Minds•On Physics Activity

AT•20

Solving Rotational Dynamics Problems

Purpose and Expected Outcome

In this activity, you will learn more about rotational *dynamics*, which involves the forces exerted on rotating systems and the response of those systems (i.e., angular acceleration). You will learn how to apply the concepts of *torque* and *moment of inertia* to problem situations involving rotating systems.

Prior Experience / Knowledge Needed

You should know dynamics. You should know Newton's laws and how to apply them to physical situations. You should have some experience analyzing and solving problems in dynamics, and you should know how to apply empirical force laws. In addition, you should have some experience with rotational kinematics, and you should be able to recognize when a system is accelerating. You should know the definitions of *torque*, *net torque*, and *moment of inertia* relative to a fixed axis.

NEWTON'S 2ND LAW IN ROTATIONAL FORM

Newton's 2nd law ($\mathbf{F}_{\text{net}} = m\,\mathbf{a}$) is valid and applicable for all objects and systems. However, when a rigid body is spinning about a fixed axis, it is more convenient to use angular quantities, such as angular velocity and angular acceleration, to describe its motion. (At any particular instant, every part of the rigid body has a different velocity but the same angular velocity.) In terms of angular acceleration, Newton's 2nd law is written:

$$\tau_{\text{net},p} = I_p \alpha_p$$

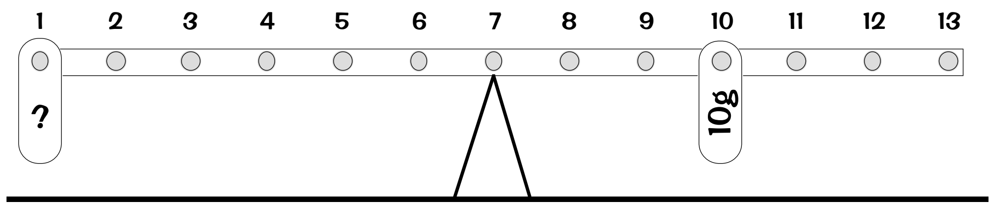
Newton's 2nd law for rotations about a fixed axis

where $\tau_{\text{net},p}$ is the net torque on the rigid body about a fixed axis through point p, I_p is the object's moment of inertia for rotations about the same axis, and α_p is its angular acceleration. Note that $\tau_{\text{net},p}$ and α_p are vectors.

Explanation of Activity

Solve each of the problems described below. If necessary, translate the problem to a linear dynamics problem, and think about how you would solve it.

A1. A 10g hanger is placed on a device as shown. The pegs are evenly spaced and labeled 1 through 13. Hangers of various masses are available.



(a) What mass will balance the 10g hanger when placed on peg #1? Explain why it balances.

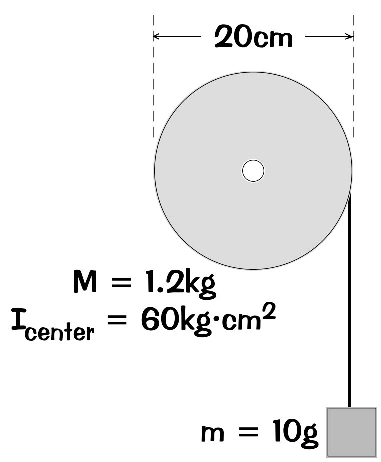
(b) Where should you put a 15g hanger to balance the 10g hanger? (The unknown hanger is removed.)

(c) Where should you put a 3g and a 4g hanger (at the same time) to balance the 10g hanger?

(d) Is it possible to balance the arrangement with only the 10g hanger (and nothing else)? If so, how? If not, explain why not.

(e) How many ways are there to arrange a 2g, a 3g, and a 5g hanger so that each is on its own peg, and the arrangement is balanced? Describe at least two arrangements. (The 10g hanger is removed.)

A2. A string is wound around a metal wheel that is free to spin on a frictionless pivot. A hanging mass is connected to the other end of the string. The wheel is given a twist, causing it to start rotating at $2\frac{1}{2}$ rad/s in the counterclockwise direction. All known quantities are shown in the figure.



(a) What is the initial velocity of the hanging mass?

(b) Estimate the angular acceleration of the disk.

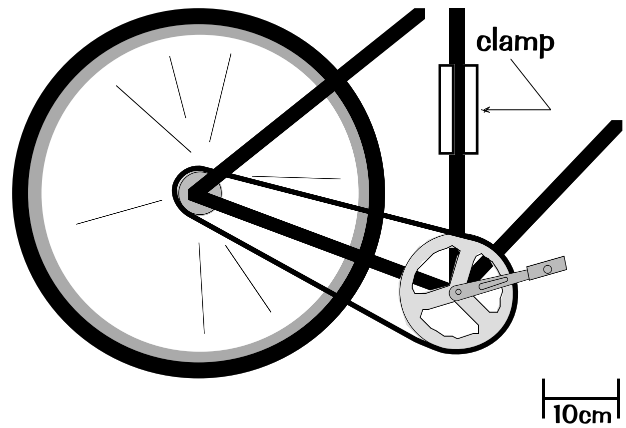
(c) Approximately when does the disk stop? Explain.

(d) Estimate the velocity of the mass at t = 2s.

(e) Estimate the acceleration of the mass at t = 3s.

continued

A3. A bicycle is supported off the ground using a clamp (shown in the scale drawing) attached to the post. The wheel weighs about 50N, and a force of 15N is applied to the pedal.

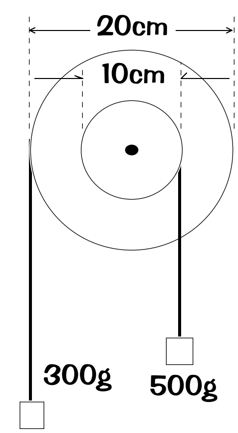


(a) Estimate the moment of inertia of the wheel.

(b) Estimate the net torque applied to the front gear, the tension in the chain, and the net torque applied to the back gear.

(c) Estimate the angular acceleration of the wheel.

A4. Two masses are attached to strings wound around a double pulley as shown. The double pulley has a total mass of 1200g (1.2kg), and the total moment of inertia about its center is 50,000g·cm^2 (0.005kg·m^2).



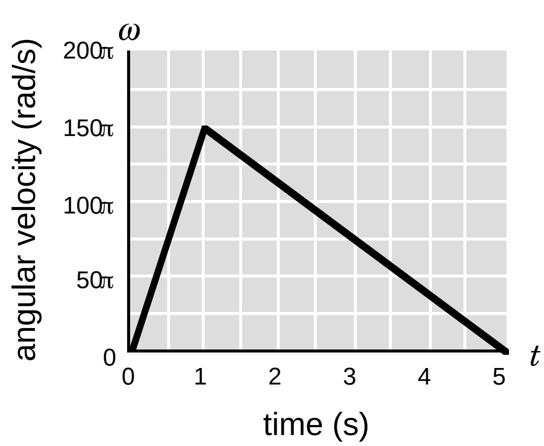
(a) If the arrangement is released from rest, which direction will it start to rotate? Explain.

(b) Estimate the angular acceleration of the double pulley.

(c) Which mass is traveling faster at any instant, or are they traveling with the same speed? Explain. If their speeds are different, what is the ratio of their speeds?

(d) Estimate the velocity of the 300g mass at t = 2s.

A5. The hard disk on your computer is "spinning up" according to the graph at right when a malfunction occurs, and the hard disk slows down again.



(a) If the net torque exerted on the hard disk initially is about 0.08N·m, estimate the hard disk's moment of inertia.

(b) What is the net torque exerted on the hard disk after the malfunction?

(c) What is the net torque exerted on the hard disk at t = 5s? Explain.

Reflection

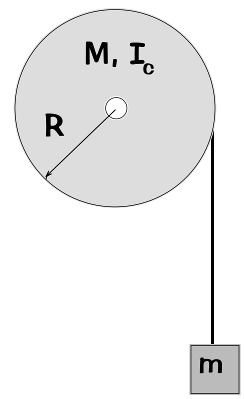
R1. What do you find most difficult about solving problems in rotational dynamics?

R2. For any of the situations or problems, did you think about what the linear motion situation or problem might look like? Why or why not?

R3. (a) What is the general relationship between the angular displacement $\Delta\theta$ of a spinning wheel and the displacement Δy of a mass hanging from a string wound around the wheel? Explain. In your relationship, what are the units of the angular displacement? Why?

(b) What is the general relationship between the angular velocity ω of the wheel and the velocity v_y of the hanging mass? Explain.

(c) What is the general relationship between the angular acceleration α of the wheel and the acceleration a_y of the hanging mass? Explain.



R4. Reconsider situation A2, in which a hanging mass is attached to a string wound around a solid wheel.

(a) When the arrangement is free to spin, which is larger, the tension in the string or the weight of the hanging mass? Explain your reasoning.

(b) Did you ignore this difference when you solved problem A2? Did you know that you had ignored this difference?

(c) How does this affect your answers? (If you do not ignore this difference, which answers become slightly larger, which ones stay the same, and which ones become slightly smaller?)

R5. Reconsider situation A3, in which a bicycle is held off the ground with a clamp.

(a) What features did you ignore to answer the questions?

(b) How would your answers change if you did not ignore these features? (If you did not ignore these features, which answers would be larger, which would stay the same, and which would be smaller?)

R6. Is it possible to exert a force at the edge of an object without exerting a torque about its center? Give an example of a situation involving a bicycle wheel in which a force is exerted to the rim of the wheel, but no torque is exerted about the center of the wheel.