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Study of the Concepts and Misconcepts of Weightlessness

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ABSTRACT: This article aims at clearing the usual misconceptions about weightlessness and strengthening the foundations of the concept of gravity in a layman's language. This project is for readers who don't even have a background of high level physics. Not all of us are well versed with the language of mathematics and hence is sparingly used in this paper. The article proposes a very simple method of boolean questionnaire, along with some easy to conduct activities aiding to clear myths about gravitational concepts residing in a person's mind. The suggested activities can be accomplished with tools from daily use and hence are cost efficient. In contrast to imagining or hearing, performing these activities will lead to a better understanding of the concept.

I. INTRODUCTION

The concept of acceleration due to gravity is being taught from VIth standard onwards in the class. But the students are unaware of the concept of weight and weightlessness till standard XII and beyond. The topic is quite confusing for students as well as the teachers that lead to several misconceptions about weightlessness. There is a belief in most the students that weightlessness is due to zero gravity or exists only in space. Hence, in order to remove the confusion and to explain the principle of weightlessness in a very simple manner, I had chosen the topic.

II. MATERIAL AND METHODS

My methodology is very simple questionnaire method. A framework of questions are prepared and given to all available students in two-three schools and colleges of XIth and XIIth standard students. The survey led to the inference that students did not have any correct idea about weightlessness.

This project is for readers who don't even have a background of higher level physics. Not all of us are well versed with the language of mathematics so it is used minimally. I believe very strongly that unless one can convey `in words' what is going on, one does not fully comprehend the subject oneself! Here, I have attempted to use a language that can be understood by all.

Probably, all of us have seen pictures of astronauts in space-crafts orbiting around the earth. Astronauts and everything inside the craft, float as if they have no weight. You must have read that astronauts become 'weightless' in an orbiting spacecraft. In this article, we will discuss and try to understand why they behave as if they are `weightless'.

Ask high school or college students (or even their physics teachers) how far earth's gravity extends? You will find that majority believe that it extends only to the edge of the atmosphere.

It is a common misconception that, space-crafts orbit beyond the limit where gravitational pulls vanishes. So astronauts become weightless.

It is true that the gravitational pull of earth goes on decreasing as we move away from earth. But even at a distance over 384500 kms, it is strong enough to force the moon to orbit around the earth. How can it vanish at a distance of only 200-300 Kms, where our space-crafts and astronauts orbit? In fact, at this distance the gravitational pull reduces by 7% only.

Weightlessness is quite an abstract concept which we don't experience in real life. To understand it, we will discuss many other related concepts first. Many activities are also suggested in this article. The activities are very simple and can easily be performed. The materials required for the activities are available in most houses. So, read – perform activities – learn and enjoy science.

A. What is gravity?

There exists a force of attraction between every two objects and we call this force of attraction 'gravitational force'. This force of attraction depends upon how massive the objects are and distance between them. More massive the objects, more is the attraction; farther the objects, lesser would be the attraction. Since the earth is very massive, we generally say that the earth attracts all other objects (in fact, earth and the objects both attract each other) and call this attraction as the gravitational pull of the earth.

B. What does Earth's gravity do?

Due to gravitational force of attraction of the earth, all objects are attracted by the earth. If you leave a book in mid-air, it doesn't just remain there, it is pulled by earth and hence it falls down. Hold a book on your palm. Here you prevent it from falling down, so the book exerts a force on your palm. We call this force as weight of the book. More massive the book more will be the weight.

The scenario is altogether different in space-crafts. Everything inside it keeps floating. If an astronaut inverts a glass full of water, the water insider the glass does not fall down. Even the astronauts float inside the space-craft. Everything inside the space-craft behaves as if they are `weightless' – they are in zero gravity zone. To understand this behaviour, let us proceed step by step.

1. What is weight?

First of all we will discuss what weight is. If you have to weigh an object, what would you do? You would either hang it on a spring balance or place it on weighing scale.

Suppose you hold a spring balance with an object hung to its hook. Here the object is being pulled by the earth but the spring balance prevents it from falling. Consequently, the object pulls (applies force) and stretches the spring of the balance. By measuring this stretch, we find the weight of the object. What have we done to find the weight? We have measured the force applied by the object on the spring which prevents it from falling down.

Even when you place an object on a weighing scale, the object compresses the spring of the scale. Here also, we measure this compression and find the force applied by the object on the spring.

So, can we not think weight to be "the force exerted by an object on its support, whether that support is a platform on which the object rests or a suspension from which the object hangs"? Note, weight is not just another name for the gravitational force on an object; in fact it is a force exerted by an object on its support.

2. Do objects really fall together?

We see that heavier objects fall faster than a dried leaf or a paper or feather. Scientists before Galileo also believed that heavier objects fall faster than lighter objects. Actually, air causes this difference in rate of fall. Effect of air resistance is more on lighter objects than on heavier ones. If there were no air the scenario would have been different.

More than four centuries ago the great Italian scientist Galileo performed experiments and found that objects having different mass fall together. It is believed that he dropped two balls of different weights (mass) from the Leaning Tower of Pisa and found that both reached the ground at the same time. Doing simple mathematics, we can understand why two objects of different mass fall together.

Imagine two objects at the same distance from the earth; one with mass m and the other with mass $10m$. We know that the force of attraction between two objects depends upon their masses. Let F be the force of attraction between earth and the object with mass m. Obviously, the force of attraction between the object with mass $10m$ will be 10 times F i.e. $10F$.

Since, force F acts on mass m and force $10F$ acts on mass $10m$, both the objects would move at the same rate. In scientific terminology we can say that both would accelerate at the same rate (in vaccum).

This is the reason why, irrespective of their masses, objects fall at the same rate during *free fall* (when no other force except gravity acts on an object). Now perform an activity to verify if objects really fall together?

Activity

Hold a ball in front of a heavy doll's face. Release them simultaneously from the same height. You can observe them falling together. Now think a step ahead. Suppose the ball is at the doll eye level. Throughout the fall, though the ball remains unsupported, it maintains the same level with respect to the doll's eye. Hence, from the falling doll's perspective the ball would appear to be floating.

3. During free fall does an object become weightless?

In the second point, we discussed that during a free fall objects fall together. In the first point, we discussed that if objects fall together, they won't exert force on each other. So, during free fall an object should not exert any force on its support and hence should *become* weightless.

Activity

For this activity, you need only a spring balance, a heavy nut (or stone) and a friend's help.

Procedure

(i) Attach the nut to the hook of the spring balance. It shows the weight of the nut.

(ii) Ask your friend to raise the setup over his head and leave it. You have to carefully observe the reading on the spring balance during its fall. You will see that the scale shows the weight of the nut to be zero.

(iii) Repeat the experiment several times.

(iv) To prevent damaging the spring balance, ask a friend to be ready to catch the setup before it hits the floor. If you don't have a spring balance, rubber bands can also serve the purpose.

You must now be convinced that during free fall, the scale shows the weight of a body to be zero.

4. Whether objects fall straight down or along a trajectory when they are in a free fall?

So far we have discussed cases where objects fall straight down. Now let us think, what would happen in a situation when object fall down but at the same time move forward (fall in a trajectory).

Let a bullet be fired from a gun in horizontal direction. Here the force applied by the gun makes the bullet move forward and at the same time gravity pulls it down. As a result the bullet travels along a curved path (trajectory) before hitting the ground.

In this case also the bullet's downward movement is *only* due to gravity; no other force is acting the direction of gravity or opposite to the gravity. The forward movement in no way affects the downward movement. The only difference this forward movement makes is that the bullet instead of falling straight down, falls some distance ahead.

If the above arguments are taken to be true, then if a bullet is fired horizontally and the same time another bullet is dropped from the same height, both should hit the ground at the same time. To examine this, you neither need a gun nor bullets, just perform the next activity.

Activity

You need only a plastic foot ruler and a chalk sticks.

Procedure

(i) Place three chalk sticks in a straight line on the edge of a table. Hold the foot ruler with flat surface touching all three chalk sticks.

(ii) Tightly hold one end and stretch back the other end of the ruler. Release the pulled end. The ruler hits all three chalk sticks simultaneously.

(iii) Notice, whether the chalk sticks strike the floor simultaneously or at three different times.

To summarize, objects fall straight down when they are in a free fall. We also know that during free fall, since objects fall together, they can't exert force on each other, so they behave as if they are weightless.

C. Case study of a lift.

Let us first look at a simpler case that a falling elevator. An elevator is at rest with a bag hanging from a spring scale. The scale reading indicates the downward force exerted on it by the bag.

This force exerted on the scale, is equal and opposite to the force
exerted by the scale upward on the bag and we call its magnitude *w.* Two force act on the bag; the downward gravitational force and the upward force exerted by the scale equal to *w*. Since the bag is not accelerating, we obtain

$$w - mg = 0$$

When we apply $\Sigma F = ma$ to the bag where $mg$is the weight of the bag. Thus $w = mg$ and since the scales indicates the force *w* exerted on it by the bag, it registers a force equal to the weight of the bag, as we expect. If now, the elevator, has an acceleration *a* then applying $\Sigma F = ma$ to the bag, we have,

$$w - mg = ma$$

Solving for *w*, we have

$$w = mg + ma$$

We have chosen the positive direction as upwards. This, if the acceleration *a* is upwards, *a* is positive and the scale which measures *w* will read more than *mg*. We call *w* the apparent weight of the bag, which in this case would be greater than its actual weight (*mg)*. If the elevator accelerates downwards, *a* will be negative and *w*, the apparent weight, will be less than *mg*. The direction of the velocity *v* does not matter. Only the direction of the acceleration *a* influences the scale reading. Suppose for example the elevators acceleration is *0.5g upward*, then we find

$$w = mg + m * (0.5g) = 1.5mg$$

That is the scale reads *1.5* times the actual weight of the bag. The apparent weight of the bag is *1.5* times its real weight. The same is true of the person. His/hers apparent weight (equal to the normal force exerted on him/her by the elevator floor) is *1.5* times his/her real weight. We can say that he/she is experiencing *1.5g* just as astronaut's experience so many *g*'s at a rocket launch. If instead, the elevator's acceleration is *a = -0.5g (downward)* then

$$w = mg - 0.5mg = 0.5mg$$

That is, the scale reads half the actual weight. If the elevator is in free fall (e.g. if the cable breaks), then *a = -g* and *w = mg – mg = 0.* The scale reads zero now. The bag appears weightless. If the person in the elevator accelerating at *–g* lets go of a pencil, it would not fall to the floor.

True, the pencil would be falling with acceleration *g*. But so will be the floor of the elevator and the person. The pencil would hover right in front of the person. This phenomenon is called apparent weightlessness as it is in reference frame of the person. Even if objects don't fall or seem to have weight, it does not imply that gravity disappears. In-fact it is still acting on the object whose weight is still *mg*. The objects seem weightless only because the elevator is in free fall and there is no contact force to make use fell the weight.

D. Orbiting space-crafts are also in free-fall?
You must know that a moving object continues to move in a straight line unless some force acts to change its direction. Suppose a bullet is fired from point *A* in direction *AB*. If there were no gravity, the bullet would have travelled on and on (neglecting air resistance) along the straight line *AB*. But gravity pulls the bullet and curves its path. Faster the bullet is fired, farther it will travel before hitting the ground. Suppose a bullet is fired horizontally from a few kilometres high tower in India in northern direction. If it is fired at a very high speed (initial velocity) it can be made to reach the North Pole. By increasing its speed (initial velocity) it can be may cross the South Pole and land in India again. On further increasing the speed, it will go round the earth twice before landing in India. If we go on increasing the speed, can we not achieve a speed at which the bullet will keep on going round the earth on and on?
Scientists calculate the speed at which a space-craft should be fired (horizontally) so that it will keep on going around the earth on and on. Space craft, after reaching a particular height achieve this speed and begin to orbit around the earth. Though a space-craft is orbiting the earth, in fact, it is continuously falling towards the earth. If it were not so, the space-craft would had escaped away in a straight line tangential to the orbit. Since everything inside the craft including the craft itself falls at the same rate they don't exert any force (weight) on each other. Since they fall at the same rate, they don't appear to fall with respect to each other – they appear to float. So they behave as if no gravity is acting on them.
No doubt space craft are *not* in zero gravity zone. But while orbiting they behave as if they are in zero-gravity zone.
So scientist conduct experiments in space-craft to explore the effect of zero gravity on living and non-living things (In this article, the effect of gravitational attraction by other heavenly bodies, particularly the moon and the sun, the effect of the spin of the earth, buoyant effect of the air, etc. have not been considered. On one hand this would be deep waters for me, on the other hand this article is for readers who want to know something and not for the science person who know everything).

Activities
Activity # 1
(i) Punch a hole in the side of the bottle near its bottom.
(ii) Cover the hole with thumb and fill water in the bottle. On removing the thumb water streams out.
(iii) Again cover the hole and fill water in the bottle. Stand on a table and release it. Water does not stream out of the hole, throughout the bottle's fall.
(iv) In the first case, since bottle is held it doesn't fall. But water finds a way and falls (streams out) through the hole.
(v) During the free fall, since bottle and the water inside it both fall at the same rate, water doesn't stream out.

Activity # 2
(i) Using a thread hang a nail below a strong magnet. Length of the thread should be such that the nail is just outside the range of being attracted by the magnet.
(ii) Drop the setup from a suitable height and observe whether the nail is pulled up by the magnet during free fall.
Activity # 3
If you immerse a piece of wood in water and release, it bounces up. Examine this phenomenon in free fall.

You need:
Tall wide plastic jar, wooden block of suitable size and a bicycle spoke.
Procedure:
(i) Screw the threaded end of the spoke into the wooden block.
(ii) Make a hole in the lid of the jar.

(iii) Fill the jar full with water. Press the block down into the water and tighten the lid such that the spoke protrudes through the hole in the lid.
(iv) Press the block down into water and release; it bounces up.
(v) Once again press the block and release the jar from sufficient height. Ask you partner to observe the wooden block. Does it bounce during the free fall.
(vi) For better observation, you can glue a paper flag on the outer end of the spoke.

Activity # 4
(i) Hold a drinking glass under a running tap. It overflows. What would happen if the glass is released? Will it continue overflowing during the fall?
(ii) First think over, reason out and then perform the activity to confirm the result.

Activity # 5
You need:
Two heavy nuts, plastic cup, rubber bands.

Procedure
(i) Cut two rubber bands and straighten them. Tie the nuts at one end of each rubber band.
(ii) Make a small hole in the bottom of the cup and insert the free ends of both the rubber bands in the bottom of the cup. Knot the rubber bands to prevent them from going back. Stretch the rubber bands and hang the nuts outside the cup.
(iii) During free fall with the nuts remain outside the cup?

III. SUMMARY

(i) Weight of an object is the force exerted by that object on a support which prevents it from falling towards the earth.
(ii) During *free fall* all objects fall together (with the same acceleration) irrespective of their masses.
(iii) During *free fall* since objects fall together, they don't exert force on each other. So the objects are *weightless.*
(iv) While orbiting, space-crafts are in a state of free fall, so contents inside it behave as if they are weightless.

IV. FUTURE WORK

The concept of weight and acceleration due to gravity introduced in the earlier classes should be taught with activities and fundamentals should be made clear.

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