} \times 0.25\ s \\ &= 1.25\ m \end{aligned}$$

Thus,

(i) its speed on striking the ground, = 5 $m\ s^{-1}$
(ii) its average speed during the 0.5 s = 2.5 $m\ s^{-1}$
(iii) height of the ledge from the ground, = 1.25 m

6. **NCERT Example:** An object is thrown vertically upwards and rises to a height of 10 m. Calculate (i) the velocity with which the object was thrown upwards and (ii) the time taken by the object to reach the highest point.

Answer
Distance travelled, s = 10 m
Final velocity, v = 0 $m\ s^{-1}$,
Acceleration due to gravity, g = 9.8 $m\ s^{-2}$.

Acceleration of the object, $a = -9.8\ m\ s^{-2}$ (upward motion)

(i)

$$\begin{aligned} v^2 &= u^2 + 2\,a\,s \\ 0 &= u^2 + 2 \times (-9.8\ m\ s^{-2}) \times 10\ m \\ -u^2 &= -2 \times 9.8 \times 10\ m^2\ s^{-2} \\ u &= \sqrt{196}\ m\ s^{-1} \\ u &= 14\ m\ s^{-1} \end{aligned}$$

(ii)

$$\begin{aligned} v &= u + a\,t \\ 0 &= 14\ m\ s^{-1} u^2 - 9.8\ m\ s^{-2} \times t \\ -u^2 &= -2 \times 9.8 \times 10\ m^2\ s^{-2} \\ t &= 1.43\ s \end{aligned}$$

Thus,

(i) initial velocity, $u = 14\ m\ s^{-1}$
(ii) Time taken, $t = 1.43\ s$

You should, now, be able to answer the following questions:

1. Does a freefalling object accelerate? If yes, what is the value of the acceleration?
2. Why is the acceleration under freefall independent of the object's mass?
3. Does the value of the acceleraion under gravity vary on the surface of the earth? If yes, at what point on the surface of the earth is it the highest and what point is it the lowest?
4. Two objects, one weighing 2 *kg* and another 200 *kg*, are dropped from a height of 10 *m*. Will they hit the ground at the same moment with the same velocity?

Conclusion

On any planet, a freefalling object (under gravity) experiences an acceleration independent of its mass.

Note to Teacher

The goal of the lesson is to introduce the important concept of freefall with all the mathematical tools reqired to solve problems related to it. It relates different consequences of freefall such as acceleration, position, time and velocity. The lesson also explains the dependency of the value of acceleration on the location on the earth. Sufficient time must be given to understand this lesson and solve many numericals to get the required familiarity for the topic.

Student Worksheet

1. Does a small object falling towards the earth makes it accelerate?
2. If yes, calculate the acceleration experienced by the earth?

   Hint: g = 10 $m\ s^{-2}$, m = 0.2 kg, r = 6371 $\times$ 10^3 m
3. Does the motion of an object depends on its mass under freefall?
4. If not, why does a nail fall faster than a feather?
5. Is the value of g constant on the earth?
6. Why is it not constant?
7. How much distance does an object of mass 10 kg fall in 1 s?
   (Take g as 10 $m\ s^{-2}$).
8. How much distance does an object of mass 100 kg fall in 2 s?
   (Take g as 10 $m\ s^{-2}$).
9. Will a ball point pen work in space? If yes, why? If no, why?
10. Take a matchbox and keep a small piece of paper on top such that no part of the paper is protruding from the sides. With this setup, drop this from a height. Which will hit the ground first?
    (a) Matchbox
    (b) Paper
    (c) Both
    (d) None of the above

Gravitation - Lesson 14
Mass vs Weight

Mass is an *intrinsic property of an object which is a constant*, whereas **weight** is the *force experienced by the object under a gravitational field.* Weight is proportional to the mass of the object. The mass of an object remains the same everywhere, but its weight changes as g changes. But, in real life, we do interchange these words as if they mean the same. But that is not correct. Mass is something that resists the change in position or velocity of an object, meaning the greater the mass, the greater the force required to move a body. We call this property as inertia. But weight is just the force experienced by an object due to gravity. Incidentally, as acceleration due to gravity is no constant on earth, the force experienced by a body is also no a constant, it changes with loacation. That is why we interchange these, but in reality, weight is a force and is measured in Newtons (N), not Kgs or grams. We can calculate the weight of an object as,

$$W = m \times g \ Newtons$$

We can read it as, $W \propto m$, and hence we use it as an indicator for the mass of the object.

Sidenote: There is no method available to measure mass as it is an intrinsic property. We can only measure its effect. One of its effects is the weight experienced by the object. Therefore we use different methods to find the weight and then divide the weight by 9.8 to get the mass in Kgs or grams.

Let us look at a few examples:

1. **Example 1:** Weight of an object on earth is 980 N. What is its mass?

   Answer
   Weight, W = 980 N,
   Acceleration due to gravity, $g = 9.8\ m\ s^{-2}$.

   We know that,

$$\begin{aligned} & W = m \times g \\ \Longrightarrow\ & m = \frac{W}{g} \\ & m = \frac{980}{9.8} \\ & m = 100\ kg \end{aligned}$$

   Thus, the mass of the object is 100 kg.

2. **Example 2:** Mass of an object is 50 kg. What is its weight on the earth?

   Answer
   Mass, m = 50 kg,
   Acceleration due to gravity, $g = 9.8\ m\ s^{-2}$.

   We know that,

$$\begin{aligned} W &= m \times g \\ &= 50 \times 9.8 \\ &= 490\ N \end{aligned}$$

   Thus, the weight of the object is 490 N.

3. **NCERT Example:** Mass of an object is 10 kg. What is its weight on the earth?

   Answer
   Mass, m = 10 kg,
   Acceleration due to gravity, $g = 9.8\ m\ s^{-2}$.

We know that,

$$\begin{aligned} W &= m \times g \\ &= 10 \times 9.8 \\ &= 98\ N \end{aligned}$$

Thus, the weight of the object is 98 N.

You should, now, be able to answer the following questions:

1. Does mass of an object depend on location?
2. Does weight of an object depend on location?
3. Calculate your weight. Will you weigh the same on the north pole?
4. Inertia is the direct measure of ________________?

Conclusion

Mass is an property of an object which is directly proportional to inertia whereas weight is the force experienced by an object due to gravity, it varies with a change in acceleration due to gravity.

Note to Teacher

The goal of the text is to state the clear distinction between mass of an object versus its weight. One is the fundamental property of matter and other is just the consequence of gravity. Although, these words are colloquially interchanged, the text tries to draw a clear distinction between them.

Student Worksheet

1. What is the force experienced by any object under the influence of the earth's gravity?
2. What is the other name for this?
3. Can the mass of an object change (assuming nothing is done to the object physically)?
4. What is the SI unit of mass?
5. What is the SI unit of weight?

6. How do you calculate the weight of an object on earth?
7. Calculate your weight?
8. Will you weigh the same if you were at the north pole?

Gravitation - Lesson 15
Weight on other planets

Like us, different planets have different masses, and therefore different '*g*'. '*g*' on earth is higher than that of the moon, why? Because the moon weighs way less than the earth (about 81.25 times less), and also it's much smaller that the earth (about 3.6 times smaller). This results in a samller gravitational pull which is about six times less than that of the earth. This also means that if you measure weight on the moon, you would weigh six times less, i.e., a person weighing 60 N on Earth will weigh only 10 N. Another consequence of this is that you can jump way higher than you can on the earth. But this is not the case on all planets. If you happen to visit Jupiter, a massive planet, the same person will weigh about 150 N, which is much more than your body might be used to carry, about 2.5 times that of the earth. Even crazier would be visiting the Sun (Good luck coming without burning to ashes), and you will weigh 1680 N, 28 times your weight (assuming you weigh 60 N), this will surely crush your bones if you manage, somehow, to evade the scorching heat on the surface of the Sun. To find out the acceleration due to gravity on a planet, we just need to know the mass of the planet and its radius, as g is given by,

$$g_{planet} = G\frac{M}{r^2}$$

To compare it to the earth's gravitational acceleration, just divide it by 9.8.

$$g_{relative} = \frac{g_{planet}}{g_{earth}}$$

As mass remains the same, we can use the relative acceleration to find the weight of an object on other planets. First let us calculate the acceleration due to gravity on moon.
Mass of the moon, M_m = 7.36×10^{22} kg
Radius of the moon, R_m = 1.74×10^6 m
Universal gravitational contant, G = $6.67 \times 10^{-11} N\ m^2\ kg^{-2}$

Acceleration due to gravity is given by,

$$g_{moon} = G\frac{M_m}{R_m}$$
$$g_{moon} = (6.67 \times 10^{-11} N\ m^2\ kg^{-2}) \times \frac{7.36 \times 10^{22}\ kg}{(1.74 \times 10^6\ m)^2}$$
$$g_{moon} = 1.621\ m\ s^{-2}$$

Comparing Moon's acceleration due to gravity to earth's,

$$g_{relative} = \frac{g_{moon}}{g_{earth}}$$
$$g_{relative} = \frac{1.621}{9.8}$$
$$g_{relative} = \frac{1}{6}$$

This means that the an object will weigh 6 times as less as it weighs on earth. For example, if an object weighs 600 N on earth, it will weigh just 100 N on moon.

Let us look at a few examples:

1. **Example 1:** How far will you jump on the moon, if you can jump 1 m on earth, given that you are jumping with the same initial vertical velocity?

   Answer
   We know that acceleration due to gravity on moon (a_m) is about $\frac{1}{6}$ times that of the earth (g). It is intuitive to conclude that you would jump 6 m on the moon, which is correct. Let's prove it below:

   The ratio of accelration due to gravity on earth and on moon,

$$\frac{a}{a_m} = \frac{6}{1}$$

Final velocity will be 0 $m\ s^{-1}$ on earth as well as on moon, because when you jump, at the highest point, you will stop momentarily.

Using the equation, $v^2 = u^2 + 2as$
Final velocity on earth,

$$\begin{aligned} v_e^2 &= u_e^2 + 2gs_e = 0 \\ \implies u_e^2 &= -2gs_e \end{aligned}$$

Final velocity on moon,

$$\begin{aligned} v_m^2 &= u_m^2 + 2a_m s_m = 0 \\ \implies u_m^2 &= -2a_m s_m \end{aligned}$$

As initial velocities is same, we can write,

$$\begin{aligned} -2a_m s_m &= -2gs_e \\ \implies s_m &= \frac{g}{a_m} s_m \\ \implies s_m &= \frac{6}{1} \times 1 \\ \implies s_m &= 6\ m \end{aligned}$$

2. **Example 2:** Mass of an object is 50 kg50 kg. What is its weight on the moon?

Answer
Mass, $m = 50\ kg$,
Acceleration due to gravity, $g = 1.621\ m\ s^{-2}$.

We know that,

$$\begin{aligned} W &= m \times a_m \\ &= 50 \times 1.621 \\ &= 81.05\ N \end{aligned}$$

Thus, the weight of the object is 81.05 N.

3. **NCERT Example:** An object weighs 10 N when measured on the surface of the earth. What would be its weight when measured on the surface of the moon?

Answer

We know, Weight of object on the moon = (1/6) × its weight on the earth. That is,

$$W_m = \frac{W_e}{6} = \frac{10}{6}\ N$$
$$= 1.67\ N$$

Thus, the weight of object on the surface of the moon would be 1.67 *N*.

You should, now, be able to answer the following questions:

1. The mass of an object on earth is 20 *kg*. What will be its mass on the moon?
2. Calculate your weight. Now calculate your weight if you were on the moon?
3. How far will you jump on the Jupiter, if you can jump 1 *m* on earth? The acceleration due to gravity on jupiter is about 2.36 times that of the earth.
4. If a stone of mass 10 *kg* is dropped from a distance of 10 *m* on the moon, what is its speed when it hits the ground? What will be the answer if the stone has a mass of 100 *kg* or a 1000 *kg*?

Conclusion

Different planets have different acceleration due to gravity which depends on the planet's mass and radius.

Note to Teacher

The lesson aims to exemplify the different weight on different planets. The goal is to understand that weight is present due to gravity and that the acceleration due to gravity is different on different planets. As a result, weight along with other parameters related to motion changes.

Student Worksheet

1. How far will you jump on the moon, if you can jump 2 *m* on earth?
2. How much will a 100 *kg* object weigh on the sun ($g_s = 28.02 \times g_e$)?
3. If an object weigh 98 *N* on earth and 6.958 *N* on Pluto. Find the ratio of the ratio of the gravitational acceleration of pluto with respect to earth?

Gravitation - Lesson 16
Thrust vs Pressure

Consider this scenario. You are trying to fix a nail on your wall with a hammer. You hit the nail with some amount of force, let's say, and the nail is fixed. What if you tried to hit the nail and missed and directly hit the wall with the hammer with the same force? What would happen in that case? Will the hammer also go inside the wall as the nail went in? No, it will not. But why? The force applied is the same, then what is the difference?

The above scenario shows us that we cannot describe every physical event happening around us just by knowing the amount of force. This is what physics is; we try to explain the physical events around us. Apart from the force, we need to know that on how much area the force is acting. If the force is acting on a teeny-tiny bit of area, like in the case of the nail, it will impact that part of the wall. Suppose the area is larger, as, in the case of a hammer directly hitting the wall, the force is spread across a region. This will allow the wall to withstand the force, and the hammer does not go inside the wall. This happens due to something called pressure. But before we define pressure formally, we need to understand another bit of data that we overlooked.

What if you hit the nail at an angle? What would happen? The nail would bend and go inside the wall in a crooked manner. But will it pierce the wall as quickly as in the case when you were hitting it head-on? No, it will not. Something's changed in the second case. Not only does the area matter, but we also need to know the component of force hitting directly perpendicular to the wall. This component (perpendicular) of force will push the nail in, and the rest is used to bend the nail. This perpendicular component is called the thrust, and the thrust acting per unit area is known as the pressure. Thrust is a component of force; thus it has units of force, i.e., Newtons, but the pressure is thrust divided by area,

$$Pressure = \frac{Thrust}{Area}$$

this will have units of $N\,m^{-2}$, which is also called PaPa (Pascal), in honour of the 17th century French Scientist Blaise Pascal.

$$g_{relative} = \frac{g_{moon}}{g_{earth}}$$
$$g_{relative} = \frac{1.621}{9.8}$$
$$g_{relative} = \frac{1}{6}$$

This concept can also explain why we have a hard time standing for long hours but can sleep for the same time without any problem. This is because when we are standing, the weight is concentrated on the legs and bones inside our legs are under enormous pressure, so after some time, the bones and muscle in our legs get tired and exhausted. While sleeping, our weight is distributed about the whole back of our body, making it easier to sleep for long hours. This is why we are comfortable sitting or sleeping rather than standing.

Let us look at a few examples:

1. **Example 1:** How much is the thrust applied by a person having a mass of 40 kg, considering the person is standing perpendicular to the surface?

   Answer
   Thrust is the force which is perpendicular to the surface, in this case the weight is that force. Hence,

   $$Thrust = weight = m \times g = 40 \times 9.8 = 382\ N$$

2. **Example 2:** We have about $51,615\ kg$ of air per $5\ m^2$ above our heads due to the atmosphere. What is the pressure exerted?

Answer

$$\begin{aligned} Thrust = F &= m \times g \\ &= 51,615\ kg \times 9.8\ m\ s^{-2} \\ &= 5,05,827\ N \end{aligned}$$

$$\begin{aligned} Pressure &= \frac{Thrust}{Area} \\ &= \frac{5,05,827\ N}{5\ m^2} \\ &= 101165.4\ N\ m^{-2}, or \\ &= 1.01 \times 10^5\ Pa \end{aligned}$$

This value is also known as the atmospheric pressure at sea level.

3. **NCERT Example:** A block of wood is kept on a tabletop. The mass of wooden block is 5 kg and its dimensions are 40 $cm \times$ 20 $cm \times$ 10 cm. Find the pressure exerted by the wooden block on the table top if it is made to lie on the table top with its sides of dimensions (a) 20 $cm \times$ 10 cm and (b) 40 $cm \times$ 20 cm.

Answer
The mass of the wooden block = 5 kg
The dimensions = 40 $cm \times$ 20 $cm \times$ 10cm
Here, the weight of the wooden block applies a thrust on the table top. That is,

$$\begin{aligned} Thrust = F &= m \times g \\ &= 5\ kg \times 9.8\ m\ s^{-2} \\ &= 49\ N \\ \text{Area of a side} &= \text{length} \times \text{breadth} \\ &= 20\ cm \times 10\ cm \\ &= 200\ cm^2 = 0.02\ m^2 \\ \text{Pressure} &= \frac{49\ N}{0.02\ m^2} \\ &= 2450\ N\ m^{-2} \end{aligned}$$

When the block lies on its side of dimensions 40 $cm \times 20\ cm$, it exerts the same thrust.

$$\begin{aligned} \text{Area} &= \text{length} \times \text{breadth} \\ &= 40\ cm \times 20\ cm \\ &= 800\ cm^2 = 0.08\ m^2 \\ \text{Pressure} &= \frac{49\ N}{0.08\ m^2} \\ &= 612.5\ N\ m^{-2} \end{aligned}$$

The pressure exerted by the side 20 $cm \times 10\ cm$ is 2450 $N\ m^{-2}$ and by the side 40 $cm \times 20\ cm$ is 612.5 $N\ m^{-2}$.

You should, now, be able to answer the following questions:

1. What is the difference between Force, Thrust and Pressure? Also, mention their respective SI units.
2. Why it is advised to lay flat when stuck in wet sand?
3. In which case the pressure is maximum?
   (a) Standing up
   (b) Lying flat

Conclusion

Thrust is the perpendicular component of the force applied on a surface and Pressure is the thrust acting per unit area.

Note to Teacher

The purpose of the text is describe Force, thrust and pressure in comparitive but distinctive manner. Eventhough, they all seem to be similiar and relative, they are quite different. These are not independet concepts, they are introduced to address different situations in real-life. For some scenarios Force might be an apt description, for other thrust or pressure. The text also illustrates the importance of these concepts through different examples.

Student Worksheet

1. What are the SI units of thrust?
2. What are the SI units of pressure?

3. How much is the thrust applied by a person weighing 40 *Kg*, assuming standing upright?
4. If the thrust applied by a person is 500 *N*, what is the person's mass? Assume that the person is standing upright.
5. A person is pushing a block of wood weighing 20 *kg* with 100 *N* of force along the surface. What is the thrust applied by the block on the floor?
6. Why are concrete slabs laid down beneath the railway tracks?

Gravitation - Lesson 17
Pressure in Fluids

It should be clear that a solid body, when kept on a surface, exerts thrusts downwards due to its weight and the bottom surface area is accounted for distributing the pressure. But what about fluids? How do they exert pressure? Is it the same ways as solids? It cannot be if it was true that a fluid exerts thrust only at the bottom surface, then while inflating a balloon, we would have seen the ballon stretch only from the bottom. But while inflating a balloon, it inflates from all the sides. This leads us to a fantastic fact that fluids which include liquids and gases, exert thrust and pressure undiminished in all directions. But another astonishing fact is that their weight, as for all matter, always acts towards the ground, and the surface of the liquid will always align itself in such a manner that the weight is acting perpendicular to it. For example, if you fill water in a glass, the water's surface at the top will always remain parallel to the surface of the earth, no matter how you tilt or deform the glass. It's an amazing fact to try!

You should, now, be able to answer the following questions:

1. How is the pressure distributed in fluids?
2. While inflating a balloon, why doesn't it inflate in a single direction?

3. Why is the surface of water flat no matter on what surface it is kept?

Conclusion

Fluids exert equal pressure in all directions which is perpendicular to the surface.

Note to Teacher

The objective of the lesson is to elucidate the fact that water or all fluids in general react a bit differently under gravity. Unlike solids, they exert equal pressure at all sides. The text also draws attention to the fact that surface of the water alwys aliigns in specific way. This lesson is a great prelude to buoyancy.

Student Worksheet

1. Which of the following is a fluid at room temperature:
   (a) Mercury
   (b) Air
   (c) Water
   (d) Wood
2. Is it true that a fluid exerts thrust only at the bottom of the vessel that it is stored? Why?
3. Fuilds exert thrust and pressure undiminished in all directions. But will an object experience the same amount of pressure when immersed at different levels inside of that fluid?

Gravitation - Lesson 18
Experiments on Buoyancy

1. **Floating Bottle**

    (i) Take an empty plastic bottle. Close the mouth of the bottle with an airtight stopper. Put it in a bucket filled with water. You see that the bottle floats.

    (ii) Push the bottle into the water. You feel an upward push. Try to push it further down. You will find it challenging to push deeper and deeper. This indicates that water exerts a force on the bottle in the upward direction. The water's upward force increases as the bottle are pushed deeper till it is completely immersed.

    (iii) Now, release the bottle. It bounces back to the surface.

    (iv) Does the force due to the gravitational attraction of the earth act on this bottle? If so, why doesn't the bottle stay immersed in water after it is released? How can you immerse the bottle in water?

    Yes, gravitational force does work on the bottle, but the upward force on the bottle by the water is much more than the tiny 'mg' of the bottle. To immerse it, just increase the mass of the bottle, but putting some sones in it or filling it with water.

2. **Nail and Cork in Water**

   (i) Take a beaker filled with water.
   (ii) Take an iron nail and place it on the surface of the water.
   (iii) Observe what happens:

   The nail sinks. The force due to the gravitational attraction of the earth on the iron nail pulls it downwards. There is an upthrust of water on the nail, which pushes it upwards. But the downward force acting on the nail is greater than the upthrust of water on the nail. So it sinks (Figure)

3. **Archimedis' Principle**

   (i) Take a piece of stone and tie it to one end of a rubber string or a spring balance.
   (ii) Suspend the stone by holding the balance or the string, as shown in Figure I.
   (iii) Note the elongation of the string or the reading on the spring balance due to the weight of the stone.
   (iv) Now, slowly dip the stone in the water in a container, as shown in Figure II.
   (v) Observe what happens to the elongation of the string or the reading on the balance.

   You will find that the elongation of the string or the reading of the balance decreases as the stone is gradually lowered in the water.

Note to Teacher

The goal of the experiments/activities is to introduce the idea of buoyancy. The lesson takes few real-world examples and attempts to illuminate the buoyant property of fluids.

Gravitation - Lesson 19
Buoyancy

We all must have wondered at some point in our lives how a ship, which is made of metal, remains afloat on the water, whereas a spoon, which is also made up of metal, sinks? There must be some force that pushes the ship out of the water. What is this force? To remain afloat on any fluid (water, air, liquid nitrogen, concentrated H_2SO_4), we need to keep only one thing in mind, the upward force experienced by the object must be equal to the object's weight. When this is balanced, the object remains still at a point as no external forces act upon it, and the object is at equilibrium. **This upward force is called the buoyant force, and the phenomenon of experiencing this is called buoyancy. Buoyant force always acts opposite to gravity.** But, what is the upward force, and how do we know if it is enough to push an object on the surface of the water?

You should, now, be able to answer the following questions:

1. Define buoyancy?
2. What is the condition under which a body will float when immersed in fluid?

Conclusion

When an object is immersed in a fluid, it experiences a buoyant force which is always acting opposite to gravity.

Note to Teacher

The lesson aims to establish the concept of buoyancy. The text states facts about buoyancy to instigate thought and enquiry into the reader. It does not describe the "Why?". The conclusion of the text is that the buoyant force always acts opposite to gravity.

Student Worksheet

1. What is the force experienced by an object when immersed under water?
2. Force of buoyancy always acts:
   (a) opposing the motion of the object
   (b) opposing gravity
   (c) towards gravity
   (d) None of the above
3. Force of buoyancy is also known as ________________.

Gravitation - Lesson 20
Archimedes' Principle

The only parameter to consider for buoyancy is the weight of the water/liquid displaced by the fluid. If the weight of the fluid displaced by the object is equal to the weight of the object, then the object will remain afloat. **Therefore, the force experienced by an object when immersed in a liquid is equal to the weight of the fluid displaced.** This was the principle stated by Archimedes, often known as the *EUREKA* moment.

He came across this principle while pondering about a problem given by the king of his state, Syracuse. The problem was to make sure that his crown was made from pure gold. During his extensive mental exercise of finding the solution, he thought the water displaced or the change in the level of water by the gold crowns would be equal to the volume of the crowns. If volume is known, one can weigh the crowns and deterine its density. He knew that the density of pure and impure crown will be different as adding impurity will changes the density. This happened when he was bathing and lying down in his bathtub, which made the water spill out of the bathtub and made him think along the above lines. Legend has it that at this moment, Archimedes ran through the streets of Syracuse, naked, shouting *EUREKA (I've got it)!*

This is also why we feel lighter when inside a swimming pool. We displace some volume of water, and its corresponding weight is the opposing force experienced by us, which is always acting opposite to gravity and hence, we feel lighter. The spoon sinks because it cannot displace enough water to be afloat. This is the reason why ships have a humungous bottom surface area. The same fact is valid for a hot air balloon. A hot air balloon essentially works because it has a huge volume of air which is hot and hence, lighter. So the same volume of hot air weighs less than the cold, surrounding air. And thus, the buoyant force experienced by the hot air balloon is more than its weight, and so it rises and rises until the forces cancel each other or the hot air inside the balloon becomes cold.

This principle is used in various ways. It is used to design hot air balloons, submarines, and ships of all sizes. It is also used to detect the impurity of milk by lactometers. The same principle is used by hydrometers to determine the density of a fluid.

You should, now, be able to answer the following questions:

1. State Archimedis' princple?
2. How can you measure the exact volume of an irregularly shaped object?
3. Explain the conditions under which an object remains afloat on a fluid?

Conclusion

An object when immersed in a fluid displaces the fluid according to its volume and the weight of this displaced fluid is the upward buoyant force experienced by the object.

Note to Teacher

The text introduces Archimedes' principle by delving into the history and stating the chain of events that might have led Archimedes to the concept of buoyancy. The text describes the parameter considered to calculate buoyant force. The goal here is to understand why an object floats ot sinks, which will ultimately lead to density.

Student Worksheet

1. How does a ship float on water even though the ship is so heavy?
2. Why you have to beat your hands and legs in water to swim?
3. When measuring our weight on a weighing scale, are we really measuring our complete weight? If no, explain why?
4. What are lactometers used for?
5. What are hydrometers used for?

Gravitation - Lesson 21
Experiment on Density

1. **Cork and Nail of Same Mass**

   (i) Take a beaker filled with water.

   (ii) Take a piece of cork and an iron nail of equal mass.

   (iii) Place them on the surface of the water.

   (iv) Observe what happens.
   The cork floats while the nail sinks. This happens because of the difference in their densities. The density of cork is less than the density of water. This means that the upthrust of water on the cork is greater than the weight of the cork. So it floats (Figure). The density of an iron nail is more than the density of water. This means that the upthrust of water on the iron nail is less than the weight of the nail. So it sinks.

Note to Teacher

The experiment listed introduces density. The goal here is to understand that even if two objects have the same mass, the buoyant force experienced might be different and that determines whether the object will float or sink.

Gravitation - Lesson 22
Density

The previous experiment leads us to an important fact, density. We can compare the density of different objects using a fluid. Density is, basically, a parameter that tells the object's mass per unit volume, which has units of kg/m^2.

$$D = \frac{M}{V}$$

For example, the same amount of sugar and salt weighs differently. Why? Because their density is different. If we mix two immiscible fluids, we can tell which fluid has less density, the one with the less density will always be on top. Take the case of water and oil. Whenever we try to mix water and oil, the oil always remains on top, no matter what, as its density is less than that of water, hence the buoyant force experienced by oil is greater than its weight, and therefore it floats on water. Here, we can introduce a new comparative parameter called relative density, which will tell you if the substance is denser than water or not.

$$\text{Relative density} = \frac{\text{Density of the Substance}}{\text{Density of water}}$$

It has no units, as it is a comparative parameter. $\frac{Density}{Density}$ will have no units.

Let us look at a few examples:

1. **Example 1:** Density of mercury is 13.6 $g\ mL^{-1}$. Calculate the relative density of mercury?

   Answer
   Density of mercury = 13.6 $g\ mL^{-1}$ = 13.6 $kg\ L^{-1}$
   Density of water = 1 $kg\ L^{-1}$

$$\text{Relative Density} = \frac{\text{Density of mercury}}{\text{Density of water}}$$
$$= \frac{13.6\ kg\ L^{-1}}{1\ kg\ L^{-1}}$$
$$= 13.6$$

2. **Example 2:** Relative density of silver is 10.8. The density of water is $10^3\ kg\ m^{-3}$. What is the density of silver in SI unit?

   Answer
   Relative density of silver = 10.8

   We know that,

$$\text{Relative Density} = \frac{\text{Density of silver}}{\text{Density of water}}$$
$$\text{Density of silver} = \text{Relative Density} \times \text{Density of water}$$
$$= 10.8 \times 10^3\ kg\ m^{-3}$$

You should, now, be able to answer the following questions:

1. What is the SI unit of density?
2. Define relative density?
3. What should be the value of the relative density such that the object floats on water?

Conclusion

The density of an object is its mass per unit volume, and the relative density of an object is its original density with respect to the density of water.

Note to Teacher

The aim of the text is to contniue the Archimedes' principle to density. The text intents to state that a single parameter called density is enough to determine if an object will float or sink. The text also introduces relative density which is useful to tell if an object will float on water.

Student Worksheet

1. Buoyant force depends on the:
   (a) Density of the object
   (b) Density of the fluid
   (c) Density of both
   (d) None of the above
2. An iron nail sinks in water because ________________.
3. A hollow plastic ball floats on water because ________________.
4. What can be done to the water so that the iron nail does not sink (Altering the nail is not allowed)?
5. A 10 *kg* object when immersed in water displaces 7 *L* of water. How much upward force is experienced by the object? (1 *L* = 1 *kg*)
6. Calculate the relative density of mercury? (Density of mercury = 13.6 $g\ mL^{-1}$)

Gravitation
Summary

- **Gravitational force** is the force that is responsible for the the invisible *ATTRACTION* between objects with masses.

- **Universal law of gravity:** The force of gravitation between 2 objects is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. This force acts along the line joining the center of the masses of the 2 objects.

$$F = G\frac{Mm}{r^2}$$

where,

G = Gravitational constant

M = Mass of object 1

m = mass of object 2

r = Distance between the objects (Center of mass)

- **Freefall:** Any object under the influence of gravity accelerates. Any relatively small object (with respect to the earth) will freefall with an acceleration, g. It does not depend on mass, as the force of gravity is proportional to the mass of the object, but the reaction of any object under the influence of a force is also proportional to its mass and hence the acceleration under gravity is independent of the mass of the object.

  Acceleration due to gravity,

$$g = G\frac{M}{r^2}$$

- g is an inverse function of radius from the center. Therefore, g reduces as altitude increases and it is also greater at the equator than at the poles, as the earth is not a perfect sphere and rather a sphere with flattened top and bottom.

- **Mass vs Weight: Mass** is an intrinsic property of an object which is a constant whereas **weight** is the force experienced by the object under a gravitational field. Weight is proportional to the mass of the object. Mass of an object remains same everywhere, but its weight changes as g changes.

- **Thrust vs pressure: Thrust** is the force acting on an object perpendicular to the surface whereas **pressure** is the thrust acting per unit area.
- **Pressure in fluids:** Fluids (liquids and gases) exert the same amount of pressure on the container walls.
- **Buoyancy:** The upward force, opposing the gravitational force, experienced by an object inside a fluid is called the buoyant force. If this force is enough to balance the gravitational force, then the object will float or else it will sink.
- **Archimedes' Principle:** The buoyant force experienced by an object when immersed in a fluid is equal to the weight of the fluid displaced by the object.
- **Relative Density:** Density of an object is its mass per unit volume, and relative density of an object is its original density with respect to the density of water.

Gravitation Questions

Short Answer Questions

1. A change in the speed of a moving object can be obtained by applying a ________________.
2. A change in the direction of a moving object can be obtained by applying a ________________.
3. Gravity acts on objects pertaining the property of ________________.
4. Are horizontal and vertical velocity dependent on each other?
5. Is "falling" scientifically correct?
6. Define centripetal Force?
7. How does an object under circular motion will react if the centripetal force is suddenly removed?
8. What is barycentre?
9. Write down two clauses of the newton's law of gravitation with their mathematical couterparts.
10. Who is credited with discovering the value for the universal gravitational constant?
11. List down Kepler's law of planetary motion.
12. Why is the earth round?
13. At what point on the earth's surface would you feel the highest amount of pull?
14. At what point on the earth's surface would you feel the least amount of pull?
15. Why is the earth not a perfect sphere?
16. If a stone of 1 kg is dropped from a distance of 10 m, what is its velocity when it hits the ground? (Take g as 10 $m\ s^{-2}$.
17. Mass is a
    (a) Scalar
    (b) Vector
    (c) Tensor

(d) None of the above

18. To what point is your weight acting?
19. If a stone of 100 *kg* is dropped from a distance of 10 *m* on the sun, what is its speed when it hits the ground? (Given $g_sun = 28.02 \times g_earth$).
20. How much time will a stone of 10 *kg* take to touch the ground of the moon, if dropped from a height of 10 *m*?
21. The other name of the units $N\,m^{-2}$ is also known as .
22. Why do sports-persons wear studs (shoes with pointy protrusions)?
23. It would be a nightmare to sleep on a bed with single nail, but can be comfortable (relaiveley) when there are thousands of nails kept at the same level to make a nice bed of nails?
24. Is there a force above our heads due to the atmosphere?
25. We have about 6.66 *kg* of air *per* $inch^2$ above our heads due to the atmosphere. What is the pressure? (1 $inch^2 = 0.00064516m^2$)
26. Why are tires inflated?
27. What special property fluids posses with respect to pressure which differs from solids?
28. What is buoyant force?
29. Buoyant force can be balanced by applying an ____________.
30. Define density.
31. Calculate the density of an object of mass 2 *kg* and a volume of 20 m^3.
32. Ice floats on water even though it is essentially made up of water, why?
33. Density of an object is directly proportional to the ____________.

Long Answer Questions

For simplicity, take $g = 10\ m\ s^{-2}$

1. At some point of the year, Jupiter is about 5.8×10^{11} m away from earth. Calculate the gravitational force between the two.
   $M_J = 1.9 \times 10^{27}\ kg$; $M_E = 6 \times 10^{24}\ kg$; $G = 6.67x10^{-11}\ N\,m^2\,kg^{-2}$
2. Calculate the gravitational force between the sun and the earth and hence calculate the acceleration experienced by the earth.
   $M_S = 2 \times 10^{30}\ kg$; $M_E = 6 \times 10^{24}\ kg$; $r = 1.5 \times 10^{11}\ m$; $G = 6.67 \times 10^{-11}\ N\,m^2\,kg^{-2}$

3. Using Kepler's laws of gravitation, deduce the inverse square law incorporated in the universal law of gravitation given by Newton.

4. We all have heard that the earth revolves around the sun or the moon revolves around the earth. Is it really the case? Do they really revolve around the Sun or the earth? If No, explain. Think along the lines that if we have two planets of the same mass pulling each other, how would they respond?

5. State Kepler's three laws for the motion of celestial objects and explain the variation of the speed of the earth at different seasons. Is it fast in summer and slow in winter or vice versa.
Hint: The earth is farthest from the sun in July and closest in January.

6. A rocket is propelled at the start with a constant acceleration of 30 $m\ s^{-2}$. At an altitude of 5000 m, the first part of the rocket is shed. Calculate
   (a) The time at which the part is shed.
   (b) The time taken by the part to hit the ground.
   (c) The final speed at which the part hits the ground.

7. In the above problem, we have neglected air drag. Usually the force experienced by an object due to air drag is directly proportional to its square of the velocity. Take the proportionality constant to be 0.1, mass of the part to be 500 kg and find the speed at which the part hits the ground. Also find the time and distance it takes to attain this speed from the maximum distance i.e., at the top.

8. Assume that the path of a stone, under gravity, thrown at an angle is a parabola. Using just this assumption, argue that the orbit of the planets is elliptical.

9. Assume that the earth is a hollow sphere with all the mass concentrated at the circumference. Prove that an object placed inside the shell does not experience any gravitational force.

10. Determine the different physical factors by which g varies on a planet.

11. Assume that we do not know the mass of the moon. You are given the task to calculate the mass of the moon using the some data of the moon. If a light beam can circle the moon it will circle 27.48 times around the moon in 1 *second*. It is also given that a 10 kg stone when dropped from a 10 m height on moon takes about 3.5 *seconds* to reach the ground. Using these data find the mass of the moon. $c = 3x10^8\ m/s$

12. If we doubled the mass of the moon, Calculate the amount, in meters, by which the orbit will shrink.

13. Imagine you are standing on a weighing scale and it is showing 50 *kg*. You push the scale to jump and the reading starts to increase. You jump till a height of 2 *meters* and fall back on the scale and the reading of the scale again increases drastically before settling back at 50 *kg*. If it took 0.5 *seconds* to come to a stop from the time your feet touched the floor of the scale, answer the following questions:
    (a) Will the maximum reading at the start of the jump be equal to the maximum reading at the end of the jump.
    (b) Find the maximum reading of the scale.
14. Explain the different states in which you would fell weightlessness.
15. You are in deep space along with your crew inside a space craft of of 25 *meters*. You are given a task to create artificial gravity so that your weight is equal to the weight as measured on the earth. How would you achieve this task and what should be the speed of rotation.
16. What is the difference between force, weight and thrust?
17. A person weighs 70 *kg*. In summer he wears a shoe with the sole area as 7 cm^2 and in winter, due to snow, he wears a shoe with a sole area of 15 cm^2. Find the different applied pressure on the ground by the person.
18. The dimensions of a block of wood is $60 \times 60 \times 60$ *cm*. A person is applying force of 30 *N* at an angle of 30 *degrees* with respect to the floor. Find the pressure experienced by the floor.
19. The leaning tower of Pisa leans about 4 *degrees* about the vertical axis. It weighs 14500 *metric tons* and the area of the base diameter is 15.5 *meters*. Find the pressure applied by the tower.
20. Mercury is contained inside a spherical container of radius 5 *meters*. Density of mercury is 13.6 $g\ mL^{-1}$. Find the pressure applied by mercury on the walls of the container.
21. A bucket weighs 500 *grams* and is used to ferry water from a well. Calculate the net change in the force required to pull a full bucket of water if the capacity of the bucket is 2 *liters*. Also calculate the amount of force required to pull the bucket when submerged as well as when it is outside the water. (1 *L* = 1 *kg of water*)
22. A block of gold is immersed in water, which is kept in a cylindrical container of diameter 10 *cm*. When the block of gold is completely submerged the water level is increased by 2 *cm*. Find the:
    (a) Force experienced by the block of gold.
    (b) Mass of the gold.

23. A plastic cylinder of radius 5 *cm* and 10 *cm* height floats on water. The weight of the container is 100 *grams*. How much force you have to apply in order to completely submerge the container.

24. A hot air balloon can hold about 150 m^3 of air (density = 0.*Kg* m^3 at 25 °*C*). The weight of the balloon is 15 *KN*. The pressure of the air inside the balloon changes with temperature and is given by the formula $pressure(T) = pressure(25) \times temperature$. Find the temperature at which the balloon will start to lift. Assume the balloon to be spherical.

25. Relative density of a particular substance is 0.5. If a cylindrical block of mass 100 *kg* and height of 5 *m* is made out of this substance and is put in water vertically. Find

    (a) If the block floats or sinks

    (b) Height of the block submerged

    (c) How much mass can be kept on top until the block touches the brim

Gravitation
Answers

Answers - Lesson 2

1. Attractive
2. Gravitational force is the force which is particularly responsible for the invisible attraction among entities that have a property called mass.
3. Mass (or Energy)

Student Worksheet Answers - Lesson 2

1. No (Probably)
2. Gravitational force, Electromagnetic force, Weak force and strong force.
3. Strong force

Answers - Lesson 3

1. As both the marbles were falling from the same height, their vertical velocities must be for them to hit the ground at the same instance. Hence, the vertical velocity of the second marble was 2 $m\ s^{-1}$.
2. As both the marbles have identical vertical velocity, they will the same amount of distance, i.e., 20 m in the first 2 s.

Student Worksheet Answers - Lesson 3

1. Under the conditon that their vertical velocity is same.
2. Yes
3. The objects with same vertical velocity will traverse the same amount of distance in a given time. This means that at every instance, the objects will have covered the same vertical distance.

Answers - Lesson 4

1. If the earth was flat, the stone will fall the same amount of distance in every scenario. (Although the physics is very weird and different, under some assumptions, this will be the answer).

2. Because the earth's surface starts to curve, hence the stone travels more than the building's height.

3. Yes, this is true for all objects which has mass.

Student Worksheet Answers - Lesson 4

1. The building's height.

2. Yes

3. Once the earth's surface starts to curve, the stone travels more than the building's height.

Answers - Lesson 5

1. A force that keeps an object in a circular motion by pulling it towards the centre is known as centripetal force.

2. Yes

3. Below are few real-world examples where we see centripetal force in action:

   (a) When a train, aeroplane or any vehicle takes a turn while moving.
   (b) In mixer grinder and blender.
   (c) While whirring a stoone on a thread.
   (d) When fan is rotating.

4. Yes

Student Worksheet Answers - Lesson 5

1. Centripetal Force

2. Gravitational Force

3. Yes

4. Gravitational Force

Answers - Lesson 6

1. The tangent to a circle is always 90° or perpendicular to the line joining the point to the centre of the circle.

2. If we try to gradually increase the gravitational force, the motion of the object in question would look like a spiral. As the force is increasing, the object will experience more force than the previous instance and the orbit will start to shrink. As it shrinks gradually, the object will follow a spiral path.

Student Worksheet Answers - Lesson 6

1. (c) straight line
2. Tangent
3. Because there is no force to bend the object towards the centre.

Answers - Lesson 7

1. Yes
2. The barycentre

Student Worksheet Answers - Lesson 7

1. Because the acceleration is very small and hence, negligible.
2. No, both the moon and the earth revolves around a common centre. That point is, actually, inside the earth, but it is not the centre of the earth.

Answers - Lesson 9

1. Every object in the universe attracts every other object with a force that is:

   (a) Directly proportional to the product of their masses, and

   (b) Inversely proportional to the square of the distance between them.

2. Consider two bodies, A and B, of mass M and m respectively, which are separated by $r\ m$. Then by the Universal law of Gravitation, the force of gravity is,

$$F = G\,\frac{Mm}{r^2}$$

   where G is the universal gravitational constant which is equal to $6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$

3. (a) Halved

   The universal law of gravitation says that the force of gravitation between two objects of mass M and m respectively, separated by a distance r is:

(a) Directly proportional to the product of their masses, and

$$F \propto Mm$$

(b) Inversely proportional to the square of the distance between them.

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

If the mass of one object is reduced by half without changing distance between them, then the gravitational force would become

$$F' \propto M \times \frac{m}{2} = \frac{Mm}{2}$$

4. (d) Quadrupled

   The universal law of gravitation says that the force of gravitation between two objects of mass M and m respectively, separated by a distance r is:

   (a) Directly proportional to the product of their masses, and

   $$F \propto Mm$$

   (b) Inversely proportional to the square of the distance between them.

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

   If the distance between them is reduced by half, keeping their masses equal, the gravitational force between them would become

   $$F' \propto \frac{1}{\left(\frac{r}{2}\right)^2} = \frac{4}{r^2}$$

Student Worksheet Answers - Lesson 9

1. Line joining the center of masses
2. Product of the masses
3. Square of the distance between the centre of masses
4. $N\,m^2\,kg^{-2}$
5. $6.67 \times 10^{-11}\,N\,m^2\,kg^{-2}$

Answers - Lesson 10

1. Sir Henry Cavendish

2. Given,
   Mass of the lead ball, M = 160 kg,
   Mass of the steel ball, m = 1 kg,
   Distance between the lead and the steel ball, r = 0.225 m,
   Force experienced by the lead ball, $F = 2.1 \times 10^{-7}\ N$
   The gravitational force between two objects is given by,

$$\begin{aligned} F &= G\,\frac{Mm}{r^2} \\ 2.1 \times 10^{-7} &= G\,\frac{160 \times 1}{0.225^2} \\ \implies G &= \frac{(2.1 \times 10^{-7}) \times 0.225^2}{160 \times 1} \\ G &= 6.64 \times 10^{-11}\ N\,m^2\,kg^{-2} \end{aligned}$$

Student Worksheet Answers - Lesson 10

1. By using a torsional spring meter

2. Because by knowing the gravitational constant, one could measure the mass of the earth.

Answers - Lesson 11

1. Elliptical

2. Kepler's laws of planetary motion:

   (a) Planets move in ellipses with the Sun at one focus.
   (b) The radius vector describes equal areas in equal times.
   (c) The squares of the periodic times are to each other as the cubes of the mean distances.

Student Worksheet Answers - Lesson 11

1. The radius vector describes equal areas in equal times.

2. As the area swept by the radius vector needs to be equal. If the object that is revolving a massive planet, is not tracing a circle. This means that the path is ellipse. When the object is at the closet to the massive planet, the object will speed up to cover more area and when it is farthest, it will slow down such that the area swept is at equal time duration is equal.

Answers - Lesson 13

1. Yes. It's value is 9.8 $m\ s^{-2}$

2. While freefalling, gravitational force acts on all objects which is directly proportional to their masses, but to move any object we need to overcome inertia which is also directly proportional to the mass. Hence, the mass term cancels out and we see all objects, heavy or light, fall at the same rate under the influence of gravity given that no other forces such as air drag is affecting them.

3. Yes. As the distance from the centre of the earth to the surface is lowest at the poles and is highest at the equator. Therefore, the value of acceleration due to gravity is highest at the poles and lowest at the equator.

4. Yes, as acceleration due to gravity is independent of the object's mass, both of them will experience the same acceleration and hence fall at the same rate.

Student Worksheet Answers - Lesson 13

1. Yes

2. The acceleration experienced by earth,

$$Ma = G\frac{mM}{r^2}$$
$$a = G\frac{m}{r^2}$$
$$a = 6.67 \times 10^{-11} \times \frac{0.2}{(6371 \times 10^3)^2}$$
$$a = 3.28 \times 10^{-28}\ m\ s^{-2}$$

3. No

4. Because of air drag

5. No

6. Because the earth is not a perfect sphere and hence the distance from the center is not constant.

7. As the mass of object has no effect on an object under freefall, the distance covered in 1 second can be calculated as follows:
Initial velocity, $u = 0\ m\ s^{-1}$,
Time taken, $t = 1\ s$
As acceleration due to gravity is acting along to the direction of motion.
Hence, $g = 10\ m\ s^{-2}$.

We know that,

$$s = ut + \frac{1}{2}at^2$$
$$= 0 + \frac{1}{2} \times 10 \times 1^2$$
$$s = 5\,m$$

8. As the mass of object has no effect on an object under freefall, the distance covered in 2 seconds can be calculated as follows:
   Initial velocity, $u = 0\ m\ s^{-1}$,
   Time taken, $t = 2\ s$
   As acceleration due to gravity is acting along to the direction of motion.
   Hence, $g = 10\ m\ s^{-2}$.

   We know that,

$$s = ut + \frac{1}{2}at^2$$
$$= 0 + \frac{1}{2} \times 10 \times 2^2$$
$$s = 20\,m$$

9. No, as there is no gravity to pull the ink downwards.
10. (c) Both

Answers - Lesson 14

1. No
2. Yes
3. ________________ *kg*. No, the weight will be more on north pole as acceleration due to gravity is more at the north pole.
4. Mass

Student Worksheet Answers - Lesson 14

1. $F = mg$
2. Weight
3. No

4. Kilograms or *kg*
5. Newtons or *N*
6. *weight* = *mass* $\times$ 9.8
7. *weight* = 40 *kg* $\times$ 9.8 = 392 *N*
8. No

Answers - Lesson 15

1. The will be 20 *kg* as the mass of an object is constant everywhere.
2. Weight of an object on earth can be calculated as follows,

$$\begin{aligned} \text{Weight on earth} &= \text{Mass} \times \text{Acceleration on earth} \\ &= 10 \times 9.8 \\ &= 98\ N \end{aligned}$$

As the gravitational force on the surface of the moon is only $\frac{1}{6}^{th}$ as strong as gravitational force on the earth, it implies that the acceleration due to gravity on moon will also be $\frac{1}{6}^{th}$ times the acceleration due to gravity on earth. Hence, the object's weight on moon can be calculated as,

$$\begin{aligned} \text{Weight on moon} &= \text{Mass} \times \text{Acceleration on moon} \\ &= \text{Mass} \times \frac{\text{Acceleration on earth}}{6} \\ &= 10 \times \frac{9.8}{6} \\ &= 16.3\ N \end{aligned}$$

3. ________________ *kg*. As the acceleration due to gravity is 2.36 times more than that of the earth, the height jumped will be 2.36 times as less as on earth.

$$\text{Height jumped, } h = \frac{1}{2.36} = 0.423\ m$$

4. As the mass of object has no effect on an object under freefall, the final velocity can be calculated as follows:
Initial velocity, $u = 0\ m\ s^{-2}$
Distance, $s = 10\ m$

acceleration, $g = \frac{9.8}{6} = 1.625\ m\ s^{-2}$

$$\text{Final velocity, } v^2 = u^2 + 2as$$
$$= 0^2 + 2 \times 1.625 \times 10$$
$$\implies v = \sqrt{32.5}\ m\ s^{-1}$$
$$v = 5.7\ m\ s^{-1}$$

The answer will be the same for a 100 *kg* or, a 1000 *kg* stone

.

Student Worksheet Answers - Lesson 15

1. As the acceleration due to gravity is 6 times less than that of the earth, the height jumped will be 6 times as more as on earth.

$$\text{Height jumped, } h = 6 \times 2 = 12\ m$$

2. As acceleration due to gravity is 28.02 times more that that on the earth, the acceleration due to gravity on sun is given by,
   $g_s = 28.02 \times 9.8 = 274.6\ m\ s^{-2}$

$$Weight = m \times g_s$$
$$= 100\ kg \times 274.6\ m\ s^{-2}$$
$$= 27460\ N$$

3.

$$Ratio = \frac{6.958}{9.8} = 0.071$$

Answers - Lesson 16

1. **Force is a push or pull.** It acts in the direction it is applied. It's SI units is Newtons or *N*.

   Thrust is the force acting perpendicular to a surface. It is also measured in *N*.

   Pressure is thrust acting per unit area. It is measured in $N\ m^{-2}$ or *Pa*.

2. Laying flat will increase the surface area of the body and hence distribute the force, which will stop the person from drowning further.
3. (a) Standing up

Student Worksheet Answers - Lesson 16

1. *Newtons* or *N*

2. $N\,m^{-2}$ or *Pa*

3. Thrust is the perpendicular component of the force. As the person is standing upright, all the weight is perpendicular to the surface. Hence,

$$\begin{aligned} Thrust = weight &= m \times g \\ &= 40 \times 9.8 \\ &= 392\ N \end{aligned}$$

4. As the person is standing upright, thrust = weight. Hence,

$$\begin{aligned} Thrust = weight &= m \times g \\ &= 500\ N \\ \implies m &= \frac{500}{9.8} \\ &= 51.02\ kg \end{aligned}$$

5. Thrust is the force perpendicular to the surface. Therefore net thrust is only the box's weight = $m \times g$ = 20 $\times$ 9.8 = 196 N

6. To distribute the force of the passing train evenly

Answers - Lesson 17

1. Undiminished in all directions

2. Because air is a fluid and fluids apply pressure in all directions

3. Because the force on the surface of the water is always perpendicular. As gravity acts towards the center of the earth, therefore the surface of the water is always perpendicular to that.

Student Worksheet Answers - Lesson 17

1. (a), (b) and (c)

2. No. Because fluids exerts thrust and pressure undiminished in all directions.

3. No. The level of fluid above the object will determine the downward force and the amound of fluid below the object will determine the upward force. The new force will change as the object changes it position. At the top, the object will experience a net upward force and as it is immersed deeper and deeper, it will experience more and more downward force.

Answers - Lesson 19

1. When an object is immersed in a fluid, it experiences a buoyant force which is always acting opposite to gravity, and the phenomenon of experiencing this is called buoyancy.
2. When an object is immersed in a fluid, if the upward or the buoyant force experienced by the object is equal or greater than the object's weight, the object will float.

Student Worksheet Answers - Lesson 19

1. Force of buoyancy
2. (b) opposing gravity
3. Buoyant force

Answers - Lesson 20

1. When a body is immersed fully or partially in a fluid, it experiences an upward force that is equal to the weight of the fluid displaced by it.
2. By completely immersing the object in a fluid and measuring the change in the level of fluid.
3. When an object is immersed fully or partially in a fluid, if the weight of the fluid displaced is more than the weight of the object, the object will remain afloat.

Student Worksheet Answers - Lesson 20

1. The weight of water displaced by the ship is greater than the weight of the ship.
2. Our body's volume is not enough to displace enough amount of water. Beating hands and legs displaces extra water in order for us to remain afloat.
3. No. In reality, we displace certain volume of air which exerts a force equal to the weight of the air displaced. This decrases the reading on the weighing machine. Hence, our weight is slight greater than it is shown in the weighing scale.
4. to determine the purity of a sample of milk.
5. for determining density of fluids.

Answers - Lesson 22

1. $kg\ m^{-3}$
2.

$$\text{Relative density} = \frac{\text{Density of the Substance}}{\text{Density of water}}$$

3. ≤ 1

Student Worksheet Answers - Lesson 22

1. (b) Density of the fluid
2. Density of iron $\geq$ Density of water
3. Density of the hollow plastic ball $\leq$ Density of water
4. Increase the density of water by mixing sugar or salt of any kind
5. Upward force experinced is equal to the weight f the water displaced, which is given by,

$$\begin{aligned} Volume \times Density &= 7 \times 1 = 1\ kg \\ Weight &= 7 \times 9.8 = 68.6\ N \end{aligned}$$

6.

$$\begin{aligned} 1\ mL &= 1\ cm^{-3} \\ \implies 13.6\ g\ mL^{-1} &= 13.6\ g\ cm^{-3} \\ \text{Density of water} &= 1\ g\ cm^{-3} \\ \text{Relative Density} &= \frac{\text{Density of the substance}}{\text{Density of water}} \\ &= \frac{13.6\ g\ cm^{-3}}{1\ g\ cm^{-3}} = 13.6 \end{aligned}$$

Short Answers

1. Force
2. Force
3. Mass or Energy
4. No
5. No
6. A force that keeps an object in a circular motion by pulling it towards the centre is known as centripetal force.
7. If the centripetal force is suddenly removed, the object will start to move but in a straight line in the direction of motion which will be tangential to the circle of revolution.
8. Barycentre is the central point around which two or more bodies revolve.

9. The universal law of gravitation says that the force of gravitation between two objects of mass M and m respectively, separated by a distance r is:

   (a) Directly proportional to the product of their masses, and

   $$F \propto Mm$$

   (b) Inversely proportional to the square of the distance between them.

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

10. Sir Henry Cavendish

11. Kepler's laws of planetary motion:

    (a) Planets move in ellipses with the Sun at one focus.

    (b) The radius vector describes equal areas in equal times.

    (c) The squares of the periodic times are to each other as the cubes of the mean distances.

12. Because the gravitational force pulls everything towards the center

13. At north and south poles, where the surface is closer to the centre of the earth

14. At the equator

15. Because it is spinning and hence, tends to throw the surface along the equator which flattens the poles

16. As the mass of object has no effect on an object under freefall, the final velocity can be calculated as follows:
    Initial velocity, u = 0 $m\ s^{-1}$,
    Distance, s = 10 m,
    As acceleration due to gravity is acting along to the direction of motion.
    Hence, g = 10 $m\ s^{-2}$.

    We know that,

    $$\begin{aligned} v^2 &= u^2 + 2\,a\,s \\ v^2 &= (0)^2 + 2 \times (10\ m\ s^{-2}) \times 10 \\ v^2 &= 20 \times 10 \\ v &= \sqrt{200}\ m \\ v &= 14.14\ m\ s^{-1} \end{aligned}$$

17. (a) Scalar

18. Towards the centre of the earth

19. As the mass of object has no effect on an object under freefall, the final velocity can be calculated as follows:
Initial velocity, u = 0 $m\ s^{-1}$,
Distance, s = 10 m,
As acceleration due to gravity is acting along to the direction of motion.
Hence, g = 28.02 × 9.8 = 274.6 $m\ s^{-2}$.

We know that,

$$v^2 = u^2 + 2\,a\,s$$
$$v^2 = (0)^2 + 2 \times (274.6\ m\ s^{-2}) \times 10$$
$$v = \sqrt{5492}\ m$$
$$v = 74.1\ m\ s^{-1}$$

20. As the mass of object has no effect on an object under freefall, the time taken can be calculated as follows:
Initial velocity, u = 0 $m\ s^{-1}$,
Distance, s = 10 m,
As acceleration due to gravity is acting along to the direction of motion.
Hence, g = 1.625 $m\ s^{-2}$.

We know that,

$$\text{Distance travelled, } s = ut + \frac{1}{2}at^2$$
$$10 = 0 + \frac{1}{2} \times 1.625 \times t^2$$
$$\Longrightarrow t^2 = 12.3$$
$$\Longrightarrow t = \sqrt{12.3} = 3.5\ s$$

21. Pascals

22. Studs concentrates the thrust of the body’s weight and makes the shoes sole go inside the surface, hence increasing the grip of the person.

23. Pressure is less on each nail as the force is distributed.

24. Yes

25.

$$
\begin{aligned}
Thrust &= 6.66 \times 9.8 = 65.27\ N\ inch^{-2} \\
Area &= 0.00064516 m^2 \\
Pressure &= \frac{Thrust}{Area} \\
&= \frac{65.37}{0.00064516} \\
&= 1,01,168.70\ N\ m^{-2} \\
&= 1.01 \times 10^5\ N\ m^{-2}
\end{aligned}
$$

26. To reduce the wire and tear of the wheel and the rim as the force is distributed.
27. Fluids exert thrust and pressure undiminished in all directions whereas solids exert thrust and pressure in only one direction which is towards the centre of the earth.
28. When an object is immersed in a fluid, it experiences an upward force which is always acting opposite to gravity. This force is known as buoyant force.
29. Downthrust
30. Density is defined as an objects mass per unit volume.
31. Density is defined as an objects mass per unit volume. Hence,

$$
\begin{aligned}
\text{Density} &= \frac{\text{Mass}}{\text{Volume}} \\
&= \frac{2}{20} \\
&= 0.2\ kg\ m^{-3}
\end{aligned}
$$

32. When Ice is formed, it expands which creates tiny air pockets which decreases its density
33. Mass

Long Answers

1. The gravitational force berween any two bodies is given by,

$$F = G\,\frac{Mm}{r^2}$$

$$\text{Mass of Jupiter, } M = 1.9 \times 10^{27}\ kg$$
$$\text{Mass of Earth, } m = 6 \times 10^{24}\ kg$$
$$\text{Distance, } r = 5.8 \times 10^{11}\ m$$
$$F = (6.67 \times 10^{-11}\ N\,m^2\,kg^{-2}) \times \frac{1.9 \times 10^{27}\ kg \times 6 \times 10^{24}\ kg}{(5.8 \times 10^{11}\ m)^2}$$
$$= 2.26 \times 10^{18}\ N$$

2. The gravitational force berween any two bodies is given by,

$$F = G\,\frac{Mm}{r^2}$$

$$\text{Mass of Jupiter, } M = 2 \times 10^{30}\ kg$$
$$\text{Mass of Earth, } m = 6 \times 10^{24}\ kg$$
$$\text{Distance, } r = 1.5 \times 10^{11}\ m$$
$$F = (6.67 \times 10^{-11}\ N\,m^2\,kg^{-2}) \times \frac{2 \times 10^{30}\ kg \times 6 \times 10^{24}\ kg}{(1.5 \times 10^{11}\ m)^2}$$
$$= 35.57 \times 10^{21}\ N$$

The acceleration experienced by earth can be calculated as,

$$F = ma$$
$$35.57 \times 10^{21}\ N = (6 \times 10^{24}\ kg) \times a$$
$$\implies a = \frac{35.57 \times 10^{21}\ N}{6 \times 10^{24}\ kg}$$
$$= 5.93 \times 10^{-3}\ m\,s^2$$

3. Kepler's first law states that "The orbit of a planet is an ellipse with the Sun at one of the foci". We can assume that the orbit is circular as circle is a special type of ellipse with both its foci coinciding at the center. In this very special case, the planet of mass M is going around the Sun at velocity $v$and the radius is r. The centripetal force experienced by the planet is $F_c = \frac{mv^2}{r}$ which makes $F_c \propto \frac{v^2}{r}$. As the motion of the planet is periodic, let us assume the period to be T, that means the planet takes 'T' amount of time to complete one revolution around the sun. Then the velocity of the planet is given by $velocity = \frac{Distance}{Time}$. In T amount of time, the distance covered by the planet is $2\pi r$. Therefore, $v = \frac{2\pi r}{T}$. Substituting this in F_c gives, $F_c \propto \frac{r}{T^2}$, which can also be written as $F_c \propto \frac{r^3}{T^2} \times \frac{1}{r^2}$; By Kepler's III law, $\frac{r^3}{T^2} = constant$, which implies, $F_c \propto \frac{1}{r^2}$. This is how Newton arrived at the famous inverse square relationship for the universal law of gravitation.

4. No, the earth and the other planets do not revolve around the Sun. In fact, the moon also

does not revolve around the earth. Even though the pull by the small planets or the moon is very small, it does have an effect and the effect is that they revolve around a common center called the barycenter. The whole solar system revolves around a common point, including the sun. For the earth and the moon the barycenter is inside the earth, about 1700 Km inside the earth's surface, as for the solar system, the barycenter changes it location which depends upon the instantaneous location of all the planets. And as for the planets with equal mass, they would revolve around the center of the line joining their center of masses. This is most commonly seen in stars, and these type of star system is called as binary stars.

5. The 3 Kepler's laws for the motion of celestial objects is as follows:

   (a) The orbit of a planet is an ellipse with the Sun at one of the foci.

   (b) The line joining the planet and the Sun sweep equal areas in equal intervals of time.

   (c) The cube of the mean distance of a planet from the Sun is proportional to the square of its orbital period T. Or,

$$\frac{r^3}{T^2} = constant$$

.

The variation of speed of any planet along its orbit depends upon the distance from the massive object around which it is rotating. From Kepler's II law, the area swept by the line joining the planet and the Sun is equal, this implies that the speed needs to be larger when it is closer to the sun and slower if the planet is farther from the sun. Therefore, the speed of earth is highest in January and slowest in July. This also tells that the distance from the sun is not responsible for the occurrence of seasons on earth.

6. Acceleration of the rocket, $a_r = 30\ m\ s^{-2}$
   Acceleration due to gravity, $g = 10\ m\ s^{-2}$
   Effective acceleration, $a = (30 - 10) = 20\ m\ s^{-2}$
   Distance, $s = 5000\ m$
   Initial velocity, $u = 0\ m\ s^{-1}$

   (a) Time at which first part was shed,

$$\begin{aligned} \textit{Distance travelled, } s &= \frac{1}{2}at^2 \\ 5000 &= 0.5 \times 20 \times t^2 \\ t &= 22.36\ seconds \end{aligned}$$

   (b) Time taken by the part to hit the ground has to be calculated in two parts. In the first part, we calculate the time it takes to reach the top after the part was shed because the part will not start falling the moment it is shed. The part will travel upwards till its velocity becomes zero and then start falling back to the ground, which is the second part. For the first part, we need the initial velocity once the part is shed,

$$
\begin{aligned}
v &= u + at \\
v &= 0 + at \\
v &= 20 \times 22.36 \\
v &= 447.2\ m\ s^{-1}
\end{aligned}
$$

Take the current distance as ground zero and the time to be zero seconds as well. At the maximum distance the final velocity will be zero. As the part is already shed, it will experience only the acceleration due to gravity downwards.
Acceleration due to gravity, $g = -10\ m\ s^{-2}$
Time taken to reach the maximum height,

$$
\begin{aligned}
v &= u + at \\
0 &= 447.2\ m\ s^{-1} - 10 \times t_{up} \\
\implies t_{up} &= 44.72\ s
\end{aligned}
$$

Distance covered in 44.72 seconds, to reach the maximum height,

$$
\begin{aligned}
v^2 &= u^2 + 2as \\
0^2 &= 447.2^2 - 2 \times 10 \times s_{up} \\
\implies s_{up} &= 9999.4\ m
\end{aligned}
$$

The part was shed at 5000 m and it has travelled an additional 9999.4 m so that its velocity becomes zero. Total distance to be covered to reach the surface,

$$s_t = 5000 + 9999.4 = 14999.4m$$

Time taken to cover this distance,

$$
\begin{aligned}
s_t &= ut + \frac{1}{2}at^2 \\
14999.4 &= 0 + \frac{1}{2} \times 10 \times t_{down}^2 \\
\implies t_{down} &= \sqrt{2,999.88} = 54.77\ s
\end{aligned}
$$

Total time to hit the ground is,

$$t = t_{up} + t_{down}$$
$$t = 44.72 + 54.77$$
$$t = 99.5\ s$$

(c) Final velocity when the part hits the ground,

$$v = u + at$$
$$v = 0 + 10 \times 99.5$$
$$v = 547.7\ m\ s^{-1}$$

7. If the air drag force is directly propotional to square of the velocity, then

$$F_{drag} \propto v^2$$

As the constant of proportionality is 0.1, we can write the drag force as,

$$F_{drag} = 0.1\ v^2$$

The maximum velocity, v_{max} will be attained by the object when the drag force is balanced by the weight of the object,

$$\begin{aligned} F_{drag} &= mg \\ 0.1 \times v_{max}^2 &= 500 \times 10 \\ v_{max} &= 223.6\ m\ s^{-1} \end{aligned}$$

Time take to reach this velocity,

$$\begin{aligned} v &= u + at \\ 223.6 &= 0 + 10 \times t \\ \implies t &= 22.36\ s \end{aligned}$$

Distance travelled to reach this velocity,

$$s = ut + \frac{1}{2}at^2$$
$$s = 0 + \frac{1}{2} \times 10 \times (22.36)^2$$
$$s = 2499.85\ m$$

8. A stone follows a parabolic path when thrown upwards at an angle. The more force

we apply i.e., more acceleration and hence more initial velocity the parabola starts to stretch and the stone covers a larger distance. At a particular initial velocity, the stone moves just the right amount of horizontal and vertical distance as the earth's surface curves. This enables the orbit to be circular or elliptical.

9. Consider an arbitrary point inside the hollow sphere. Let this point be r_1 and r_1 meters away from each of the walls respectively. Imagine a torch light is being shone from this point towards the walls. Note that the angle, *theta*(θ), at both the ends is very small (this can be made sure using a very good quality torch light). The illuminated region one of the parts that applies a gravitational force at this point. Also the illuminated region contains the mass that affects this force. More the area implies more the mass, therefore the mass depends on the area. The area is proportional to the radius (πr^2), and r is given by the arc length $r_1\theta$ and $r_2\theta$. Therefore we can write,

$$\frac{m_1}{m_2} = \frac{r_1^2 \times \theta^2}{r_2^2 \times \theta^2} = \frac{r_1^2}{r_2^2}$$

The total force experience at this point by an object of mass, M, is,

$$F_{total} = \frac{Gm_1}{r_1^2} - \frac{Gm_2}{r_2^2}$$
$$F_{total} = GMm_1 \times \left(\frac{1}{r_1^2} - \frac{m_2}{m_1 \times r_2^2}\right)$$

But,

$$\frac{m_2}{m_1} = \frac{r_2^2}{r_1^2}$$

$$F_{total} = GMm_1 \times \left(\frac{1}{r_1^2} - \frac{r_2^2}{r_1^2 \times r_2^2}\right)$$
$$F_{total} = 0$$

If we carry this same argument for all the different angles at which the light can be shown, by symmetry of the sphere, the total force at this arbitrary point and henceforth, all the points inside the hollow sphere is zero.

10. The different physical factors by which g varies on a planet:

   (a) The mass density of the planet: The distribution of the mass determines the center of mass of the planet and hence the distance to the surface changes with this.

   (b) The speed of rotation of the planet: The speed of rotation determines how much centripetal force is experienced at the equator and the planet bulges at the equator. This changes the distance of every point on the planet to the center of mass.

(c) The shape of the planet: The shape of the planet determines the actual distance between the center of mass and the surface.

11. The force of gravitation is given by,

$$F = G\frac{Mm}{r^2}$$

The radius of the moon can be given by,

$$\begin{aligned}
Speed &= \frac{Distance}{Time} \\
Distance &= speed\ of\ light \times total\ time \\
27.48 \times 2\pi r_{moon} &= speed\ of\ light \times total\ time \\
r_{moon} &= 1737499.37\ meters
\end{aligned}$$

Acceleration due to gravity on moon, a_{moon},

$$\begin{aligned}
s &= ut + 0.5at^2 \\
10 &= 0 + 0.5 \times a_{moon} \times 3.5^2 \\
a_{moon} &= 1.63\ m/s^2
\end{aligned}$$

We know that,

$$\begin{aligned}
F &= G\,\frac{Mm}{r^2} \\
ma_{moon} &= G\,\frac{Mm}{r^2} \\
1.63 &= 6.67 \times 10^{-11}\,\frac{M}{(1737499.37)^2} \\
\implies M &= 7.37 \times 10^{22}\ kg
\end{aligned}$$

12. Changing the mass affects the force of gravity between the objects but does not change the size of the orbit. The force of gravitation between the earth and the moon will double but the reaction ($F = ma$) to this force by the moon will also double. Hence, the effect of mass cancels out and we have the same orbit as before. This is the same reason as to why objects in freefall does not react to their masses, they will all fall at the same speed regardless of their mass.

13. (a) Yes, as the energy is always conserved, the reading will be equal.

(b) Initial velocity while jumping is same as final velocity whicle landing. This is given by,

$$v^2 = u^2 + 2as$$
$$v^2 = 0 + 2 \times 10 \times 2$$
$$\implies v = \sqrt{40} = 6.32\ m\ s^{-1}$$

The aceeleration experienced y the person while landing can be calculated as,

$$v = u + at$$
$$0 = 6.32 + a \times 0.5$$
$$\implies a = -12.64\ m\ s^{-2}$$

Net downward acceleration, $a_{net} = g + a = 22.64\ m\ s^{-2}$

$$F = ma = 50 \times 22.64$$
$$F = 632\ N$$

As the weighing scale divides the force by the acceleration due to gravity, which is 10, the reading will be, 63.2 *kg*.

14. Different states in which you would fell weightlessness:
    (a) At the center of the earth: We would feel no gravity as the mass is symmetrically divided along all directions and the pull from all the sides are equal. All forces, hence, cancel out and we feel no gravity at that point.
    (b) During freefall: During freefall, the gravity is pulling the objects in proportion to their respective masses and the objects react to that force with proportion to their respective masses. Hence, everything falls at the same rate and no gravity is felt by any of the objects.
    (c) At infinite distance: At infinite distance the r^2 term in the denominator is too large and the force due to gravity is zero.

15. To find the acceleration due to the centripetal force, the acceleration due to gravity should be equal to the acceleration due to rotation of the spaceship.

$$mg = \frac{mv^2}{r}$$
$$10 = \frac{v^2}{25}$$
$$v = 15.8\ m/s^2$$

16. **Force** is a push or a pull. It is way of expending energy.
    Weight is the force experienced by an object under gravity. This always acts towards

the center of the earth.
Thrust is the Force experienced by an object perpendicular to its surface.

17. Pressure is thrust per unit area.

$$Thrust,\ F = mg$$
$$F = 70 \times 10 = 700\ N$$

$$P_{summer} = \frac{700}{7 \times 10^{-4}}$$
$$P_{summer} = 100 \times 10^{4}\ Pa\ or\ N/m^{2}$$
$$P_{winter} = \frac{700}{15 \times 10^{-4}}$$
$$P_{winter} = 46.67 \times 10^{4}\ Pa\ or\ N/m^{2}$$

18. As pressure is always perpendicular tot he surface. The component of force acting perpendicular is,

$$F = mg\sin(\theta)$$
$$F = mg\sin(30^{o})$$
$$F = 15\ N$$
$$P = \frac{Perpendicular\ Force}{Area}$$
$$P = \frac{15}{3600 \times 10^{-4}}$$
$$P = 41.67\ Pa\ or\ N/m^{2}$$

19. As pressure is always perpendicular tot he surface. The component of weight acting perpendicular to the ground is,

$$F = mg\cos(\theta)$$
$$F = 14500 \times 10 \times \cos(4^{o})$$
$$F = 144.6 \times 10^{6}\ N$$
$$P = \frac{144.6 \times 10^{6}}{\pi \times (15/2)^{2}}$$
$$P = 8,18,533.37\ Pa\ or\ N/m^{2}$$

20. Volume of the container, V_c = $\frac{4}{3}\pi r^3$ = 523.53 m^3
Area of the container, A_C = $4\pi r^2$ = 314.16 m^2
Mass of mercury inside the container, M_c = 13.6 $\times$ 523.56 $\times$ 1000 = 7.12 $\times$ 10^6 kg
Force on walls, F = 7.12 $\times$ 10^6 $\times$ 10 = 71.2 $\times$ 10^6 N
Pressure applied on walls, P_c = $\frac{71.2\times10^6}{314.16}$ = 226.63 $\times$ 10^3 Pa or N/m^2

21. When the bucket is full, the total weight of the bucket is, M_{bucket} = 0.5 kg + 2 kg = 2.5 kg
Force experienced when outside of the well, F_{out} = 2.5 $\times$ 10 = 25 N
Volume of water displaced when the bucket is submerged, V_{sub} = 2 L = 2 Kg of water displaced by mass.
Force of buoyancy, F_{buoy} = 2 $\times$ 10 = 20 N
Net difference in force, F_{net} = 25 $-$ 20 = 5 N
Therefore, when the bucket is submerged, the person has to apply 5 N of force whereas when it is out of the water, the person has to apply 25 N of force. So, the net change is 20 N.

22. (a) Force of buoyancy, F_{buoy} = $mass\ of\ water\ displaced$ $\times$ 10
Mass of water displaced, $M_{displaced}$ = $Volume\ of\ water\ displaced$ $\times$ $density\ of\ water$
Volume of water displaced, $V_{displaced}$ = $Area\ of\ the\ cylinder$ $\times$ $change\ in\ height$
$V_{displaced}$ = $\pi \times r^2 \times h$ = 157.08 $\times$ 10^{-5} m^3
$M_{displaced}$ = 157.08 $\times$ 10^{-5} $\times$ 1000 = 157.08 $\times$ 10^{-2} kg
F_{buoy} = 157.08 $\times$ 10^{-2} $\times$ 10 = 15.708 N

(b) Mass of gold,

$$\begin{aligned} M_g &= \text{Volume of water displaced} \times \text{density of gold} \\ &= 157.08 \times 10^{-5} \times 19300 \\ &== 30.31\ kg \end{aligned}$$

23. Force of buoyancy when the cylinder is completely submerged,
F_{buoy} = $Volume\ of\ water\ displaced$ $\times$ $density\ of\ water$ $\times$ g
Volume of water displaced, $V_{displaced}$ = $area\ of\ the\ base$ $\times$ $height$
$V_{displaced}$ = $\pi \times r^2 \times h$ = 785.4 $\times$ 10^{-5} m^3
F_{buoy} = 785.4 $\times$ 10^{-5} $\times$ 1000 $\times$ 10 = 78.54 N
Force due to the weight of the cylinder, F_{weight} = 0.1 $\times$ 10 = 1 N
Force to be applied to submerge the cylinder, $F_{submerge}$ = F_{buoy} $-$ F_{weight} = 77.54 N
Or just keep a weight of 7.754 kgs on top of the cylinder to completely submerge it.

24. Force of the hot air balloon due to the weight of the gas and its own physical weight,
F_{weight} = ($Mass\ of\ the\ air$) $\times$ g + 15 KN
Mass of the air, M_{air} = $volume\ of\ air$ $\times$ $density\ of\ air$

M_{air} = 150 $\times$ 0.1 = 15 kg
Force of buoyancy, F_{buoy} = $mass\ of\ air\ displaced \times g$
F_{buoy} = 15 $\times$ 10 = 150 N
F_{weight} = 15000 N
The balloon will start to lift when the net force becomes zero and the force of buoyancy becomes greater than the weight of the balloon. To find the temperature at which the balloon rises, we need to find the Force as the temperature rises. To find the force at a particluar temperature, the given formula can be multiplied by surface are of the balloon,

$$pressure(25) = \frac{Mass\ of\ air \times 10}{surface\ area\ of\ the\ balloon}$$

Multiplying both sides with surface area of the balloon,

$$\begin{aligned} Force(T) &= Force(25) \times Temperature \\ &= (\text{Mass of air} \times \text{acceleration due to gravity}) \times Temperature \\ &= (150 \times 10) \times \end{aligned}$$

This force is the upward force, which should balance the net downward force,

$$\begin{aligned} F_n &= Force(T) \\ 15000 &= 150 \times T \\ \implies T &= 100°C \end{aligned}$$

25. (a) As the relative density is less than 1, it means that the density of the block is less than that of water which will make it float.

(b) Force of buoyancy when immersed in water,
F_{water} = $weight\ of\ water\ displaced$ = $volume\ of\ water\ displaced \times density\ of\ water \times g$
Force of buoyancy when immersed in the fluid of similar density,
F_{same} = $weight\ of\ the\ fluid\ displaced$ = $volume\ of\ fluid\ displaced \times density\ of\ the\ fluid \times g$
When densities are same, the substance will completely submerge.
Note that force of buoyancy is always the same for an object, no matter in which fluid it is placed.
$F_{water} = F_{same}$
$volume\ of\ water\ displaced \times density\ of\ water \times 10 = volume\ of\ fluid\ displaced \times density\ of\ the\ fluid \times 10$

$$\frac{density\ of\ the\ fluid}{density\ of\ water} = \frac{volume\ of\ water\ displaced}{volume\ of\ fluid\ displaced}$$

Density of fluid is same as the substance.

$$\textit{relative density} = \frac{\textit{area of the base} \times \textit{height submerged}}{\textit{area of the base} \times \textit{textittotalheight}}$$
$$\textit{relative density} = \frac{\textit{height submerged}}{\textit{total height}}$$

0.5 = $\textit{height submerged}/5$
$\textit{height submerged}$ = 2.5 m

(c) When the block of cylinder is floating, the force of buoyancy is equal to the weight of the block = 100×10 N
At 1000N the submerged height is 2.5m.
For 5m to be submerged, the total force required is $5 \times \frac{1000}{2.5}$ = 2000 N
$\frac{1000}{10}$ = 100 kg mass should be placed on the cylindrical block to completely submerge it.