Lab 5: Circular Motion

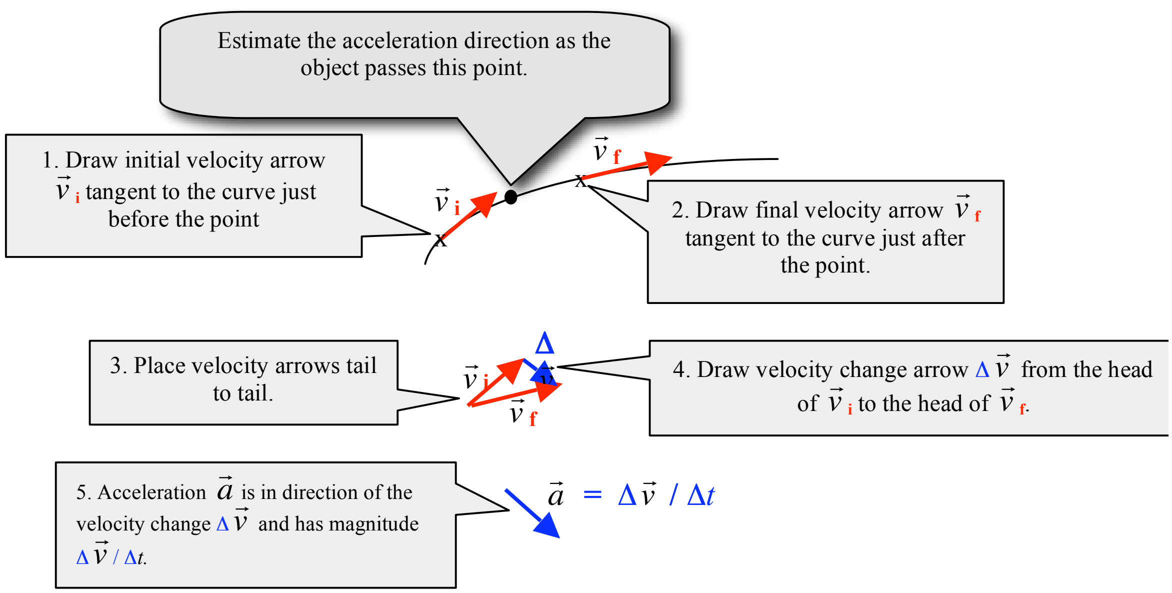
I. Introduction

The lab today involves the analysis of objects that are moving in a circle. Newton's second law as applied to circular motion can be used to solve a problem in the form of an experiment.

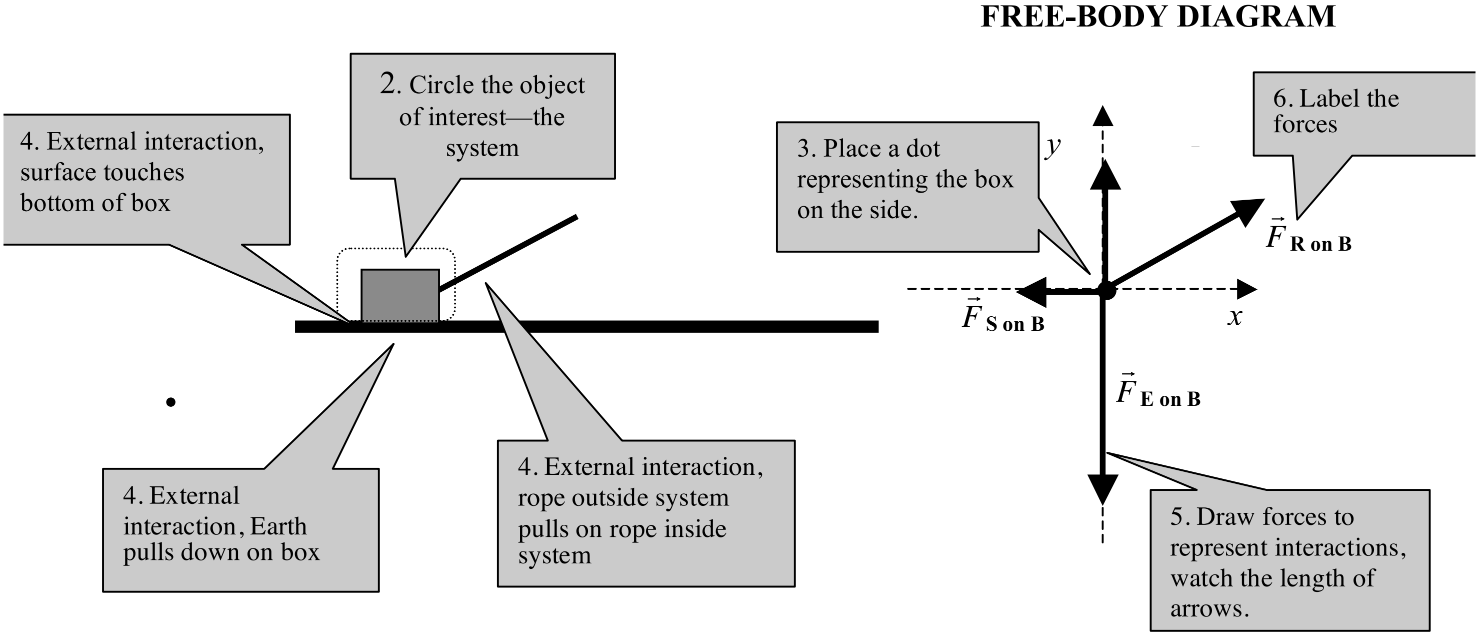
II. Theory

We will use Newton's second law in component form to help analyze circular motion problems. Using Newton's second law in component form involves picturing the system, choosing a system object, analyzing the kinematics of the motion of the system object, analyzing the forces exerted on the system object by other objects, and applying Newton's second law to the situation. We use special diagrammatic methods for the kinematics and dynamics parts of this analysis.

Velocity subtraction method—a estimate the direction of acceleration during two-dimensional motion:



Free-body diagrams:
1. Sketch the situation described in the problem.



Newton's second law in component form: The component form of Newton's second law used for circular motion is applied for a radial axis with the positive direction toward the center of the circle (so the centripetal acceleration is positive) and in some cases to a vertical *y* axis:

$$\sum F_r = m\, a_r$$
$$\sum F_y = m\, a_y$$

where $a_r = a_c = v^2/r$ is the radial (centripetal) acceleration.

III. Experiment 1—circular motion and the pendulum

Equipment: a pendulum, a spring scale.

Problem: A 500-g block hangs at the end of a string that is about 1 m long. The top of the string is connected to a Newton force scale. When hanging straight down, the scale reads about 5 N (note that $mg \approx (0.50\text{ kg})(10\text{ N/kg}) = 5\text{ N}$). If you pull the bob to the side so that the string is horizontal and then release it, will the scale read somewhat more than 5 N, less than 5 N, or about 5 N as the bob passes the lowest point directly below the scale?

Procedure: To answer this question, complete the following procedure.

a) Attach the bob to the spring, let it hang freely and record the reading of the spring. Make a free body diagram for the bob to help understand the scale reading.

Scale reading:

Free-body diagram when hanging at rest straight down:

b) Now imagine that you pull the bob to the right so the string is horizontal. You then release the bob and let it swing down (do not perform the experiment yet). Use the velocity subtraction method to determine the direction of the bob's acceleration as it passes the lowest point on its path—when passing directly below the Newton scale.

Use the velocity subtraction method to estimate the acceleration direction:

c) Next draw a free-body diagram for the pendulum bob when passing this lowest point on its path—when passing directly below the Newton scale. Be sure to make the lengths of the force arrows the correct relative length. Also, label each arrow with two subscripts indicating the external object causing the force and the system object (the pendulum bob) on which the force is exerted.

Free-body diagram when bob is passing lowest point in its swing:

d) Use your knowledge of Newton's second law (the acceleration is proportional to the net force) applied to circular motion to check for the consistency of the two diagrams. If they are inconsistent, change one or both diagrams so they are consistent.

e) Next, use this analysis to predict whether the scale will read the same, more or less than 5 N when the bob is moving past the lowest point on its swing.

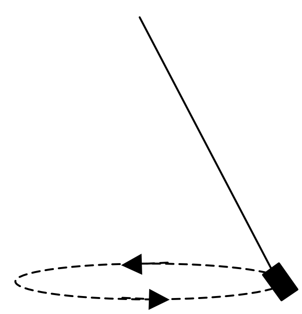
Prediction:

f) Now perform the experiment and record the result. Did the result match your prediction in part (e)? Explain.

IV. Experiment 2—the net force on a conical pendulum

Equipment: Pendulum bob (perhaps a 500-g block or something like that), string, ring stand with long cross arm, meter stick, a stopwatch.

Problem: A conical pendulum consists of a hanging object (we'll call it a block) at the end of a string. The block moves in a horizontal circle and the string moves along a path that is like an inverted conical ice cream cone. Today, we would like to combine measurements and theory to determine the net force due to all objects that interact with the block as it moves in a horizontal circle. Note that we are trying to determine the net force and not a particular force exerted on the block. We would like to do this in two independent ways.



Method 1

- Set up the conical pendulum—the block hanging at the end of a string. Place a meter stick with the 50 cm mark directly under the block.
- Practice swinging it in a conical circle. To do this, hold the string near its attachment point at the top and moving the hand gently in a circle until the block moves in a nice horizontal circle. The results work best if the circle has a medium large radius—the string will make at least a 30° angle with the vertical. A bigger angle works better.
- Record the radius of the circle.

- Measure the time interval for the block to make ten trips around the circle.
- Use the last two measurements and your knowledge of circles to calculate the block's speed while traveling around the circle.
- Knowing the speed and the radius of the circle determine the acceleration of the bob. Use this number to calculate the net force.
- Make a free-body diagram for the block when at one point along the circle. At the side indicate with an arrow the net force exerted on the block.

Method 2

- Take a spring scale and pull the block to the side so the string makes the same angle as when doing the experiment in Method 1. Hold the block stationary in that position and read the spring scale to determine the force that it is exerting on the block.
- Construct a free-body diagram for the block when held stationary at the side.
- The diagram should look like that drawn above only now with the force of the scale added. Thus, the scale's force is now balancing the other forces shown in the diagram and must be equal in magnitude to the net force when the block was moving in a circle and opposite in direction to that net force. So you now have an independent measure of the net force on the block when it was moving in a circle.

Compare Results: After using both methods, compare the two outcomes.

V. Homework

In Lab VI, you will be doing experiments involving statics. The following problems will help you prepare for that lab. Please solve the problems before coming to lab and bring the solutions with you to turn in at the beginning of the lab.

1. What does it mean if the lever arm of a force is 0.50 m? (b) What does it mean if the torque of a force is positive? Negative? (c) What does it mean if the torque caused by a 10-N force is zero? (d) What does it mean if the torque of a 10-N force is 5 N•m?

2. The fulcrum of a uniform 4.0-m long, 200-N seesaw is located 2.5 m from one end. Your sister weighing 300 N sits on the long end. Determine the mass of her friend sitting at the other end of the balanced seesaw.