14005 Centripetal Force Apparatus

Purpose:
To investigate uniform circular motion and centripetal acceleration.

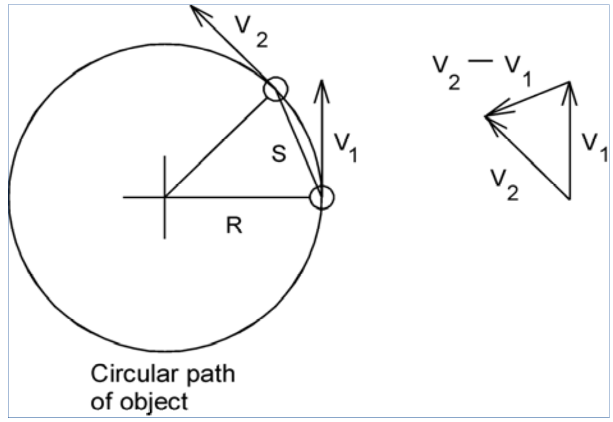


Figure 1

Required Accessories:
Stopwatch or Clock with a sweep second hand
Graph Paper
Meter stick
Balance to weigh washers

Discussion and Theory:

The velocity of an object not only has a magnitude (speed), but also a direction. This makes velocity a vector. A change in velocity occurs any time there is an acceleration of the object (or a force acting on that object). An object that is in free fall is accelerating downward; it's speed is continually increasing because it is acted upon by the attractive force of gravity. An object that is moving in a circle at a constant speed also experiences an acceleration. The magnitude of the velocity (speed) is constant. However, the direction of the velocity is continually changing as the object moves around the circular path. Acceleration is the change in velocity divided by the time required to make that change.

To calculate the acceleration of an object in uniform circular motion it is helpful to look at the geometry of the motion. At some instant in time the object has a velocity V_1. After a length of time(Δt), has elapsed, the velocity of the object is V_2. Remember, the speed (length of the vector) is the same, only the direction has changed. The object is also a little further around it's circular path and the angle it has covered is α. The distance the object has traveled along its circular path is equal to its speed times the length of time that has passed (Δt).

Comparing the two illustrations in fig.1, you will see that the two triangles are similar in that they are both isosceles and the angle at the vertex is α. We can now set up a ratio between the radius of the circle,R, and the distance traveled, S, to the velocity, V, and the change in velocity, ΔV, which is $V_2 - V_1$.

$R/S = V/\Delta V$

Because $S = V\Delta t$, we can substitute for S.

$R/(V\Delta t) = V/\Delta V$ or: $V\Delta t/r = \Delta V/V$

But, acceleration $= \Delta V/\Delta t = V^2/R$

This shows us that the magnitude of the acceleration is equal to the square of the speed of the object divided by the radius of its circular path. As Δt approaches zero, the direction of the acceleration vector approaches being parallel with the radius vector. In the limit, the direction of the instantaneous acceleration vector is always towards the center of the circular path, so it is a centripetal acceleration.

Every accelerated object must have a force acting upon it and this force must be in the direction of the acceleration. We will always be able to point to an object in the environment that is exerting a force on the circulating, accelerating, body. In this experiment the force was provided by the string pulling the stopper toward the center of the circle. In the case of the Moon orbiting the Earth, the centripetal acceleration is provided by the gravitational attraction of the Earth. For an electron orbiting a nucleus, the centripetal acceleration is provided by electrostatic attraction.

Procedure:

Thread the string through the hole in the rubber stopper and tie the string back onto itself. Thread the free end of the string through the handle. The length of thread between the rubber stopper and the handle should be approximately one meter.

Hold the free end of the thread firmly in one hand and the handle in the other. Make sure you have an area clear of people and furniture then begin to swing the rubber stopper slowly in a horizontal circle overhead. Feel the pull on the string as the speed of the rubber stopper increases. As the speed of the rubber stopper increases, does the pull on the thread increase or decrease? Try swinging the rubber stopper at a constant speed and slowly let some thread out to increase the radius of the circle. How does the force on the string change? What happens when you let go of the string? When the string is released, the centripetal force becomes zero.

After you have gotten a feel for the apparatus, make some quantitative measurements of the centripetal force. Return the string to its original one meter length and slip a paper clip over the thread just below the handle. Tie a loop in the free end of the thread. Slip three or four washers onto the thread, then hold them in place by clipping a paper clip to the loop in the thread. Slowly begin to swing the rubber stopper overhead. Increase the speed of rotation until the marking paper clip is just below the bottom of the handle (do not let it touch the handle!). The centripetal force and the weight of the washers are in equilibrium when the paper clip marker is stationary.

Measure the period of the rubber stopper by timing a fixed number of revolutions. The average speed is the circumference divided by the period. Weigh the paper clips and washers to determine the gravitational force and, hence, the tension in the string.

Let's examine our derived formula again.

$a = V^2/R$

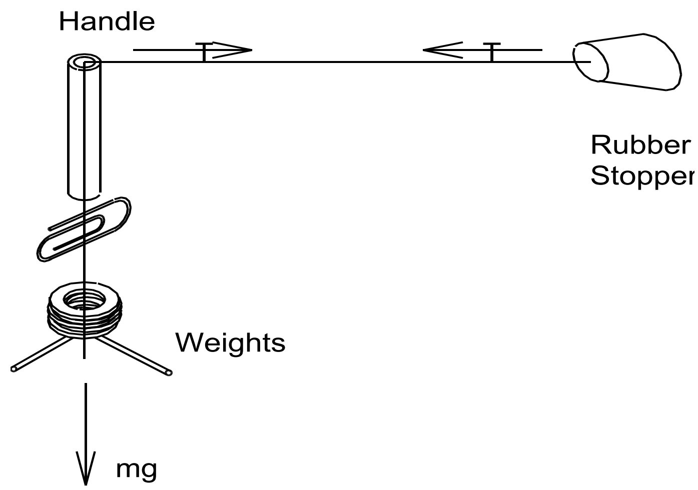
But, invoking Newton's Second Law,

$F = ma = mV^2/R = m4\pi^2R/T^2$

If our derived formula is correct, then F/V^2 will be constant for all of our data pairs. This constant will be equal to the mass of the rubber stopper divided by the radius of the circle.

We could also plot the force, F, as a function of V^2. Again, if our formula is correct then the resulting graph should be a straight line through the origin. What is the value of the slope?

This derivation path avoids dealing with the apparatus as a conical pendulum where the string to the rubber stopper makes a non right angle with the string to the washers in all cases. That derivation gives the same final forms to the expression:



$F = ma = m4\pi^2R/T^2 = mV^2/R$

Time Allocation:

Some prior assembly is required for this product. Individual experiment times will vary depending on methods of instruction, but normally will not exceed one class period.

Feedback:

If you have a question, a comment, or a suggestion that would improve this product, you may call our toll free number.