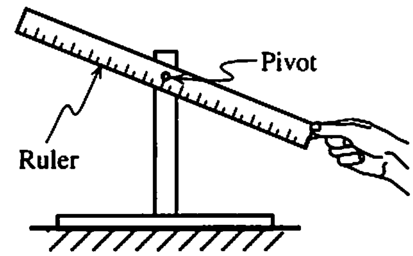
I. Drawing extended free-body diagrams

A. A ruler is placed on a pivot and held at an angle as shown at right. The pivot passes through the center of the ruler.



Predict the motion of the ruler after it is released from rest. Explain your reasoning.

Check your prediction by observing the demonstration.

1. Is the angular acceleration of the ruler in a *clockwise sense*, in a *counterclockwise sense*, or *zero?* Explain how you can tell.

   What does your answer imply about the *net torque* on the ruler about the pivot? Explain.

2. What is the direction of the acceleration of the center of mass of the ruler? If $\vec{a}_{cm} = 0$, state that explicitly. Explain how you can tell.

   What does your answer imply about the *net force* acting on the ruler? Explain.

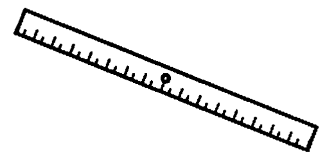
B. Draw a free-body diagram for the ruler (after it is released from rest). Draw your vectors on the diagram at right. Draw each force at the point at which it is exerted.

Label each force by identifying:

- the type of force,
- the object on which the force is exerted, and
- the object exerting the force.

The diagram you have drawn is called an *extended free-body diagram.*

Extended free-body diagram for ruler



Is the point at which you placed the gravitational force in your diagram consistent with your knowledge of the net torque about the pivot? Explain.

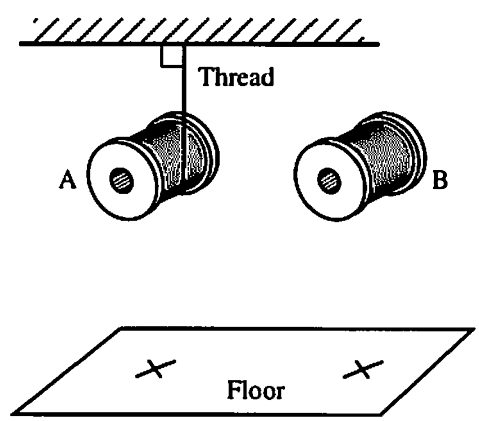
C. How would your free-body diagram change if the ruler were twice its original length and the same mass as before? Explain.

II. Distinguishing the effect of net torque and net force

Two identical spools are held the same height above the floor. The thread from spool A is tied to a support, while spool B is not connected to a support. An "x" is marked on the floor directly below each spool.

Both spools are released from rest at the same instant. (Make the approximation that the thread is massless.)

Draw an extended free-body diagram for each spool at an instant after they are released but before they hit the floor.



Extended free-body diagram for spool A	Extended free-body diagram for spool B

For each spool, determine the direction of the net torque about the center of the spool. If the net torque is zero, state that explicitly. Explain your reasoning.

A. *Predict:*

- which spool will reach the floor first. Explain how your answer is consistent with your extended free-body diagrams.

- whether spool A will *strike the floor to the left of the "x," strike the floor to the right of the "x,"* or *fall straight down.* Explain how your answer is consistent with your free-body diagrams.

Describe how the net force is related to the individual forces on a free-body diagram when the forces are exerted at different points on the object.

B. Obtain two spools and a ring stand. Use the equipment to check your predictions. (Be sure the thread of spool A is vertical before the spools are released.)

1. How does the *magnitude* of the acceleration of the center of mass ($\vec{a}_{cm}$) of spool A compare to that of spool B? Is this consistent with your free-body diagrams? Explain.

2. How does the *direction* of the acceleration of the center of mass ($\vec{a}_{cm}$) of spool A compare to that of spool B? Is this consistent with your free-body diagrams? Explain.

C. Consider the following discussion between three students.

Student 1: *"The string exerts a force that is tangent to the rim of spool A. This force has no component that points toward the center of the spool, so this force does not affect the acceleration of the center of mass."*

Student 2: *"I disagree. The acceleration of the center of mass of the spool is affected by the string. Any of the force not used up in rotational acceleration will be given to translational acceleration. This is why the acceleration of the center of mass of spool A is less than g."*

Student 3: *"The net force on spool A is the gravitational force minus the tension force. By Newton's second law, the acceleration of the center of mass is the net force divided by the mass. A force will have the same effect on the motion of the center of mass regardless of whether the force causes rotational motion or not."*

With which student(s), if any, do you agree? Explain your reasoning.

If necessary, revise your description in part A of how the net force is related to forces exerted at different points on an object.

➪ Discuss your answers with a tutorial instructor before continuing.

D. Write down Newton's second law for each spool. Express your answer in terms of the mass of each spool (m), the acceleration of the center of mass of each spool ($\vec{a}_{cm}$), and the individual forces acting on each spool.

Write down the rotational analogue to Newton's second law for each spool. Express your answer in terms of the relevant rotational quantities, that is, in terms of the angular acceleration ($\vec{\alpha}$), the rotational inertia (I), and the torque ($\vec{\tau}_{net}$). Express the torque in terms of the individual forces and appropriate distances.