Circular Motion

This is the outline of exercises that we want you to do in lab. This is a complement to the material in the lab manual. Please read the manual to learn about the tools and techniques; use this document to guide your experiments and calculations in the lab.

In this lab, you should pick one of the problems to work on first. When you complete it, get as far as you can on the other.

Problem #1: Running in Circles

As we've seen, when you run in a circle, you lean into the turn. **And we want to figure out - and measure - the angle of the lean for a particular circular motion.**

You are to do your measurements outside. You may stay outside to complete your calculations as well.

Go outside to the plaza to the south of the main entrance to the Physics wing. There is a sculpture with a circular patch of concrete underneath it. Pick a person to run in a circular path around this patch of concrete. (If, and only if, the weather is too bad - or the light is too dim - for you to go outside, you should have your person run in a circle around the pendulum in the atrium on the first floor of the Physics wing.)

First, do a bit of preparation:

- Draw a free-body diagram for the person running in a circle.
- Draw an arrow to represent the total ground force on them - the vector sum of the normal force and the friction force.

Now, do a bit of measurement:

- Have the person run in a circle at a steady speed; for best results, have them go around a few times to get the hang of the motion so that they are moving smoothly.
- Measure the radius of their circular path.
- Measure the time for them to complete one complete revolution.
- Take a photo of them when they are running to determine the angle of their lean. What is the angle relative to the vertical?

Finally, do a bit of calculating:

- What is their acceleration as they run in the circle?
- Determine the values of the forces acting on them.
- What do you calculate for the angle of the lean? How does this match your measurement?

Now, let's bring it all together:

- Why are highway on-ramps and off-ramps banked? Discuss the physics involved.

Problem #2: Taking Things in Stride

The maximum speed at which you can walk is ultimately a circular motion problem; and since you are on Earth, our gravity defines the limit. When you take a stride, your body pivots over and around the foot that is in contact with the floor; this motion is a segment of a circle. We'll explore two aspects of this situation here.

First, let's measure the vertical acceleration of your body as you walk. You can use the iPad accelerometer in the Physics Toolbox Sensor Suite app (though the orange PhyPhox app takes better data for this activity), or the Video Physics app using a high-speed video recording. In either case, record data for a person walking across the room at a reasonable speed, then at a fairly zesty pace - walking as rapidly as you can without breaking into a jog. Examine the regular walk first:

- Why do you read a positive acceleration? Why do you read a negative acceleration?
  - What part of your stride produces these accelerations? Show this in a motion diagram, and a few free-body diagrams.
  - Discuss: How are you modeling your walking as circular motion?
- Now look at the faster walk. Look at the magnitude of the negative acceleration now; what do you notice?
  - Explain what is going on. Explain why, if you were to move faster, you will simply leave the ground.
- Using your free-body diagram, develop a formula to predict the maximum possible walking speed, and predict what a group member's maximum walking speed should be.
- Make a measurement: How fast can this person walk?
  - Is your measured value consistent with your prediction?

Now, let's bring it all together:

- When we sent astronauts to the moon, they tended to hop from place to place instead of walking. Why? Discuss the physics involved.
  - Bonus Calculation: How fast could your group member walk, if they were on the moon?

Problem #3: How Slow Can You Go?

Do your calculations before performing the experiment. You MUST do your measurements outside - don't swing the bucket indoors!

When you swing a filled bucket (of water) over your head, how slow can you go?

First, do a bit of preparation:

- Draw a free-body diagram for the forces on a bucket of water that a person swings in a vertical circle over their head.
- If the person is going as slow as they possibly can, what does the free-body diagram look like?

Now, do a bit of measurement:

- Pick a person to swing a water-filled bucket in a circle at a constant speed over their head.
- Determine the radius of the path that the water will follow.

Do a bit of calculating:

- For the slowest possible swing of the bucket, what is the speed of the bucket for the person you picked?
- At this speed, how much time does one complete swing require?

And, do a test:

- Have the person swing the bucket over their head. Go quickly, and then go more and more slowly until the slowest speed is reached. You'll know it when you reach it! (How can you tell?)
- Measure the time for one complete swing. How does this match your prediction?

Now, let's bring it all together:

- Back in 2014, there was an ad campaign that featured a person running through a loop-the-loop. He went in a full circle, and it was pretty impressive What are some physics-ey considerations that would make running upsidedown in this fashion tough?

Problem #4: Penny Pusher

First, place the penny on the plastic turntable (on the opposite side as the tape), and tip the turntable, slowly, to a steeper and steeper angle until a penny just starts to slide down the plastic.

- How can you use this angle to predict the frequency of rotation which will cause the penny to fly off the turntable?
- What measurements will you need to make to calculate this? After writing out your calculations, gradually increase the speed of the turntable until the penny flies off, then measure the rotational frequency. Does this match your prediction?

Now, set several pennies on the turntable at different distances from the center and make a prediction:

- If you increase the speed of the turntable, which penny will fly off the turntable first? Which will fly off last? Explain your reasoning, and then test your prediction. Were you correct?

Let's think about the implications of this experiment:

- As a kid, you may have had a chance to play on a merry-go-round. While it is spinning, why is it fairly easy to walk when near the center, but fairly difficult as you move further out?

Report

You'll be recording your work on the whiteboard tables as you go, and so be clear when summing up your process and your conclusions. Keep your discussions short, sweet, and to the point, please. Be sure to indicate what work you did on the report (as opposed to what your lab partners did).

Remember: The point of the report is to show your TA how well each of you understand the material, how well you designed and performed experiments, how well you can discuss your results, and how much of a scientist you were - not to show them you can parrot the textbook, always get the "right" answer, or do everything. The process, your reasoning, and your improvement are the key to earning full credit.

Be sure that each of your group members submit this as an assignment on Canvas as a single pdf file, and include your own self/peer evaluation in an attached comment.

Looking Ahead: Conservation!

At this point you are very familiar with a $=F_{net}/m$, you might even have begun seeing that formula in your dreams. It is a wonderful relationship to refer to when accelerating objects away or towards you, or as you saw in lab today in a circle, but there is even more to physics than this. Soon, you will encounter the idea of conservation - measurable values that must remain the same through some event. You already know one of these concepts - momentum. An object's momentum won't change, unless a force is applied to it. We'll get a chance to explore this in more detail next week, along with some other conservation rules!