Union College **Spring 2025**

Physics 110

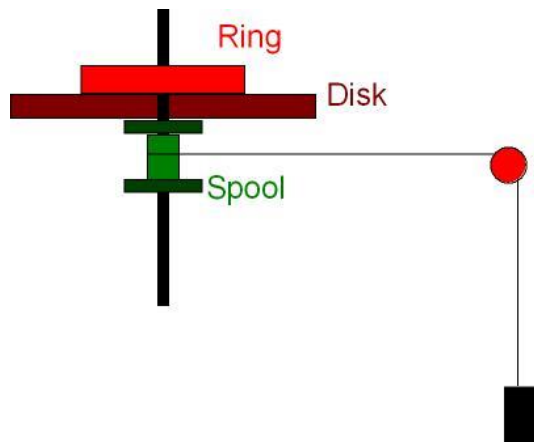
Name: _______________________ Partners: _______________________________________

Lab 6: Measuring the Rotational Inertia Using the Energy Principle

In this experiment you will empirically measure the rotational inertia of a body by applying energy principles to a rotating turntable connected to a falling mass.

Apparatus:

The figure shows a cross sectional sketch of the apparatus. A hanging mass is connected to a rotating apparatus by a string that passes over a pulley. The pulley, which is effectively massless and frictionless, is connected to the computer so that the Capstone software can be used to infer the speed of the string passing over the pulley**.** The other end of the string is wound around a spool that is coaxial with the rotational apparatus, including a large disk. Another object whose rotational inertia you wish to measure is placed on top of the disk; in the figure, a ring is placed on the disk. As the mass falls, it pulls the string, which causes the rotational apparatus and object to spin. By using conservation of energy and measuring the speed of the string and the height the mass fell, we will infer the rotational inertia of the rotating objects. We will then use this apparatus to empirically measure the rotational inertia of a complex object placed onto the disk.



Pre-lab Calculations:

In the experiment, the entire system will start from rest and the mass, $m_{hanging}$, will fall a vertical distance Δy and obtain a final speed v_f. The spool has radius r_{spool}, and the entire rotational apparatus, with disk and object on top, has rotational inertia I and reaches a final rotational speed ω_f. Assume no energy dissipation due to friction or air resistance and neglect the kinetic energy in the string and pulley.

1. List all the terms of energy in this situation. Hint: there are three terms.

2. a. Write the conservation of energy equation for this motion using the variables given.

b. Manipulate your equation to derive an expression for the rotational inertia, I, of the rotational apparatus in terms of m_{hanging}, Δy, v_f, and ω_f.

c. We need an equation for I that involves only known or measurable quantities, which does not include ω_f. Note, though, that there is a simple relation between ω_f and v_f, and r_{spool}. Write that expression and substitute in for ω_f to obtain an equation for I in terms of m_{hanging}, Δy, v_f, and r_{spool}.

Data Collection:

1. Use the Vernier calipers to measure the *diameter* of the rotator spool (the part of the rotator that the string wraps around) and record the radius, r_{spool} (with appropriate uncertainty).

2. Open “Pasco Capstone.”
   - Click on “hardware setup” in the upper left.
   - Click on the image of port ‘1’ and select “photogate with pulley.”
   - Click on “hardware setup” again, then “Sensor data.”
   - Click on the “add graph” icon at the top to add a second graph.
   - In each graph click on the y-axis label:

     in one select “position” and in the other select “linear speed”.

3. Construct a data table in you Excel spreadsheet with the following column headings:

   $I_{disk\ only}$; $I_{disk+ring}$; I_{ring}

   Don't forget to include appropriate units in the column headings.

4. With no object on top, hold the large **gray disk** on the rotating apparatus still while hanging a 50-g mass from the string and make sure that the string passes over the pulley and that the smart pulley is oriented at the right angle for the string to pass over the pulley directly.

5. Wind the string around the spool by turning the disk until the mass is near the pulley.

6. Click "Start" in Capstone and release the rotator and click "Stop" *before* the mass hits the ground. *Also, be sure to stop and catch the wheel* to prevent the string from winding around the other side of the spool.

7. From the graphs, using the "delta tool," obtain the final velocity and change in height of the falling mass. Make sure that your final velocity matches up in time with your final position.

8. Repeat for hanging masses of 100, 150, 200, 250, and 300 g.

9. Add the **hollow black ring** to the rotating system and repeat with all the same masses.

10. Measure, the mass, M_{ring}, the inner radius, R_1, and the outer radius, R_2, of the ring, including estimates of the uncertainties.

11. On the rotating system, replace the disk with the **disk with sculpture**, hang the 0.100-kg mass, and repeat steps 4-7. *Make just one measurement* with the sculpture.

Analysis:

1. Use your equation to calculate the rotational inertia of the rotating system for each trial.

2. Subtract $I_{\text{disk only}}$ from $I_{\text{disk+ring}}$ to get I_{ring} for each value of m_{hanging}.

3. Calculate the average value of I_{ring} and the uncertainty in that value.
   Recall that the ***experimental uncertainty*** *can be determined from the standard deviation as*

$$\delta I = \frac{\sigma}{\sqrt{N}}$$

4. Using the measurements of M_{ring}, R_1, and R_2 calculate the expected rotational inertia of the ring, as given by $I_{ring} = \frac{1}{2}M(R_1^2 + R_2^2)$.
   The ***theoretical uncertainty*** *in the above expression can be obtained using the expression*

$$\delta I = \frac{1}{2}M\sqrt{\left[(R_1^2 + R_2^2)\frac{\delta M}{M}\right]^2 + (R_1\delta R_1)^2 + (R_2\delta R_2)^2}$$

5. Do the experimental and theoretical values for the rotational inertia agree to within the uncertainties?

6. Using just one measurement, calculate the rotational inertia of the metal sculpture. For the uncertainty, assume that the standard deviation will have the same *percentage* as with the black ring and since you made only one measurement, the standard deviation will equal your standard error (i.e. the uncertainty).

   What is your measured value, with uncertainty, of the rotational inertia of the metal sculpture?

   $I_{\text{sculpture}}$ = ________________________ ± ________________________