

## Rotational Kinetic Energy

Objective: The kinetic energy of a rotating disk and falling mass are found; the change in their kinetic energy is compared with the change in potential energy of the falling mass. The conservation of energy principle, states that these changes are equal in magnitude and opposite in sign. This experiment provides a method for checking this principle.

Apparatus: Rotational Dynamics apparatus, computer and interface, bull's eye level, clamps, weight holder, weights, string, vernier calipers, meter stick, 2000 g electronic scale.

Theory: In this experiment, the kinetic energy arises from allowing a mass to fall while attached to a disk, which is free to spin. If the mass falls, a distance (h) the mass loses gravitational potential energy (mgh). This quantity should be equal to the sum of the kinetic energies gained by both the falling mass and the spinning disk.

For a disk of mass, M, and radius, R, the moment of inertia, I, is

$$I = MR^2/2.$$

If the disk is spinning with angular speed,  $\omega$ , its rotational kinetic energy is

$$\text{K.E.} = I\omega^2/2.$$

The angular speed of a disk is related to the speed ( $V_D$ ) of its outer edge by,

$$\omega = V_D/R.$$

Combing the above equations, the kinetic energy of the disk can be written as,

$$\text{K.E.} = MV^2/4.$$

The kinetic energy of a falling mass (m) with speed, v, is,

$$\text{K.E.} = mv^2/2$$

The total kinetic energy of the disk and falling mass is the sum of the individual kinetic energies. The statement of the conservation of energy now reads,

$$mgh = MV^2/4 + mv^2/2$$

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### **Procedure:**

1. Use a bull's eye level, to level the rotational motion apparatus
2. Get a string about 90 cm long.
3. Tie one end of the string to the small hole in the bottom/largest spool attached to the spindle. Tie the other end to the mass holder.
4. Use calipers to find the radius ( $r$ ) of the largest/lowest spool, record the value in Data Table I.
5. Clamp the individual pulley to the leading edge of the rotational motion apparatus.
6. Suspend the string over the individual pulley, attached to the leading edge of the rotational apparatus. Make sure the mass holder will not hit the floor at the lowest point of its fall. Use a meter stick to measure the distance, ( $H_0$ , from the floor to the bottom of the mass holder, record this distance in Data Table I.
7. Attach the smart pulley to the rotational motion apparatus so that it is in contact with the disk and spins when the disk spins.
8. Use calipers to find the radius of the smart pulley ( $R_p$ ), record the value in Data Table I.
9. Using the electronic scale, find the mass of the mass holder ( $m_h$ ), record the value in Data Table I. Add about 20 grams to the holder, record the sum of the masses in Data Table II.
10. Plug the smart pulley into channel 1 of the 750 interface.
11. Open data studio
12. Click create experiment.
13. In the experiment setup window, click channel 1 and select the smart pulley from the menu.
14. Click the Constants Tab, make sure the smart pulley constants are set as follows: Spoke arc length 0.015, spoke angle separation  $36^\circ$
15. Click on the 2nd Measurement Tab and check the angular velocity box. Make sure the units are in rad/sec.

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16. Click the Graph Button; create a graph of angular velocity vs. time.
17. Run experiment: rotate the disk to windup the string on the largest spool. Windup the string until the mass holder is just below the pulley. Use a meter stick to measure the distance ( $H_1$ ) from the bottom of the mass holder to the floor. Record this value in Data Table II.
18. Press start and release the disk, allow the mass ( $m$ ) to fall while the computer records the angular velocity of the smart pulley. Allow the mass to reach its maximum drop and begin to rise, then click stop.
19. Examine the angular velocity versus time graph. Use the cursor tool to determine the maximum angular velocity ( $\omega_{\max}$ ) of the smart pulley, record the value in Data Table I.
20. Repeat this experiment for three different masses ( $m$ ) of about 50gm, 70gm and 170 gm; remember to measure  $H_1$  for each trial. Record the values for  $H_1$  and  $m$  in Data Table II.
21. Use a meter stick to measure radius ( $R$ ) of the disk; record the value in Data Table I.
22. Use the electronic scale to find the mass ( $M$ ) of the disk, record the value in Data Table I.

### **Analysis:**

1. Using the values for the maximum angular velocity ( $\omega_{\max}$ ) of the smart pulley, calculate the angular velocity ( $\omega$ ) of the rotating disk, using the formula,  $\omega_D = \omega_{\max} (R_p/R)$ . Record the values in Table I.
2. Using the calculated values for the angular velocity ( $\omega$ ) of the disk and the dimensions of the disk and spool, calculate the speed of the outer edge of the disk. Also, calculate the speed of the falling mass. Record these calculations in Data Table I.
3. Find the formula for the moment of inertia of a disk. Using the necessary measurements of the disk, calculate the moment of inertia of the disk ( $I$ ). Record the value in Data Table I.
4. For each trial, calculate the change in gravitational potential energy of the falling mass,  $\Delta P.E. = -mg (H_1 - H_0)$ , Record the results in Data Table II.
5. For each trial, calculate the change in rotational kinetic energy ( $I\omega_D^2/2$ ) of the rotating disk. One could also use the velocity of the outer edge of the disk ( $V_D$ ) to determine the kinetic energy ( $MV_D^2/4$ ). Record the results in Data Table II.

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6. Part of the gravitational potential energy also goes into the kinetic energy ( $mv^2/2$ ) of the falling mass. Calculate the translational kinetic energy of the falling mass, for each trial. Record your results in Data Table II.
7. Determine the total change in kinetic energy ( $\Delta K.E.$ ) by adding the rotational energy of the disk to the translational energy of the falling mass. Record these values in Data Table II.
8. The principle of conservation of energy states that the total change in kinetic energy ( $\Delta K.E.$ ) should be equal in magnitude and opposite in sign to the total change in potential energy ( $\Delta P.E.$ ). Determine the total change in energy and record your values in Data Table II.
9. Determine the percent difference between the changes in the potential and kinetic energies; record your results in Data Table II.

### **Questions:**

1. Is energy conserved?
2. What are the potential sources of the error (percentage difference)?
3. Does the percent difference vary with the value of the falling mass?
4. Why does the percent difference vary, or not vary, with the value of the falling mass?

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Data Table I

Mass of disk,  $M =$

Radius of disk,  $R =$

Mass of weight holder,  $m_h =$

Radius of spool,  $r =$

Distance  $H_0 =$

Radius of Smart Pulley,  $R_p =$

Maximum angular velocity $\omega_{\max}$ (rad/sec)	Angular velocity of the disk $\omega_D$ ( $\omega_D = \omega_{\max}(R_p/R)$ )	Speed $V_D$ of outer edge of disk ( $V_D = R\omega_D$ )	Speed of Weight $v$ ( $v = V_D \times r/R$ )

Moment of Inertia ( $I$ ) of disk =

