NAME___________________________________ DATE________________

# Lab 5: Rotational motion at the playground
# Essentials of Physics: PHYS 101

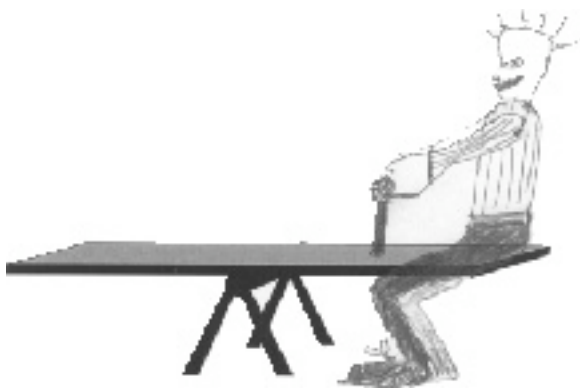
**<u>Important note:</u> this lab meets at the playground located at the SW corner of 23rd and University streets, about 7 blocks south of the UO campus.**

Many of the fun things to do at a playground involve rotational motion— moving in circles. This lab comprises four experiments: the barbell, the teeter-totter; the swing; and the merry-go-round. You will be undertaking all three experiments.

**Experiment:** ***Teeter totter tallies total torques! Story at ten***

**Introduction:**

You're sitting on one end of a teeter totter, minding your own business, when the big class bully comes along and plops down on the other end, sending you flying. You swear to seek revenge via the laws of physics. What can you do next time?



**Question**: Given that the class bully weighs twice as much as you, how can you change how you sit on the teeter totter so that you both balance when he sits on the other end? Be specific and explain your reasoning. Draw diagrams that illustrate your method.

**Procedures:**

1. Have the heaviest and lightest members of your group sit on either end of a teeter-totter.
2. Make adjustments until the two group members balance.

3. Have the third group member measure the distance from the pivot point of the teeter-totter to the center (center of gravity) of where each balanced group member is sitting. (This distance is called the *lever arm.*)
4. Do two trials with the same two group members at the same ends of the teeter-totter. Now switch ends and do two more trials. Record your average lever arm distance for each balanced group member in the table below.

   Record the (approximate) weights of the two group members below.

**Observations for Part One:**

Data Table: Part One of Teeter Totter Experiment

| | weight (lbs) | force (N) | Observations | Lever arm (m) | Torque (lever arm x force (N-m)) |
|---|---|---|---|---|---|
| member 1 | | | | | |
| member 2 | | | | | |

**Calculations/Questions:**

1. Convert weights (in lbs) to force in Newtons (N) using the following formula:

   ______ (weight in lbs ) $\cdot$ 0.455 kg/lb $\cdot$ 9.8 m/s/s = ______ (weight in N)

   Fill in the second column of the table above.
2. Calculate the torques (($\tau$) lever arm x force) and fill in the appropriate column above. What affect did the changes you made (to balance the two group members) have on the *torques* they exert on the teeter-totter?

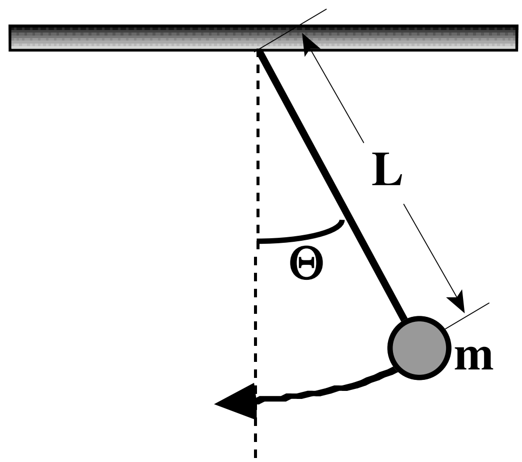
3. What can you say about the sum of the torques exerted by the two group members on the teeter-totter? Again, draw diagrams to clarify your explanation.

**Experiment: In the Swing**

**Introduction:**

Part of the enjoyment that comes from swinging at the park is the repetition of motion. Indeed a swing (or what scientists might call a "simple pendulum") is an example of an *oscillator*, something that repeats its motion over and over again. Other examples of oscillators include the strings of a guitar or the tuner inside a TV set.

The time it takes for motion to repeat is called the period, T. The period of a swing is how long it takes you to return to your starting position. The period of a swing may or may not be affected by its following characteristics.




1. It (and your) mass.
2. The length of the swing (the *lever arm*)
3. Your starting position when swinging.

**Question:** When you swing at the park, which of the above characteristics plays the greatest role in determining the period of your swinging? Why? Which is the second most important? Why?

**Procedures:**

3. Use the stopwatch to determine the period when each member of your group swings <u>through a small angle</u>. A good procedure is to record the time for 5 complete swings and divide it by 5.
4. While keeping the others constant, vary one of the above characteristics and record how period changes, again swinging through a small angle (a ladder is available to change the length of the swing, or to get into the swing!) Use one of the tables provided on the next page to record your results (be sure to label which table is which).
5. Follow this experimental procedure for each of the three variables, listed above.
6. To explore the effect of starting position, have someone hold the person in the swing at different angles away from equilibrium (hanging straight down) and then let go. You can approximate the starting angle by measuring the displacement (distance) away from equilibrium and dividing it by the length of the swing.

displacement from equilibrium / length of swing = __________ (starting angle in radians) (note: 0.5 radians is a little less than 30 degrees and corresponds to a displacement that is half the length of the swing.)

7.Enter the torque on the swinger for each trial. To do so, use the following formula:

weight of swinger x starting angle = __________ (return force)

lever arm x return force (from just above) = ___________ (torque on swinger)

**Calculations/Questions:**

1. Which of the three characteristics above, when varied, had the greatest affect on the period of swinging?

The moment of inertia, I, of a swing (simple pendulum) is proportional to its mass. If you halve the mass of someone on the swing, the swing's moment of inertia will halve, making it easier to swing.

2. If you double the mass of the swinger, how does its moment of inertia change? (be specific).

## Data Table: Swing Experiment

Characteristic/variable being observed:_________________

| Weight of swinger (N) | Lever arm (m) | Displace-ment from equil. (m) | Starting angle (radians) | Return force (n) | Torque on swinger (N-m) | Period for 5 swings (s) | Period T (s) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

Characteristic/variable being observed:_________________

| Weight of swinger (N) | Lever arm (m) | Displace-ment from equil. (m) | Starting angle (radians) | Return force (n) | Torque on swinger (N-m) | Period for 5 swings (s) | Period T (s) |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

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|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |
| | | | | | | | |

3. If you double the mass of someone on a swing, how does the torque on it change? Again, be specific.

4. How does the ratio of the torque to the moment of inertia (T/I) change when you double the mass of the swinger? This ratio, called the *angular acceleration*, determines how long it takes for the swinger to return to equilibrium from the starting position. Can you use this to explain your observations regarding how changing the mass of the swinger affected the period of swinging?

5. To verify that changing the mass has no affect on the period of swinging, have the lightest and heaviest members of your group swing side by side. Is it relatively easy for the two swingers to "synchronize?" Why?

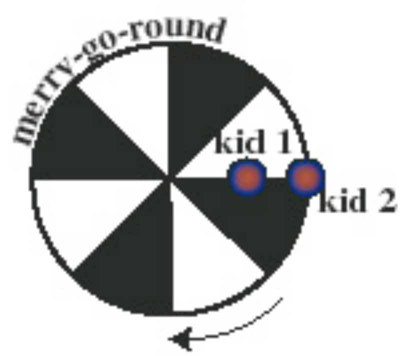
**Experiment: Merrily we go around**

## Part One: Circle round the sun

### Introduction:

Unlike the planets orbiting the Sun, kids arrayed on a merry-go-round at different distances from its center all take the same amount of time to complete a full circle (which, for a planet, would be a year) . What can we say about the speed each kids is traveling at?

**Question:** Two kids are playing on a merry-go-round. One is at the outside edge, while the other is situated half-way to the center (see diagram, below). Which kid is going faster (has a greater speed)? How much faster is that kid going?

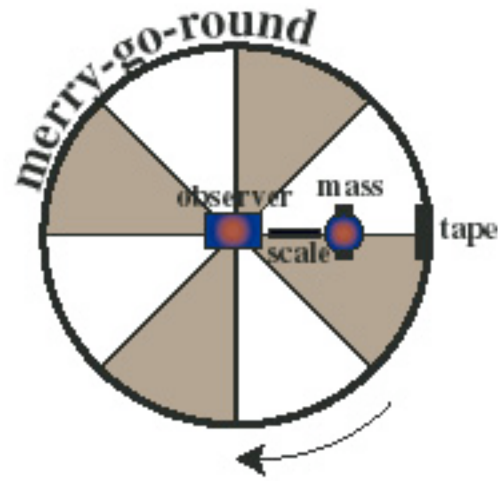



Rather than just determining the speed of the two kids, we can also measure the force necessary to keep each "kid" traveling in their respective circles. This *centripetal force* is what kept the group member from flying off (in what direction?) the merry-go-round in Part One.

### Procedures:

1. Have a group member stand at the center of the merry-go-round, facing outward. They should hold onto a 5N spring scale connected to a 1kg (total) mass+cart. The cart is set on cardboard so that it can easily slide (see diagram, below). The approximate distance between the mass and the center of the merry-go-round should be recorded in the table, below, under "radius."

2. Mark one point on the outside edge of the merry-go-round, directly along the line formed by the spring scale and the mass.
3. Set the merry-go-round spinning so that it completes one full revolution in about 4 seconds. A second group member is responsible for timing the period (time) of a revolution.
4. The person on the merry-go-round is responsible for reading the spring scale.




5. The third member of the group is responsible for recording the revolution time and the spring scale reading, which are to be entered below.
6. The entire procedure should be repeated, but with the 1kg mass+cart placed on cardboard near the outside edge of the merry-go-round (one can tape two pieces of cardboard to the merry-go-round at the two locations in advance) Again, measure the distance between the mass and the center of the merry-go-round, spin the latter at about one revolution per 4 seconds, and time the revolution and measure the force. Results should be recorded in the appropriate row, below.

**Observations:**

Data Table: Part Two of Merry-go-round Experiment

| | Radius, r, (m) | Period of revolution (s) | Force on spring scale (N) | Distance traveled (m) | Speed, s, (m/s) |
|---|---|---|---|---|---|
| 1/2 way out | | | | | |
| all-the-way out | | | | | |

**Questions/Calculations:**

1. In completing one revolution, the mass traveled a distance— the circumference of a circle centered on the merry-go-round— in some amount of time. The formula relating the distance around a circle (circumference) to the radial distance is:

   2 $\cdot$ radial distance $\cdot$ 3.142 = ______________ circumference

   Calculate the distances traveled by the mass at each position (1/2 way, all-the-way out) and fill in the “Distance traveled” column, above.

2. Is the amount of time needed for the cart+mass to complete one revolution at 1/2-way different than at all-the-way out? (hint: think about how the segments of the merry-go-round move.) Is the distance traveled different?

3. Calculate the average speed of the mass in both positions and record above (remember our definition for speed?). How much did the speed increase in moving from 1/2-way to all-the-way out?

4. When the mass is moving at a constant speed around a circle, does its velocity change (remember, velocity is both speed and direction) ? If the mass's velocity does change, would it have an acceleration? Explain.

5. Any mass undergoing an acceleration must be subject to a net force. The centripetal force, provided by the spring scale in this case, is what causes the 1kg mass to turn in a circle. This force depends both on the speed of and how far away the mass is from the center. The formula (which assumes the velocity acts perpendicular to the lever arm) is:

$$F_c = m \cdot s \cdot s / r$$

The radius doubled when we moved the mass from 1/2-way to all-the-way out. How did the average speed increase?. Fc depends on the speed "squared" ($s \cdot s$), but also on 1/r. Is this definition for centripetal force consistent with your results?

6. Two cars go through the same curve in the road on a rainy day. One is going slowly, and proceeds without problem. The other goes through the curve twice as fast and "spins out." Explain why in terms of the information above.

**Part Two: May the force be with you**

**Introduction:**

Playing on a merry-go-round is a sure fire way to get dizzy in a hurry. The motion of a kid spinning around on a merry-go-round is analogous to planets spinning around the sun. For the kid, friction between the kid's feet (and hands if they're holding on) provide a force that keeps them moving in a circle. The attraction of gravity between the sun and a planet keep it in its orbit.

**Question:** What would happen if your feet slipped while you were spinning around? Would you fly off away from the center of the merry-go-round? Would you continue in a straight line? Would you fall towards the center? Make a prediction and state your reasoning below:

**Procedures:**

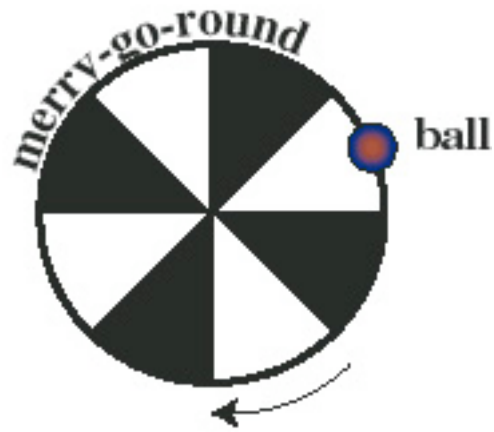
1. Have one group member stand on the outside of a spinning merry-go-round while holding a ball.
2. Another member of the group is the observer. They should stand just next to the merry-go-round.
3. The member on the spinning merry-go-round should drop the ball just as they pass the observer. You will both probably need to practice this a few times to get the timing right. (It is helpful if the merry-go-round is surrounded by sand or dirt, as the ball will leave a mark showing its path.)
4. Take turns observing the ball drop from beside the merry-go-round (a non-spinning "reference frame"). Record your observations below.

**Observations:**

1. Describe below the path the ball took when released.

**Questions:**

1. With arrows, draw on the diagram below the trajectory the ball took after release.




2. From the perspective of the spinning merry-go-round, what are the forces on the ball as the merry-go-round turns? (you will find useful terms in the "Definitions" section.) From the perspective of the observer on the ground, what are the forces on the ball? After the ball is dropped, which observer's forces are useful in describing the ball's motion?

## Part Three: *How high the moon?*

### Introduction:

Did you know that the moon is moving slowly away from the Earth? Each time we have another full moon, it has moved about 1/4 centimeters further away from the Earth. What is causing this? One explanation is that the Earth's rotation is slowing down and *conservation of angular momentum* dictates that the moon move further away to compensate. To understand this explanation, it is useful to know what the term "conservation of angular momentum" means. That is the purpose of this part of the merry-go-round experiment.

### Procedures:

1. Tie a piece of bright flagging on one handle of the merry-go-round.
2. One group member should stand on the merry-go-round at the outside edge, facing inwards.
3. Another person is the timer, responsible for timing how long the merry-go-round and person take to complete one revolution.
4. Start the merry-go-round spinning rapidly. Immediately time the period of revolution of the merry-go-round and record it, below.
5. As soon as the period is timed, the person on the merry-go-round should begin walking towards the center. The third group member should observe what happens to the speed of the outer edge of the merry-go-round as this happens and record it below.
6. The person on the merry-go-round should stop walking when they reach 1/2-way in. The timer should then determine the period of revolution and record it below.
7. Repeat this for 3 trials, and record the results of each trial below.

### Observations:

Data Table: Part Three of Merry-go-round Experiment

| | period at 1/2-way point (s) | period at outer point (s) | observations |
|---|---|---|---|
| trial 1 | | | |
| trial 2 | | | |
| trial 3 | | | |
| average | | | |

### Questions:

1. Calculate the average periods for 1/2 way and all-the-way out from the columns above. Enter in the table.
2. What happened to the period of revolution when the person walked towards the center?

3. Angular momentum depends both on the moment of inertia (distance away from the center) and the speed at which the person is spinning. In this experiment, the radius decreased as the person walked towards the center. Did the speed decrease, stay the same, or increase? How do you know this?

4. If the angular momentum is to be "conserved," it won't change as the person walks towards the center. Yet the distance from the center has decreased in doing so. What must happen to the person's speed, then, if angular momentum is to be conserved? Did you observe this?

**Epilogue:** The moon is spinning around the Earth and, thus, it has angular momentum relative to the Earth. The Earth is also spinning, but the forces of ocean tides are causing it to slow down. Thus its angular momentum is decreasing. To conserve total angular momentum, that of both the moon and Earth, the moon must move outwards to compensate.

Interestingly, the moon is also what causes some of the tidal forces causing the Earth to slow down. Obviously this is all part of the moon's grand plan to eventually escape the Earth!

**Definitions:**

| **Name** | **Symbol** | **Definition in words** | **Formula** |
|---|---|---|---|
| Center of rotation | | Example, place where teeter-totter is suspended, place where swing is attached to crosspole. | |
| Lever arm | r | Distance from center of rotation | |
| Moment of Inertia | I | Resistance to change in rotation | for dumbbell m • r • r |
| Grav. force (Weight) | $F_g$ | Force exerted on a mass (you) by another object (the Earth, usually). | F = m•g |
| Acceleration | g | The (constant) acceleration (9.8m/s/s) of any thing | g = F / m (only |

| | | | |
|---|---|---|---|
| of gravity | | falling near the Earth's surface under the influence of Earth's gravity (assuming no other forces act on it). | at Earth's surface!) |
| Torque | $\tau$ | Force which causes a change in rotation. It is a force applied at some distance (r) from the center of rotation. | $\tau = r \bullet F$ |
| Period | T | Time for a complete cycle of rotational motion. E.g., time it takes to go round once on a merry-go-round. | |
| Angular velocity | $\omega$ | Rotation through some angle divided by the time elapsed. | $\omega = \Delta\theta / \Delta t$ |
| Angular Acceleration | $\alpha$ | Change in angular velocity caused by a non-zero torque . A given torque will cause a greater change in angular motion when acting on objects with smaller moments of inertia. | $\alpha = \Delta\omega / \Delta t$ or $\alpha = \tau / I$ |
| Angular momentum | L | Tendency for a rotating body to keep rotating. Proportional to the moment of inertia and the angular velocity. | $L = I\,\omega$ |

**Units:**

Lever arms are measured in meters, just as any other distance is measured.

Moments of inertia have units of mass and distance squared (kg • m • m).

Periods are measured in seconds (s)

Angular velocity is radians / second. A radian is related to a degree of angle. You can use degrees / second for this lab if you wish.

Angular acceleration is then radians / second / second (or degrees / s / s).

Angular momentum has units of kg • m • m / s