AP Physics Lab #8: Exploring Circular Motion (Big Ideas 5,4)

***Question**: How can I design and experiment to explore the variables that affect the speed of an object in a circular pattern and to also analyze the motion of a conical pendulum.*

College Board Big Ideas:

4.D.1.1: The student is able to describe a representation and use it to analyze a situation in which several forces exerted on a rotating system of rigidly connected objects change the angular velocity and angular momentum of the system.

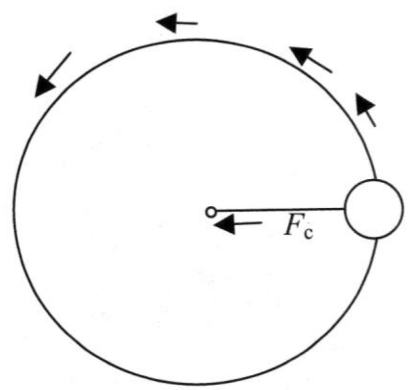
4.D.1.2: The student is able to plan data collection strategies designed to establish that torque, angular velocity, angular acceleration, and angular momentum can be predicted accurately when the variables are treated as being clockwise or counterclockwise with respect to a well-defined axis of rotation and refine the research question based on the examination of data.

5.E.2.1: The student is able to describe or calculate the angular momentum and rotational inertia of a system in terms of the locations and velocities of objects that make up the system. Students are expected to do qualitative reasoning with compound objects. Students are expected to do calculations with a fixed set of extended objects and point masses.

Objectives:

1. *Explain how centripetal force, the radius of a circle, and the mass of an object affect the object's linear speed when it travels in a circle.*
2. *Sketch a free body diagram of an object traveling in a horizontal plane.*
3. *Sketch a free body diagram of the forces acting on a conical pendulum.*
4. *Design an experiment to study the variables that affect the motion of a conical pendulum.*

Exploring Circular Motion Pre-Lab:



According to Newton 's first law, an object will travel in a straight line at a constant speed unless an outsideforce is acting upon the object. For an object to travel in a circle, a centripetal or "center-seeking "force must be applied to the object. A ball or a rubber stopper tied to a string can be twirled in a circle as long as there is tension in the string.The string tension provides the centripetal force, as shown in the diagram to the right. Please note that on a FBD, never label the center-seeking force as the centripetal force. Always label the actual force exerted on the object (i.e., $F_{tension}$).

If the string is suddenly cut, the ball or stopper will continue in a straight line from the point where the string is cut. Since the ball or stopper is no longer pulled into a circle, it will leave the circle at a tangent (straight line) of its original circular path. The centripetal force needed to keep the object traveling in a circle may be determined using Newton 's second law: $F_C = ma_c$, where $a_c = V^2_T/r$, V_T is the tangential velocity.

P1. Imagine you are running around a circular track at a constant speed. Explain how you can determine how fast you are moving around the track. What must you measure and how do you calculate your speed?

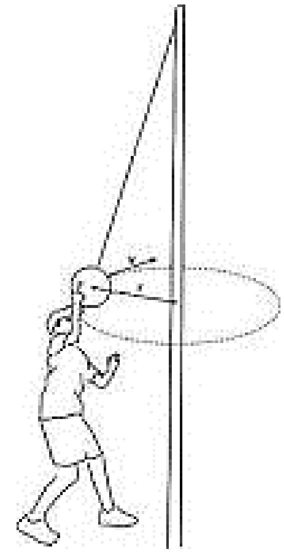
P2. The speed at which you run around a track is technically your tangential speed. Derive a formula for the tangential speed in terms of π, r, T.

P3. Finally, restate Newton's second law for circular motion, $F_c = ma_c$, in terms of m, π, r, and T.

P4. In the scenario outlined in P1, what would happen if you encountered a large patch of ice on the circular path? Please justify your answer and provide a sketch to illustrate this scenario.

P5. Sketch and label the FBD of the three forces that act on your body when you run around a flat circular track?

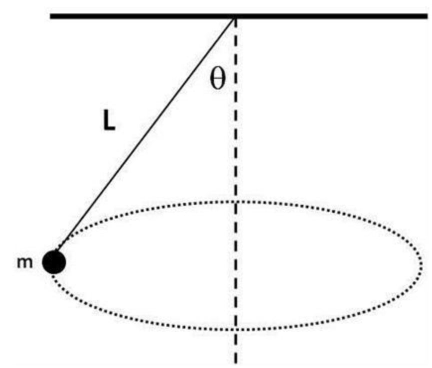
P6. What provides the centripteal force that acts on your body that keeps you traveling in a circle?



Tetherball is a game for two opposing players. The equipment consists ofa 6-10' vertical pole (like a short flag pole) secured to the ground. A ball similar to a volleyball is suspended by a rope from the top ofthe pole to a height of 2 feet above the ground. (See the diagram) Each player hits the ball trying to make the rope wrap around the pole either clockwise or counterclockwise. The player to be the first to wrap the rope and ball around the pole is the winner.

A tetherball behaves similar to a conical pendulum, in that the x-component of the tension of the rope provides the centripetal force needed to keep the ball traveling in a circle while the y-component of the tension counters the weight of the ball.

P7. Sketch and label a free body diagram of the forces acting on the tetherball as it swings around the pole at an angle of Θ (see diagram 2).

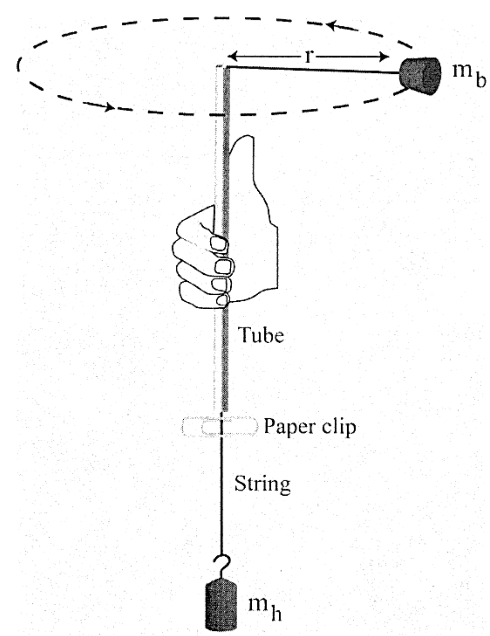


P8. Sum the forces in both the horizontal (x) and vertical (y) directions that act on the tether ball.

Exploring Circular Motion Lab:

Materials: centripetal force apparatus, hanging masses, meter stick, Smart phone, flying pigs, video analysis, digital probe ware (to explore data collection)

Centripetal Force Apparatus*: A centripetal force apparatus is a device specially designed for this activity. See Figure on next page. The activity involves twirling an object (such as a rubber ball or stopper) around in a circle. The object is attached to a string that passes through a tube. A mass is suspended from the opposite end of the string. To set the object into circular motion, the tube is held vertically, and the object is sent into a circular twirl by spinning the tube at a constant speed. The hanging mass provides the centripetal force, F_c, which is required to keep the object moving in a circle. An alligator clip or paper clip is attached to the string about 2 cm below the tube. The clip serves as a reference to ensure that the radius of the circle does not change as you twirl the ball or stopper.*



The design and use of this apparatus assumes that the ball or rubber stopper travels in a horizontal plane. Technically is does not. In actuality, the gravitational pull on the ball or stopper will create a slight angle between the horizontal plane and the part of the string nearest the ball. If the speed of the twirl is sufficient, this angle will be very small and thus, may be ignored. However, have your lab partner ensure you do not have a substantial angle deviation from the horizontal plane. This may take some practice.

Measuring Period Time*: The interval of time taken to complete one cycle of a regularly repeating phenomenon is called the period, T. For example, the period of the lunar cycle, the time it takes the moon to orbit the Earth, is 27.3 days. If a period is short, it may be difficult to measure. In such a case it is useful to measure the time it takes for a certain number of cycles, for example, 10, and then divide by the number of cycles: T = time for 10 cycles /10. The result will yield the average period. The number of cycles you choose depends upon how difficult it is to measure the individual period of time. The shorter the time period, the more difficult it is to measure accurately. Consequently, you should measure the time of a large number of cycles when using this technique. To verify if your choice of cycles is appropriate, you can test your measurements. For example, if you decide (a guess) to try 20 cycles to determine the period of one cycle, then you can repeat the same procedure using 30 cycles. If the result is essentially the same, then your choice of 20 cycles is appropriate.*

Part 1- Exploring Circular Motion: *In this activity, you will perform an experiment in which you explore the variables that affect the speed of an object traveling in a circle. Specifically, you will explore the effects of mass and radius on the period of an object moving in a circle.*

General Set-up*: Suspend a 100-gram mass from the loop of the centripetal force apparatus. Practice twirling the stopper, using a radius of your choice. The speed of the stopper should be fast enough to keep the angle between the horizontal plane and the part of the string nearest the ball or stopper very close to $\Theta=0$. If the 100-gram mass does not yield a constant zero or very low angle to the horizontal, try using other masses until you have mastered twirling the stopper in the horizontal plane. Select your choice and attach an alligator clip or paper clip onto the string about 2 cm below the tube. The clip will serve as a visual reference point to be certain that the radius of the circle remains constant as you twirl the ball. Twirl the stopper and verify that the clip always remains 2 cm ± 1 cm below the tube. Do not allow the clip to touch the tube or fall more than 3 cm below it. If the clip touches the tube it will exert an additional force on the ball, which cannot be easily measured.*

Q1. Draw two free body diagrams. One for the stopper and one of the hanging mass and show how the hanging mass provides the theoretical centripetal force.

Q2. You will need to set-up a data table for the next two questions. Please read questions Q3-Q5 first. Here are some suggested data to include in your experiment; however, you will need to determine the number of trials you would like to conduct. Here is a suggested template:

Trial #	Mass of stopper (kg)	Hanging mass (kg)	Radius (m)	Time for (choose #) revolutions (s)	Circum. (m)	T (s)	V_T (m/s)	F_c (theor.)	F_c (exp.)	% Error
1										

Q3. Select a radius your choice. Use the paper clip or alligator clip as a reference point to maintain this radius. Add a mass of your choice that, in combination with the radius, will enable you to comfortably twirl the ball in a horizontal plane. Determine the period of time, T, of this combination of radius, r, and hanging mass, m_h.

Q4. Repeat Q3, using four other hanging masses with different values. For each hanging mass, determine the period for the swinging ball or stopper. Be sure to maintain the radius. Record your data in the Q2 table.

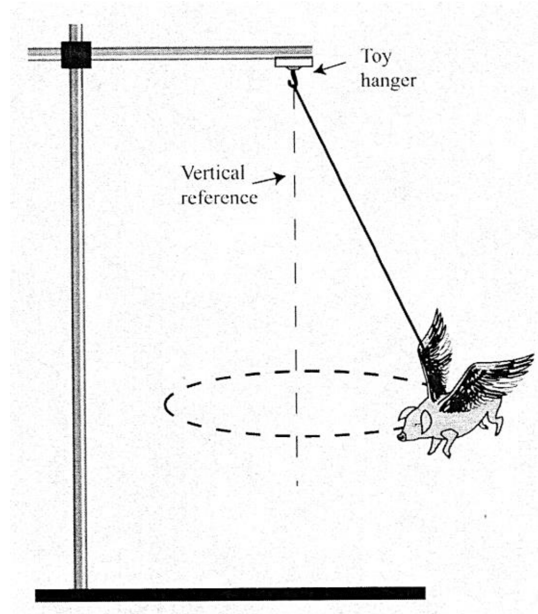
Q5. Repeat the above procedure again, but this time, maintain the same hanging mass and determine the effect of radius on the period, T of the twirling stopper. Record your data in the table from Q2.

Q6. Examine your data collected in Q3 and Q4, in which the radius was kept constant and you added hanging masses to the system. Create a graph of the F_c as a function of the period, T. Linearize the graph and determine the significance of the slope.

Q7. How is the centripetal force affected by the period? Is the relation linear, exponential, or inverse? Explain how you know refering to your graph in Q6.

Q8. Based on your answers to Q7 and Q8 and using a semi-quantitative approach, sketch a graph of the radius ® as a function of the period (T). This graph is only a sketched relationship.

Part 2- Exploring Conical Pendulums: *In this activity you will design an experiment to measure the angle of a conical pendulum. You will be provided with a toy flying pig and some hardware that, when set up as shown in the figure to the right, behaves like a conical pendulum.*



Q9. Using the materials provided and as described above, design and perform an experiment that uses the principles of circular motion to determine the angle the flying pig forms with the vertical. This will be your experimental result. Then, compare this angle with a theoretical result that you determine using a meter stick and your understanding of the geometry of a cone. Outline the step-by-step experimental procedure.

Q10. Design a table to collect data for your experiment. Also, be sure to show all calculations. Conduct your experiment.

Q11. Calculate the percentage difference between the experimental angle and the angle determined through geometry. Which method do you feel was more accurate, justify.

Write your two claims (one for each part) and write a summary for this entire investigation.

Please self-assess your lab report using the checklist/rubric.