Audio Text: Physics Lesson: Uniform Circular Motion and Centrifugal Force
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Scene 1 Time: 00:50-2:13
Location: Inside a car

Wow ... Have you noticed what happened to my body during the circular motion? ... Have you noticed the movement of my body towards the outside? ...

Peace upon you, I'm Khalid Mrashda, a physics teacher in Dhahran National Schools, Kingdom of Saudi Arabia, specializing in physics, computer science, and science teaching methods. Today, we will work together to explain the phenomenon we have seen.

 How many of you have experienced such a phenomenon? I'm sure that all of you have been through this experience. Other examples of this phenomenon include water movement in the automatic dryer, riding a roller coaster, and centrifuge to separate blood components. But, have you wondered what this phenomenon is? What force is responsible for pushing our bodies away from the center during circular motion? Think about it and pay attention to find out what this phenomenon is.

Written text on the screen: Activity 1: What is this phenomenon?

Scene 2 Time: 2:14-5:42
Location: classroom

Hello again ... Have you found out the name of the force that pushed me to the outside during the circular motion? You might have said it was centrifugal force, did you? But I have a surprise for you! There is no centrifugal force in this case!! But, if there was no centrifugal force, then what force pushed me towards the outside in this case? This is what we are going to explain now.

But, before I explain, I need to relate to some basic concepts in physics. Let's start with Newton's three laws. The first law states that:

(A text appears on the screen: An object at rest remains at rest, and an object in motion continues in motion with constant velocity unless the object experiences a net external force.)

"An object at rest remains at rest, and an object in motion continues in motion with constant velocity unless the object experiences a net external force." For example, if you put this ball on this table, it stays on the table forever unless it experiences a net external force, this is what Newton's First Law states. But, is it applicable for moving objects as well? If objects move in a straight line, for example, is Newton's First Law applicable to moving objects? The answer is absolutely.

An object in motion continues in motion with a constant velocity unless the object experiences a net external force that changes the magnitude of its velocity (increase or decrease) or its direction (east, west, north, and south). So Newton's First Law applies to static objects and moving objects.

Newton's Second Law:

This law simply relates the net force of an object and its acceleration. It states:

(The following text appears on the screen: "The acceleration of an object is directly proportional to the net force acting on the object")

"The acceleration of an object is directly proportional to the net force acting on the object" and it has the famous mathematical formula:

(The following text appears on the screen: " $F_{Net} = ma$")

 (F = ma) or force equals mass multiplied by acceleration. We see here that the greater the force, the greater the acceleration. This means that there is a direct relationship between force and acceleration. By acceleration we mean the change in magnitude of velocity or direction, or both.

Newton's Third Law:

I expect we all know Newton's third law which states that:

(The following text appears on the screen: "To every action force, there is a reaction force equal in magnitude and opposite in direction")

To every action force, there is a reaction force equal in magnitude and opposite in direction.

We need to remember something very important in Newton's Third Law; the action and reaction forces act on different objects. For example, if I take a hanging mass with a string, we will find several pairs of forces, for example: my hand with the string, my hand pulls the string up and the string pulls my hand down.
The ball and the Earth, the Earth pulls the ball and the ball pulls the earth. What concerns me is the string and the ball. The ball pulls the string down while the string pulls the ball up.

Before I finish this part about Newton's three laws, I have a question for you: What is the difference between the cases where the ball is hanged with this string and the case where it is placed in this scoop? In other words, what is the direction of the force that acts on the ball in the first case and in the second one? I will say the question again, and please focus only on the direction. What is the direction of the force which pulls the ball by this string? What is the direction of the force exerted by the scoop on the ball? Please, think about this question and I will hear your answer shortly.

(Written text on the screen: Activity 2: What is the difference in directions of the forces acting on the two balls?)

Scene 3 Time 5:43-8:28
Location: A classroom

Hello, again. I hope you were able to answer the previous question, which is related to the direction of forces on the two balls: The force by the string and the one at the bottom of the scoop. What is the direction in each case? As you know, the direction of the force will be here to the top and the direction of the force on the ball will also be to the top. Remember that because we will need this information.

Now, I would like to do some activities that you may think are about centrifugal force, but in fact they will be centripetal force only.

I will start with the activity of the ball and string. I am going to rotate the ball tied with this string in a circular motion, as you can see. Now, my question is: What if the string broke? What will the direction of the ball be? Will it be towards the center? Will it be away from the center? With centrifugal force away from the center or will it be tangential? Or perhaps another direction? What do you expect?

(A display of figures starts on the screen)

In the video clip that you are watching now, notice how the ball is released. It did not start away from the center, but it went in a straight line tangential to the circle. Is this a trick? In fact, it is not. It is the truth.

(The speaker once again on the screen)

In order to prove what happened in the video clip, I am going to do a simple experiment here and observe that the direction of the released object is tangential relative to the motion direction and not centrifugal. What I have here is a simple rotatable disc. I am going to attach a magnetic piece here. During rotation, almost in a uniform motion-which means at constant velocity- the object separates when passing by the metal piece at this point. Observe the direction of the released object when it moves in a uniform circular motion.

Is there a trick? In fact, no, there is not. This is the real explanation of what happens to the circular motion of an object. To verify what we have concluded and after watching the video clip and the activity that I have done, I hope that you do experiment # 1. In it, you will rotate an object in a circular motion and then draw what happens to the object during separation from circular motion. After that, I will come back to see your results.

(Written text on the screen: Activity 3: Let's rotate an object in a circular motion, and then draw what happens to the object during separation from circular

motion)

Scene 4 Time 8:28-11:06
Location: A classroom

Welcome, again. I hope you have found the direction of motion of the body after separation from the circular motion. To confirm that, let's watch the animation.

(an animation that shows the motion of a ball and a string appears on the screen)

Now, can we interpret the motion of the released object in this way? The interpretation is simply by Newton's First Law.

 (The following text appears on the screen: "Newton's First Law: An object at rest remains at rest, and an object in motion continues in motion with constant velocity unless the object experiences a net external force.")

That means when the net force acting on the body is removed, the object continues to move in a straight tangential line to the circumference. The only force that acted on the string is the tension centripetal force in the rope. In other words, the body was moving in a straight line and the tension centripetal force changed its motion path to become circular. After the removal of this force, the object returned to its original motion in a straight line which indicates there is no centrifugal force.

(The speaker once again on the screen)

As mentioned earlier, we can say and confirm that there is no centrifugal force. If it had existed, the object would have moved away from the center and not in a tangential direction, as we have shown in all our activities. But! Why do we still feel the presence of this force while in a car even though it is not real and it does not exist?!!

To make sure, we need to do the following activity. Please, join me in doing this activity.

Our activity is simply to fill this bucket with a reasonable amount of water and then move the bucket and the water inside it together. This quantity of water might be enough and I will need more space to make full circular motion. I will start here with almost a uniform circular motion. Notice that the water was not spilled. The same quantity of water still exists. As you can see, what happened here is a real application of force acting on an object moving in a circular motion. Now, please do this activity, then discuss it with your colleague. Each person in the group explains what happened for two minutes. Why didn't the water spill during the circular motion? I will come back to you after you finish, God willing.

(Written text on the screen: Activity 4: Why didn't the water spill during the circular motion?)

Scene 5 Time 11:07-16:14
Location: A classroom

Hello. I hope you have found the correct answer as to why the water did not spill during the circular motion. Let's discuss this together. Do you remember what we mentioned regarding the ball and scoop? The direction of the force acting on the ball by the scoop is always towards the top, in this direction, which is the perpendicular force or in other words the normal force. This is exactly what happened to the water inside the bucket during circular motion. The water experienced a perpendicular force from the bottom of the bucket in all the points. When the bucket was at this point, it experienced a perpendicular force in this direction. When it was at this point, it experienced a perpendicular force in this direction towards the top. When it was at this point, it experienced a perpendicular force in this direction and so on. This force was towards the center each time, which indicates that it is a centripetal force, and not centrifugal force. In other words, water was trying to maintain movement in a tangential line to the circle, as mentioned in the previous activities. It was trying to maintain movement in a tangential straight line, but the bottom of the bucket acted with a perpendicular force and changed direction from this situation to this situation, to this situation which means that the acting force on the water has been towards the center in all the cases and it is a perpendicular force.

This centripetal force can be calculated from the following formulas:

(Formulas appear on the screen)

This formula shows that the centripetal force is equal to mass multiplied by velocity squared divided by the radius ... Or

$F = mv^2 / r$

Where:

F is the centripetal force (measured in Newton N)
m is the mass of the rotating object (measured in kilogram Kg)
v is the linear tangential velocity of the object (measured in meters per second m / s)
r is the radius of the circular path (measured by unit meter m).

(The speaker once again on the screen)

 Now, let's do some practical calculations to the law that we mentioned previously. I have here a mass of 50 g and a half meter string (50 cm). I will now move this mass in a circular path with a radius of half a meter around my head. As you will see, while my colleague measures the time required to complete 10 cycles. I will count, let's start now. Of course, the counting and timing will start when the motion is almost uniform. Let's see. I will try now to get a uniform motion or almost a constant speed. Let's start from now: 1-2-3-4-5-6-7-8-9-10, these were 10 cycles in six seconds and a half seconds. This means that the time elapsed was 6.5 seconds. The radius is known. The mass is known and the number of cycles is known. How can we calculate the centripetal force that acted on the mass towards the center?

First, we need to calculate the velocity. Velocity is calculated as follows:

(Calculations appear on the screen)

Velocity is equal to the displacement over time. Of course, this is equal to the circumference multiplied by the number of cycles divided by the time elapsed. And, as you know, the circumference is equal to (2 πr) multiplied by the number of cycles (n) divided by the time. When we substitute the values we have

obtained, we find that it is equal to 2 multiplied by π multiplied by half a meter multiplied by 10 cycles. Then divide the answer by 6.5 seconds. The result is 4.83 meters per second.

(The speaker once again on the screen)

If the velocity is 4.83 meters per second, we need to substitute the value of velocity in the law of centripetal force as follows:

(Calculations appear on the screen)

As we have seen previously, the law to calculate F is equal to m multiplied by the square of v divided by r. When we substitute the values we have obtained, we find that m equals 0.05. Note that the value for mass is 0.05 kilograms and not 50 grams because we have converted the amount of mass from grams to kilograms. So, we have a value of 0.05 for m, then 4.83 square for v square divided by the radius, which is half a meter and we find that the final answer is 2.33 Newton, the value of the centripetal force.

(The speaker once again on the screen)

 So after we have calculated the value of the centripetal force, I want you to calculate the value of the centripetal force by yourselves. You have hard copies for the experiment number 2 and I want you to do a similar experiment to what I have done. Do the calculations and find the results, and calculate the magnitude of centripetal force. See you soon, God willing.

Scene 6 Time 16:14-18:14
Location: Inside the car

We will now do an activity on a straight line; motion in a straight line, and then the driver will suddenly rotate to the left, so I must put on the seat belt. During linear motion, I hope that you paid attention to the motion of the mass hanging on the mirror. Now, notice that there is almost no movement for this mass. During circular motion, which will start now, observe the direction of the mass. Observe, now. The mass has almost moved in this direction. Did you observed it?

To clarify the picture further, we will do the experiment again using a larger mass and longer rubber string outside the car.

(Photographing from outside the car for a bottle of water)

Note that the bottle of water is moving towards the distant trees in a straight line as you can see, and when the circular motion starts, the bottle tries to maintain motion in the same straight path. What if the mass inside the car were you? What prevents you from going out of the car and moving in a straight line like that mass? It is the body of the car. Particularly, the car door. The car door affects your body in the same way as the bottom of the bucket does to the water inside it. That is, it prevents you from going out of the car with a push force according to the previous relationship, but our bodies feel this force as if we move to the door. When turning suddenly, our bodies continue going in a straight line, while the car was moving in a circular motion, and this is when the path of our bodies intersects with the path of the car door such that we feel as if we are pushed by the car door, while in fact, it is the door that intersected our motion. This intersection is what makes us feel that there is a centrifugal force, but in fact, it is a centripetal force by the car door on our bodies moving towards the center of the circular motion and regarding the centrifugal force; it is fictitious and non-existent.

Scene 7 Time 18:14-20:36
Location: classroom

Welcome, again. There is one thing remaining that I would like to explain, and that is the centrifuge. This device is designed for separating components of materials such as blood, for example, but is this really a centrifuge? Does it depend on the centrifugal force to work? Let us see:

This device as you can see, works on a uniform circular motion with a constant velocity, so that it can separate the materials, but what pushes the materials towards the outside? Is it really a centrifugal force? To answer this question, we need to do the following activity:
In this activity, I have here a transparent tube and a movable metal ball as you can see. Here there is no tension force pushing it towards the center as in the previous experiments. I will now move the tube in an almost uniform circular

motion with my hand as a center of the circular motion. Some might think that the path of the ball would be a circular one as it appears on the screen, but, let us discover and find the truth.

(A tube and a small ball appear on the screen and the words: The expected path)

(The speaker once again on the screen)

As you have seen, the ball was not expelled away from the rotational motion, but it kept moving in a straight line just as we talked about with Newton's laws at the beginning. This means that the body remained moving at the same status since it was not affected by any external force.

My dear audience ... We have shown that there is no centrifugal force, but it is in fact a centripetal force. This force may be a tension force, a pull force, or a perpendicular force that affects objects during the circular motion, but they are all towards the center, that is a centripetal force. The expulsion effect during riding and driving in a circular motion is nothing but intersection of our straight line motion with the circular motion of the car. All these experiments confirm that there is no centrifugal force, but in fact a centripetal force.

I hope that you have benefited from this lesson and enjoyed it. Peace, mercy and blessings of God