Activity P25: Transforming Gravitational Potential Energy to Kinetic Energy
(Rotary Motion Sensor)

Concept: DataStudio

Energy: P25 GPE to KE.DS (See end of activity)

Equipment Needed

<table>
<thead>
<tr>
<th>Equipment Needed</th>
<th>Qty</th>
<th>Equipment Needed</th>
<th>Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary Motion Sensor (CI-6538)</td>
<td>1</td>
<td>Mass and Hanger Set (ME-9348)</td>
<td>1</td>
</tr>
<tr>
<td>Balance (SE-8723)</td>
<td>1</td>
<td>Rotational Accessory (CI-6691)</td>
<td>1</td>
</tr>
<tr>
<td>Base and Support Rod (ME-9355)</td>
<td>1</td>
<td>Thread (inc. w/ CI-6691)</td>
<td>1 m</td>
</tr>
</tbody>
</table>

Note
For this activity you need to know the rotational inertia of the disk that is part of the Rotational Accessory. Refer to activity "P22: Rotational Inertia" for information about how to measure the rotational inertia.

What Do You Think?
In this activity, a falling object applies a constant net torque to a rotating disk. As the object falls, its gravitational potential energy decreases and its translational kinetic energy increases. At the same time, the rotational kinetic energy of the disk increases. How does the decrease in gravitational potential energy compare to the increase in translational and rotational kinetic energy?

Take time to answer the ‘What Do You Think?’ question(s) in the Lab Report section.

Background
The gravitational potential energy of an object depends on its weight and its vertical distance, \( h \), relative to a reference point (usually the Earth’s surface). The gravitational potential energy is:

\[
P.E_{\text{grav}} = mgh
\]

where \( m \) is the mass of the object and \( g \) is the acceleration due to gravity. The kinetic energy of a rotating object depends on its rotational inertia, \( I \), and its angular speed, \( \omega \). The rotational kinetic energy is:

\[
K.E_{\text{rotational}} = \frac{1}{2} I \omega^2.
\]

As the object falls, it has translational kinetic energy:

\[
K.E. = \frac{1}{2} mv^2
\]

where \( m \) is the mass of the object, and \( v \) is its speed.

SAFETY REMINDERS
- Follow directions for using the equipment.
For You To Do

Attach a hanging mass to the step pulley on a Rotary Motion Sensor. Let the hanging mass drop so it causes a disk to rotate. Use the Rotary Motion Sensor to measure the motion of the hanging mass and the motion of the rotating disk. Use DataStudio or ScienceWorkshop to record and display the position and velocity of the hanging mass and the angular velocity of the rotating disk. Calculate the rotational kinetic energy of the rotating disk, the translational kinetic energy of the hanging mass, and the change in gravitational potential energy of the hanging mass.

The angular speed, \( \omega \), of the rotating disk is related to the linear speed, \( v \), of the falling object:

\[
\omega = \frac{v}{r}
\]

where \( r \) is the radius of the step pulley on the Rotary Motion Sensor.

PART I: Computer Setup

1. Connect the ScienceWorkshop interface to the computer, turn on the interface, and turn on the computer.
2. Connect the Rotary Motion Sensor’s stereo phone plugs into Digital Channels 1 and 2 on the interface.
3. Open the file titled as shown:

<table>
<thead>
<tr>
<th>DataStudio</th>
<th>ScienceWorkshop (Mac)</th>
<th>ScienceWorkshop (Win)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P25 GPE to KE, DS</td>
<td>(See end of activity)</td>
<td>(See end of activity)</td>
</tr>
</tbody>
</table>

- The DataStudio file has a Workbook display, a Table display, and a Graph display. Read the instructions in the workbook.
- Data recording is set at 20 Hz. The Rotary Motion Sensor is set for 360 divisions per rotation and the ‘Linear Calibration’ is set for the ‘Medium Pulley (Groove)’.
- See the pages at the end of this activity for information about modifying a ScienceWorkshop file.
PART II: Sensor Calibration and Equipment Setup

You do not need to calibrate the sensor.

1. Mount the Rotary Motion Sensor on a support rod so the step pulley is on top.

2. Mount the clamp-on Super Pulley on the end of the Rotary Motion Sensor.

3. Use a piece of thread about 10 cm longer than the distance from the Super Pulley to the ground. Tie one end of the thread to the edge of the medium groove on the step pulley on the Rotary Motion Sensor. Drape the thread over the Super Pulley.

4. Attach the other end of the thread to a mass hanger. Adjust the angle of the Super Pulley so the thread is tangent to the step pulley and in the middle of the groove on the Super Pulley.

5. Remove the thumbscrew from the step pulley on top of the Rotary Motion Sensor. Place the disk on the pulley and attach the disk with the thumbscrew.

PART IIIA: Data Recording – Hanging Mass = 0.010 kg

1. Adjust the position of the mass hanger on the thread. Attach the hanger so it is high enough on the thread that the mass hanger will not hit the floor at its lowest position.

2. Add 5 g (0.005 kg) to the mass hanger so the total mass is about 10 g (0.010 kg).

3. Rotate the disk to wind the thread around the step pulley until the mass hanger is almost up to the Super Pulley. Hold the disk at this position.

4. Start recording data. (Hint: Click ‘Start’ in DataStudio or ‘REC’ in ScienceWorkshop.)

Make sure that data recording has started. In DataStudio, the clock display will begin to change. In ScienceWorkshop, the ‘data indicator’ under ‘REC’ will begin to flash.

After data recording starts, release the disk and let the mass fall while the Rotary Motion Sensor measures the motion.

5. Stop recording data just before the mass reaches its lower position. Stop the disk.
• “Run #1” will appear in the Data list.

6. Remove the mass hanger and measure its total mass. Record the mass in the Lab Report section.
Note: If the position, velocity, and angular velocity are negative, switch the position of the plugs in the interface.

PART IIIB: Data Recording – Different Hanging Masses

1. Repeat the data recording process but change the hanging mass to 15 g (0.015 kg) and then 20 g (0.020 kg).

2. Measure the total mass of the mass hanger after each run and record the mass in the Lab Report section.

Analyzing the Data

1. Use the Table display to determine the following:
   - change in position of the hanging mass ($\Delta h$)
   - final linear speed of the hanging mass ($v$)
   - final angular speed of the rotating disk ($\omega$)

2. Scroll to the bottom of the Table. The column of ‘Position’ data will have one more value than the columns of ‘Velocity’ and ‘Angular Velocity’.

3. Record the final angular speed of the rotating disk (last value for angular velocity), the final linear speed of the hanging mass (last value for velocity), and the change in position of the hanging mass (second to last value for position).

4. Repeat the process to find the final angular speed, the final linear speed, and the change in position of the hanging mass for the other hanging masses.

5. Use your data to calculate the rotational kinetic energy, the translational kinetic energy, and the change in gravitational potential energy for each run of data.

6. Compare the total kinetic energy (rotational plus translational) to the change in gravitational potential energy. Calculate the percent different between the KE and the GPE.

Record your results in the Lab Report section.
Lab Report – Activity P25: Transforming Gravitational Potential Energy to Kinetic Energy

What Do You Think?

In this activity, a falling object applies a constant net torque to a rotating disk. As the object falls, its gravitational potential energy decreases and its translational kinetic energy increases. At the same time, the rotational kinetic energy of the disk increases. How does the decrease in gravitational potential energy compare to the increase in translational and rotational kinetic energy?

Data

<table>
<thead>
<tr>
<th>Run</th>
<th>mass (kg)</th>
<th>angular speed (rad/s)</th>
<th>linear speed (m/s)</th>
<th>change in position (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rotational inertia, \( I \), of the disk (from activity P22) \( 1.48 \times 10^{-4} \) kg m\(^2\)

<table>
<thead>
<tr>
<th>Run</th>
<th>[ K.E_{\text{rotational}} = \frac{1}{2} I \omega^2 ]</th>
<th>[ K.E. = \frac{1}{2} mv^2 ]</th>
<th>Total KE</th>
<th>[ P.E_{\text{grav}} = mgh ]</th>
<th>% difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
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<td>3</td>
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</tr>
</tbody>
</table>

Questions

1. Is the rotational kinetic energy equal to the gravitational potential energy of the falling object?

2. How does the total kinetic energy compare to the gravitational potential energy of the falling object?
Appendix: Modify a ScienceWorkshop File

Modify an existing ScienceWorkshop file to add the Rotary Motion Sensor.

Open the ScienceWorkshop File

Open the file titled as shown:

<table>
<thead>
<tr>
<th>ScienceWorkshop (Mac)</th>
<th>ScienceWorkshop (Win)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P29 Grav PE to Total KE</td>
<td>P29_GRAV.SWS</td>
</tr>
</tbody>
</table>

- The ScienceWorkshop file has a Graph display and a Table display of Velocity versus Time (using data from a Smart Pulley).
- You need to replace the Smart Pulley with the Rotary Motion Sensor in the Experiment Setup window and set up the Rotary Motion Sensor parameters.
- Finally, close the existing displays and create a new Graph display and a new Table display.

Set Up the Rotary Motion Sensor

In the Experiment Setup window, click and drag the digital sensor plug to Channel 1. Select ‘Rotary Motion Sensor’ from the list of sensors. Click ‘OK’. Result: The Rotary Motion Sensor setup window opens.

Select ‘Medium Pulley (Groove)’ from the ‘Linear Calibration’ menu. Click ‘OK’ to return to the Experiment Setup window.

Set the Sampling Options

Click the ‘Sampling Options’ button in the Experiment Setup window or select ‘Sampling Options’ from the Experiment menu to open the Sampling Options window. Result: The Sampling Options window opens.

Under ‘Periodic Samples’ click the right arrow to set the sample rate at ‘20 Hz’ (20 measurements per second). Click ‘OK’ to return to the Experiment Setup window.

Create a New Graph Display

Close the existing Graph display. In the Experiment Setup window, click and drag the Graph display icon to the Rotary Motion Sensor icon. Result: The ‘Choose Calculations…’ window opens.

Select ‘Angular Velocity’, ‘Position’, and ‘Velocity’ from the list. Click ‘OK’ to return to the Experiment Setup
Result: The new Graph display shows a plot for each of the three measurements.

Create a New Table Display

Close the existing Table display. In the Experiment Setup window, click and drag the Table display icon to the Rotary Motion Sensor icon. Result: The ‘Choose Calculations…’ window opens.

Select ‘Angular Velocity’, ‘Position’, and ‘Velocity’ from the list. Click ‘OK’ to return to the Experiment Setup window. Result: The new Table display shows a plot for each of the three measurements.