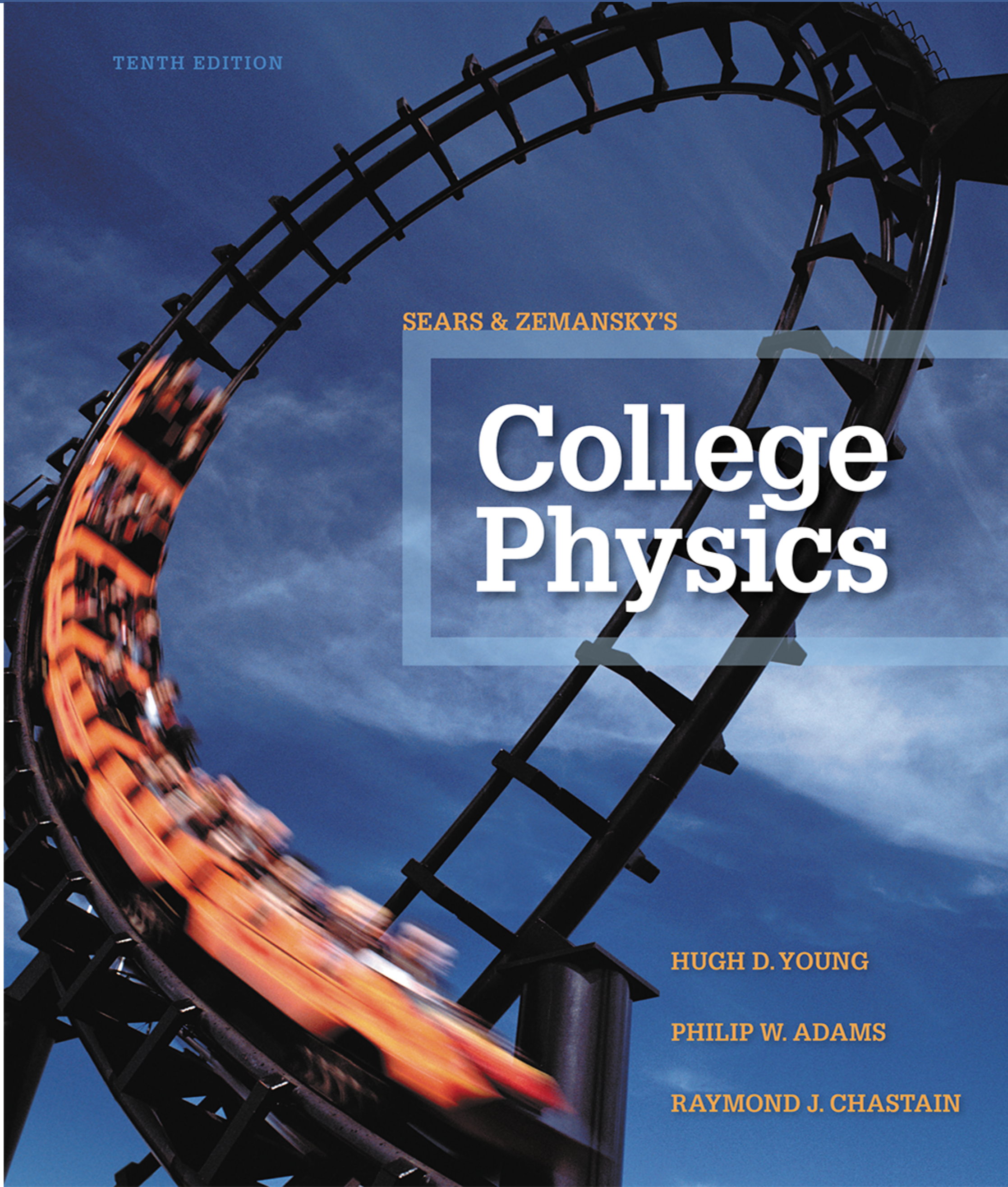
Chapter 10 Lecture

Chapter 10: Dynamics of Rotational Motion

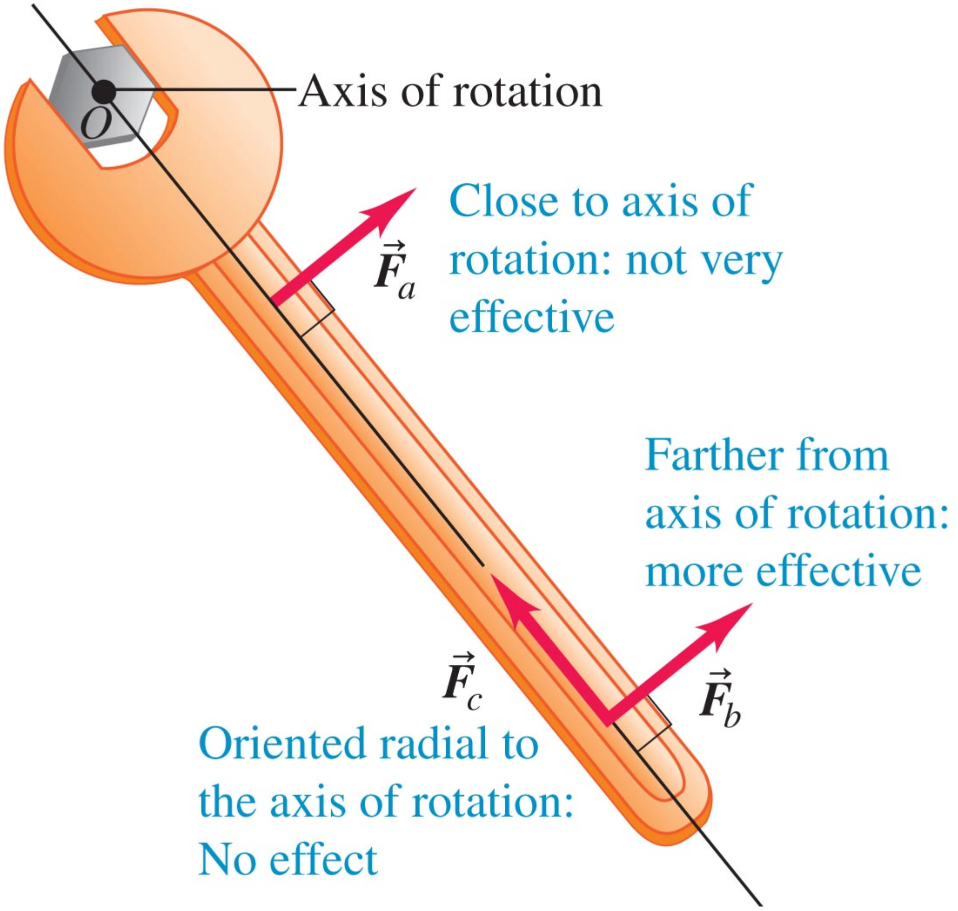


Goals for Chapter 10

- To study torque.
- To relate angular acceleration and torque.
- To examine rotational work and include time to study rotational power.
- To understand angular momentum.
- To examine the implications of angular momentum conservation.
- To study how torques add a new variable to equilibrium.
- To see the vector nature of angular quantities.

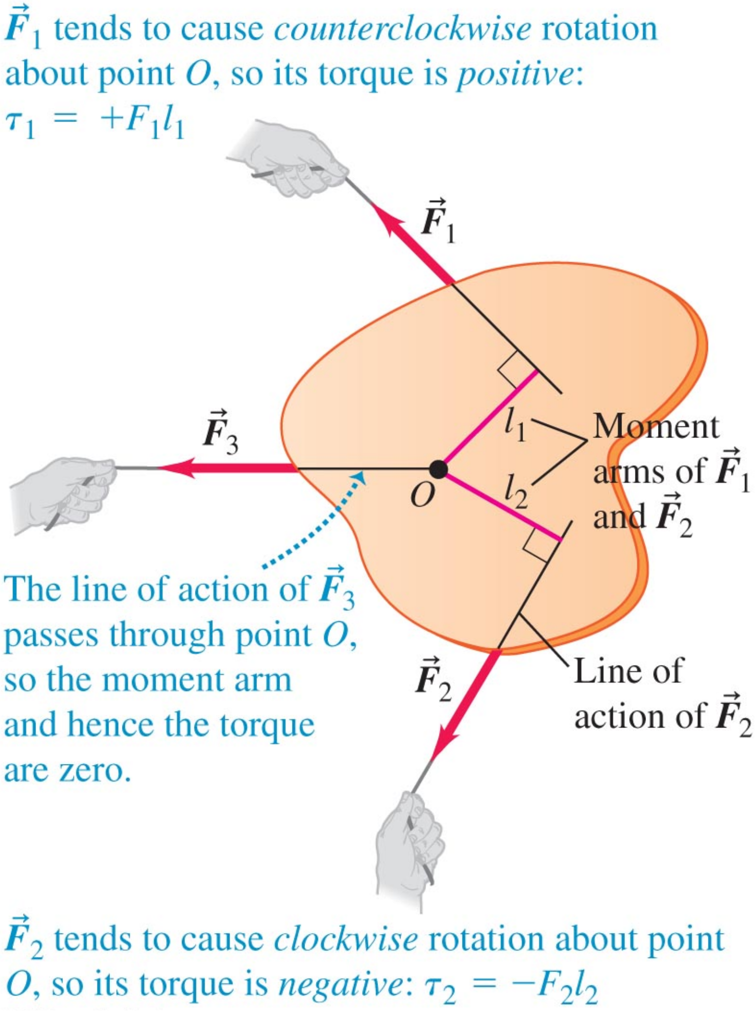
Definition of Torque – Figure 10.1

- Torque (τ) is defined as the force applied multiplied by the moment arm.
- The moment arm is the perpendicular distance from the point of force application to the pivot point.
- $\tau = Fl$



There Is a Sign Convention – Figure 10.3

- A counterclockwise force is designated as positive (+).
- A clockwise force is designated as negative (−).



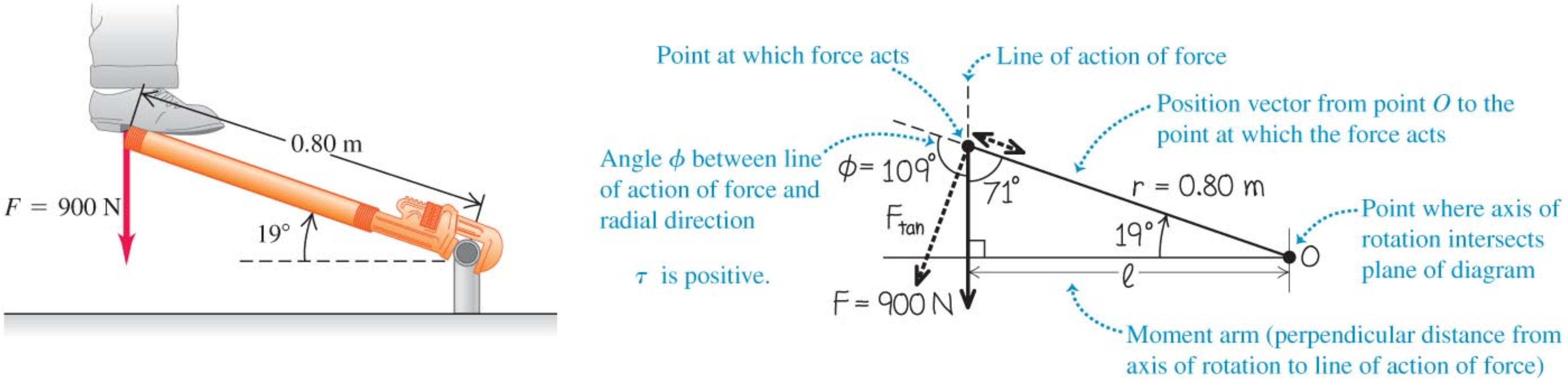
$\vec{F}_1$ tends to cause *counterclockwise* rotation about point O, so its torque is *positive*: $\tau_1 = +F_1 l_1$

The line of action of $\vec{F}_3$ passes through point O, so the moment arm and hence the torque are zero.

$\vec{F}_2$ tends to cause *clockwise* rotation about point O, so its torque is *negative*: $\tau_2 = -F_2 l_2$

A Plumbing Problem to Solve – Example 10.1

- Refer to the worked problem on pages 284 and 285.



(a) Diagram of situation

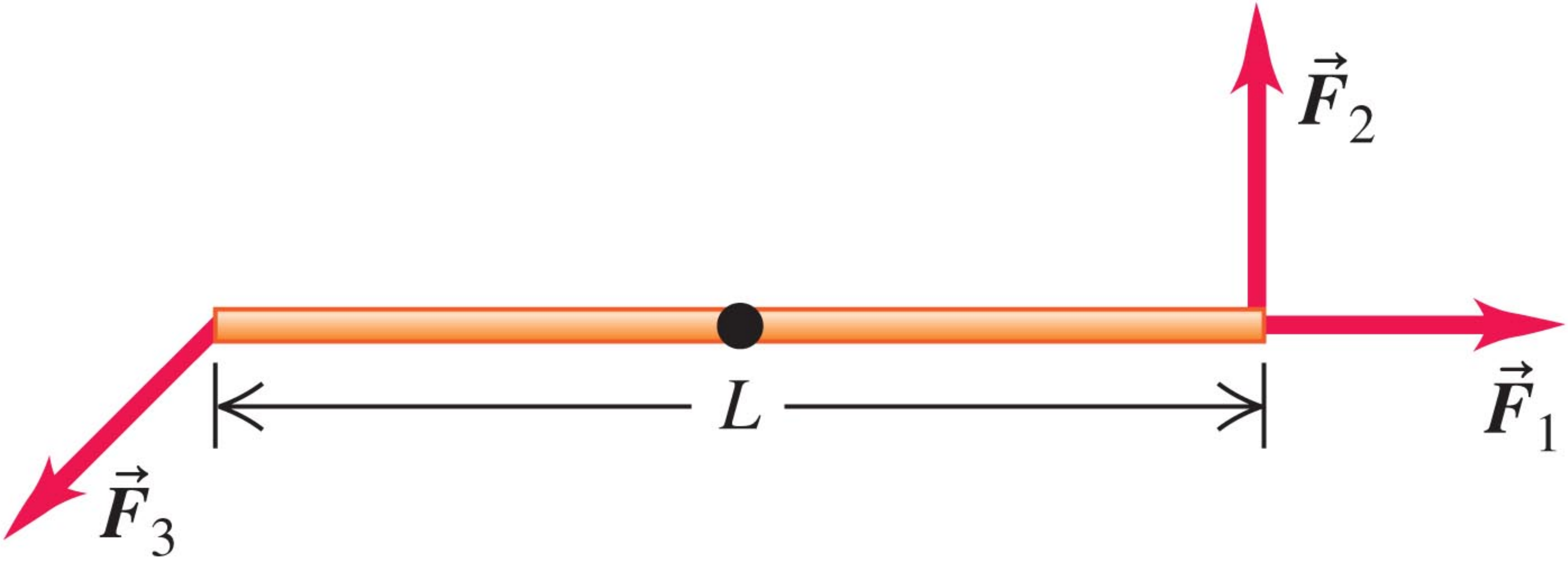
(b) Free-body diagram

Why Do Acrobats Carry Long Bars?

- Refer to the photo caption on the bottom of page 287.

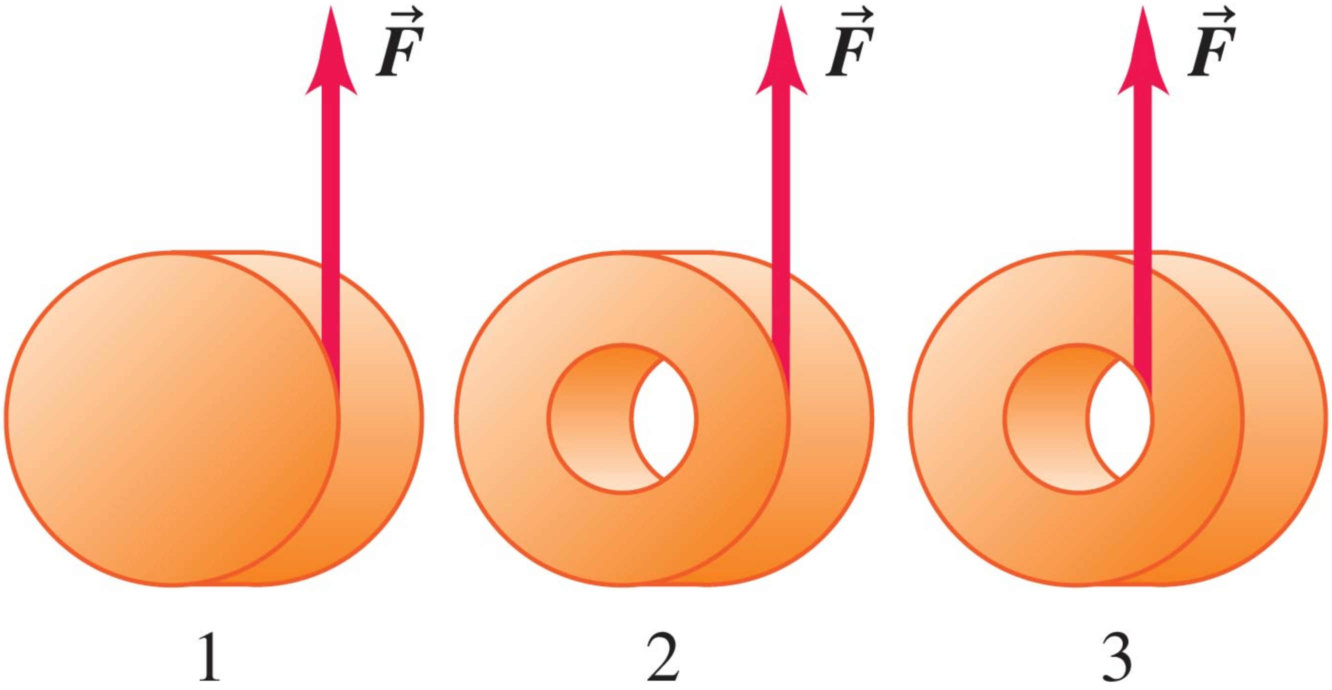
Torques on a Rod – Conceptual Analysis 10.1

- Refer to the worked example on page 284.



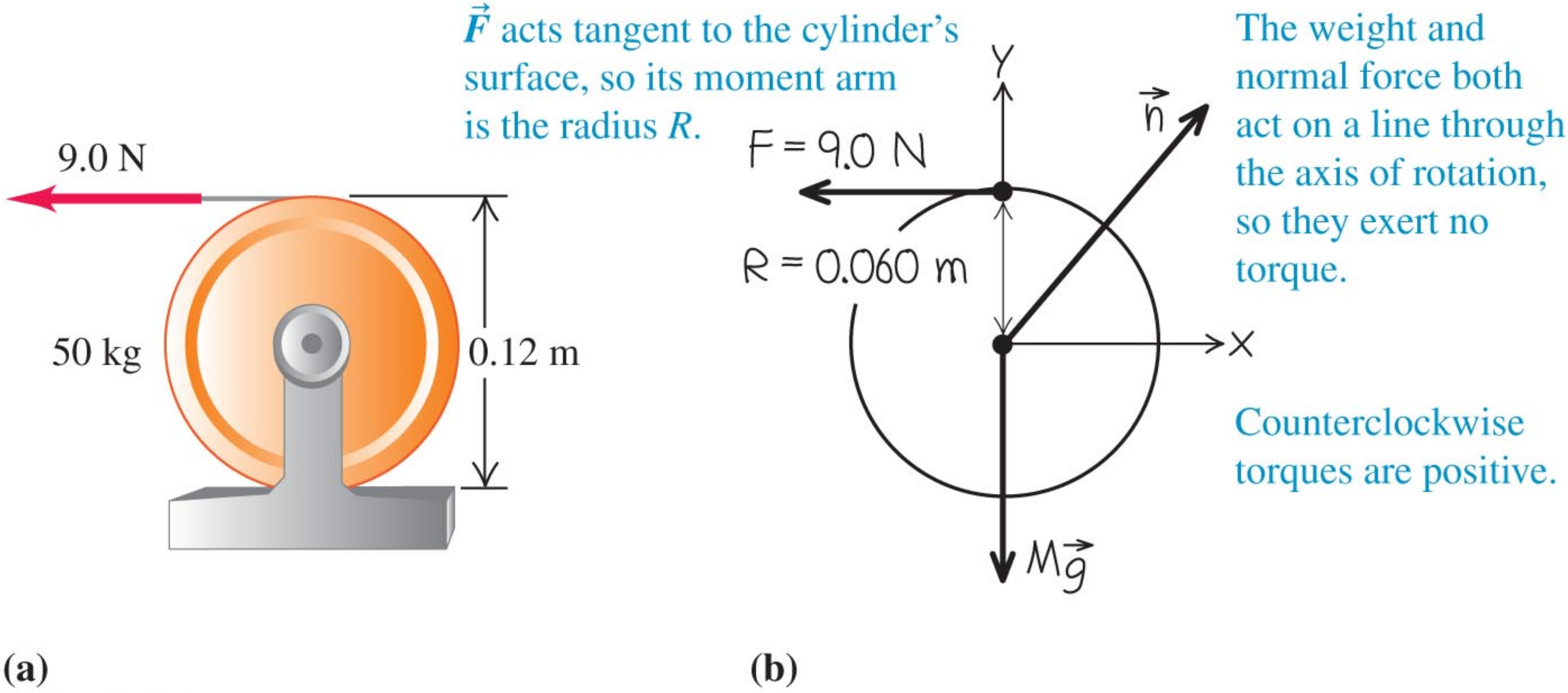
Rotating Cylinders – Conceptual Analysis 10.2

- Refer to the worked example on page 287.



Unwinding a Winch (Again) – Example 10.2

- Refer to the worked problem on page 288.



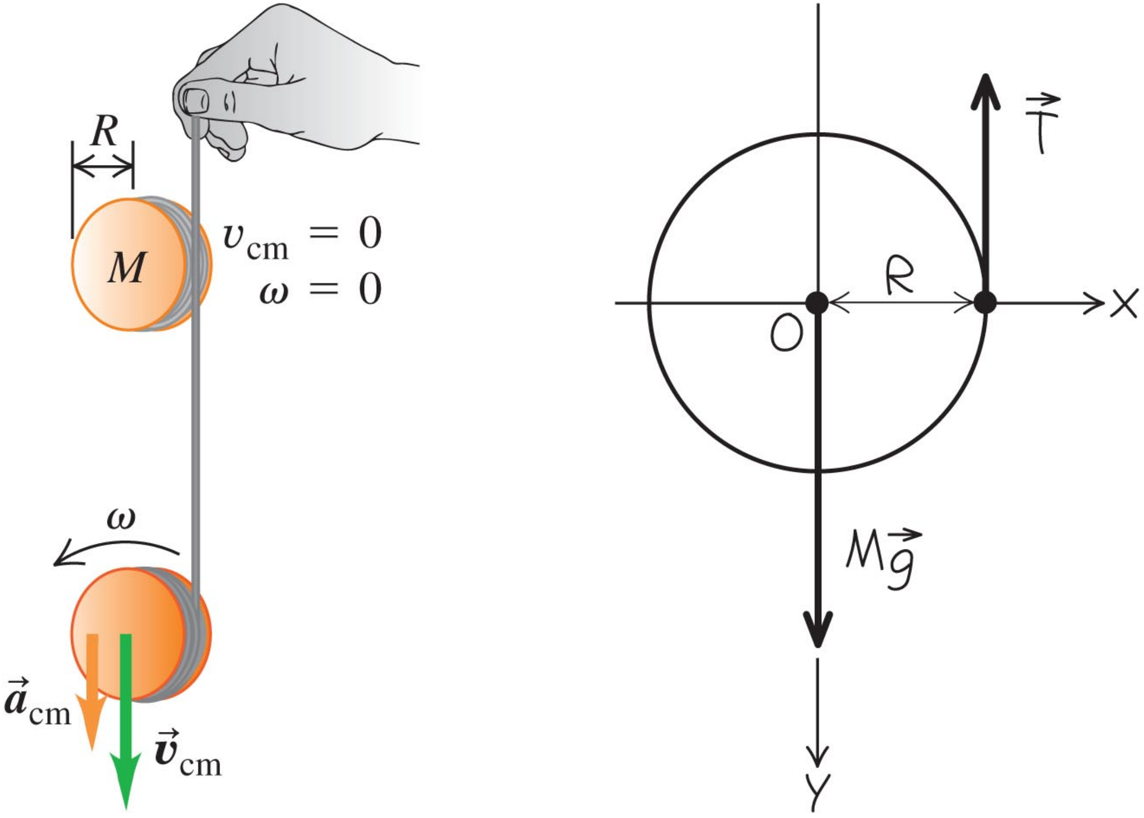
$\vec{F}$ acts tangent to the cylinder's surface, so its moment arm is the radius R.

The weight and normal force both act on a line through the axis of rotation, so they exert no torque.

Counterclockwise torques are positive.

The Yo-Yo Rotates on a Moving Axis – Figure 10.12

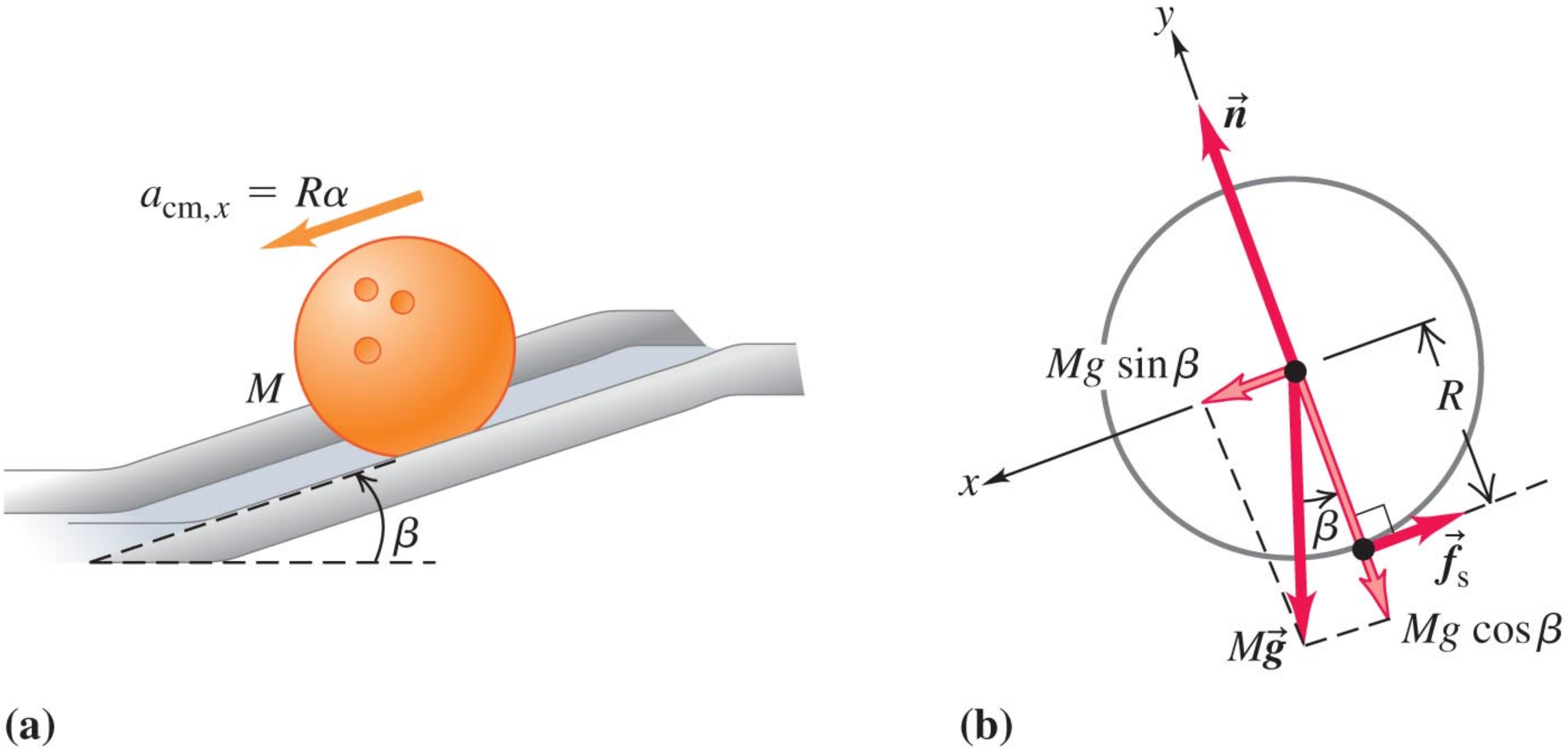
- Refer to worked example on page 290.



(a) The yo-yo **(b)** Our free-body diagram

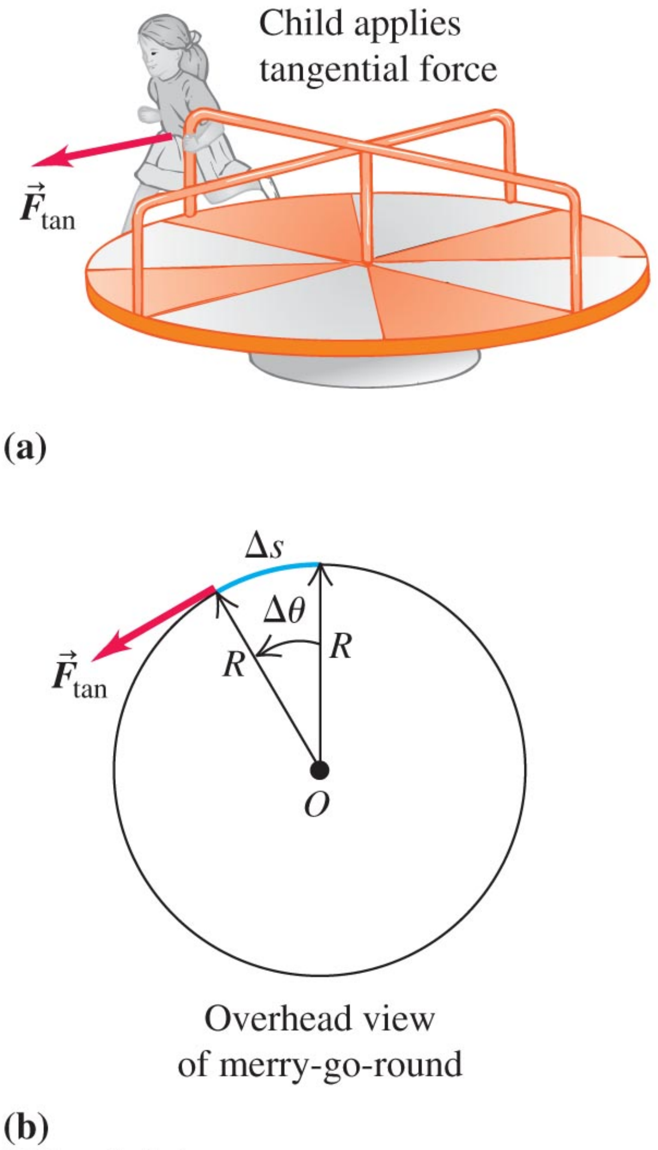
A Bowling Ball Rotates on a Moving Axis – Example 10.5

- Refer to worked example on page 291.



Work Can Be Done By a Constant Torque – Figure 10.14

- Example 10.6 follows the generic situation to the right.

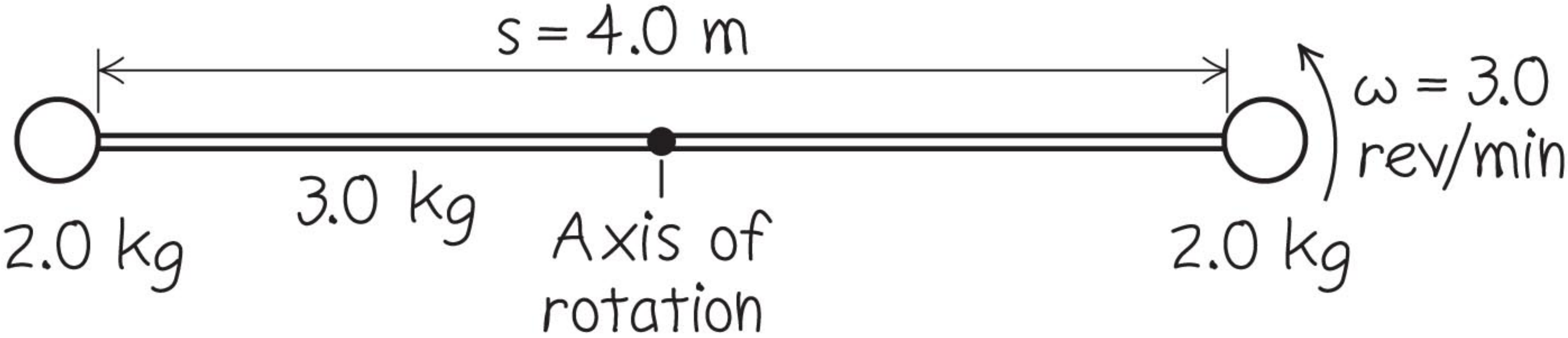


Angular Momentum – Figure 10.15

- The diver changes rotational velocities by changing body shape.
- The total angular momentum is the moment of inertia multiplied by the angular velocity.
- $L = I\omega$

Nifty Sculpture – Figure 10.17

- Follow Example 10.7 to find angular momentum and rotational energy.

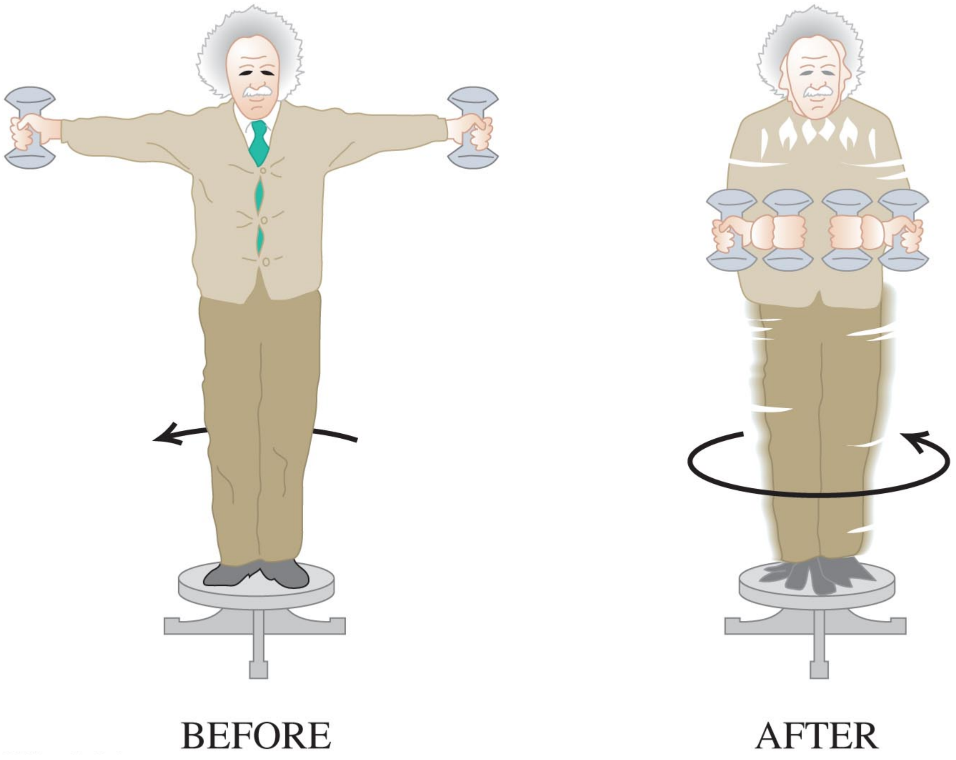


Angular Momentum Is Conserved – Figure 10.19

- The first figure shows the figure skater with a large moment of inertia.
- In the second figure, she has made the moment much smaller by bringing her arms in.
- Since L is constant, ω must increase.

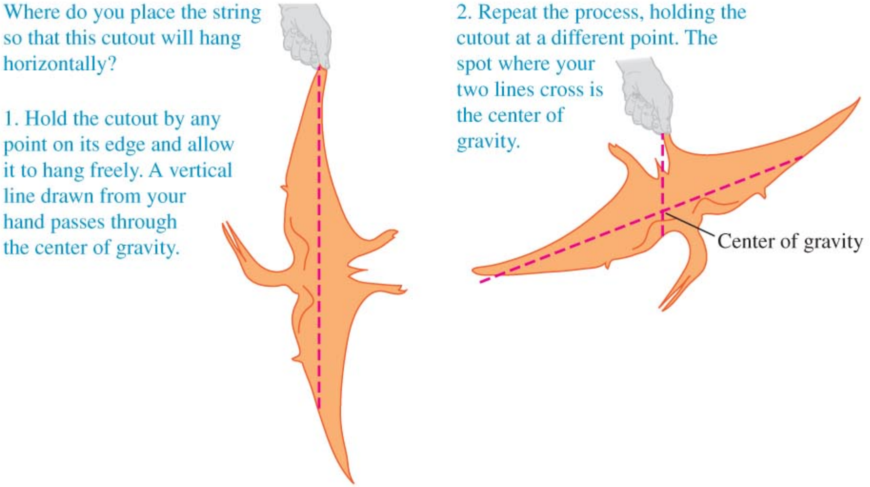
The Professor as Figure Skater? – Figure 10.22

- Example 10.9 on page 299 refers to Figure 10.22.
- It seems that danger to the instructor is proportional to interest in any given demonstration.



A New Equilibrium Condition – Figure 10.24

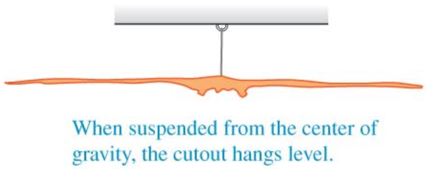
- Now, in addition to $\Sigma F_x = 0$ and $\Sigma F_y = 0$, we also must add $\Sigma\tau = 0$.
- Refer to Problem Solving Strategy 10.3



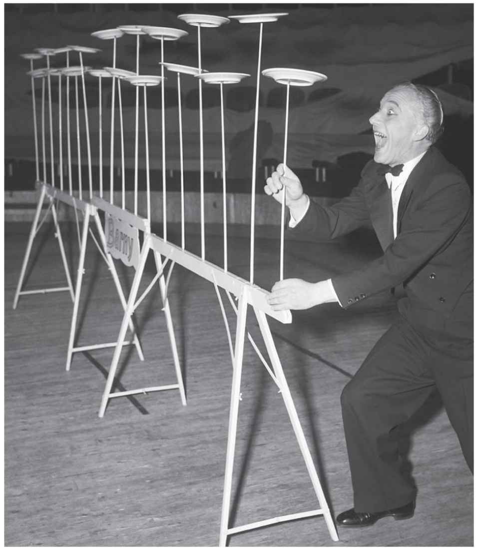
Where do you place the string so that this cutout will hang horizontally?

1. Hold the cutout by any point on its edge and allow it to hang freely. A vertical line drawn from your hand passes through the center of gravity.

2. Repeat the process, holding the cutout at a different point. The spot where your two lines cross is the center of gravity.

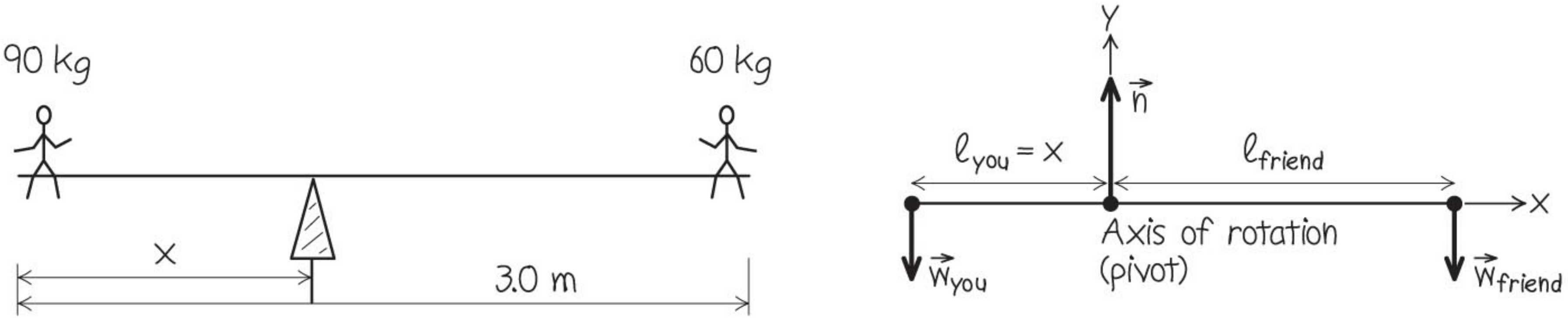


When suspended from the center of gravity, the cutout hangs level.



Balancing on a Teeter-Totter – Figure 10.26

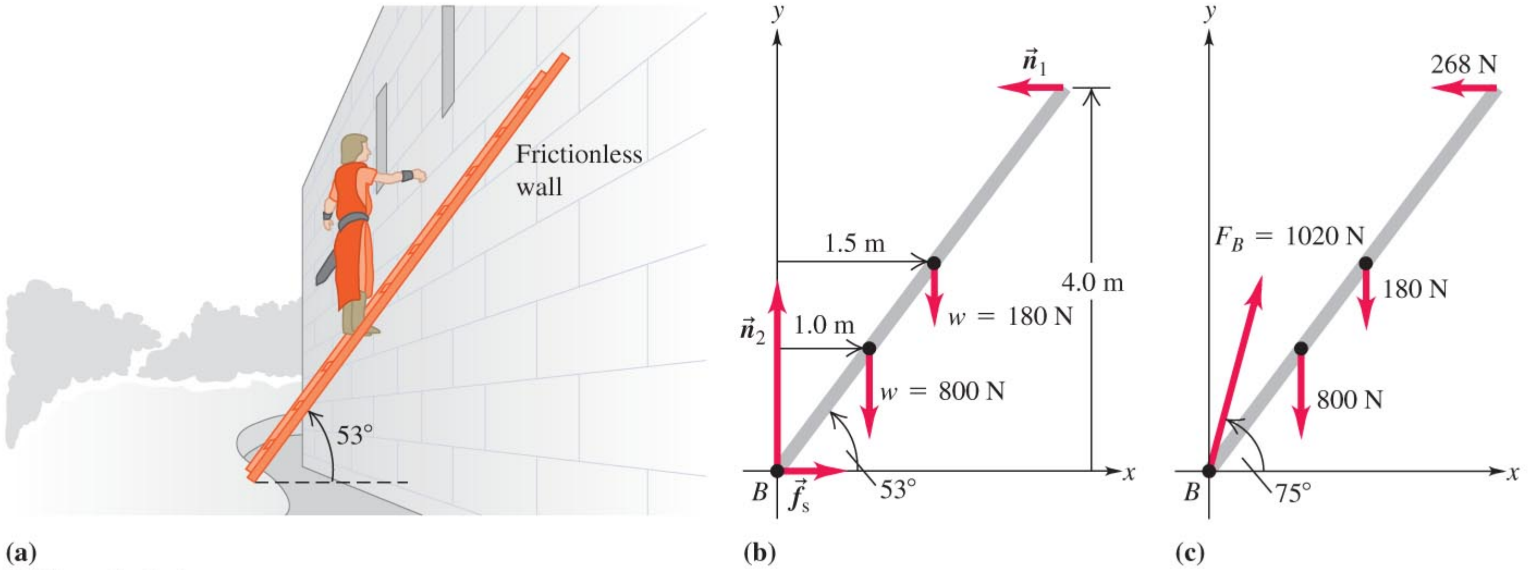
- The heavier child must sit closer to balance the torque from the smaller child.
- Refer to Example 10.11 on page 303.



(a) Sketch of physical situation **(b)** Free-body diagram

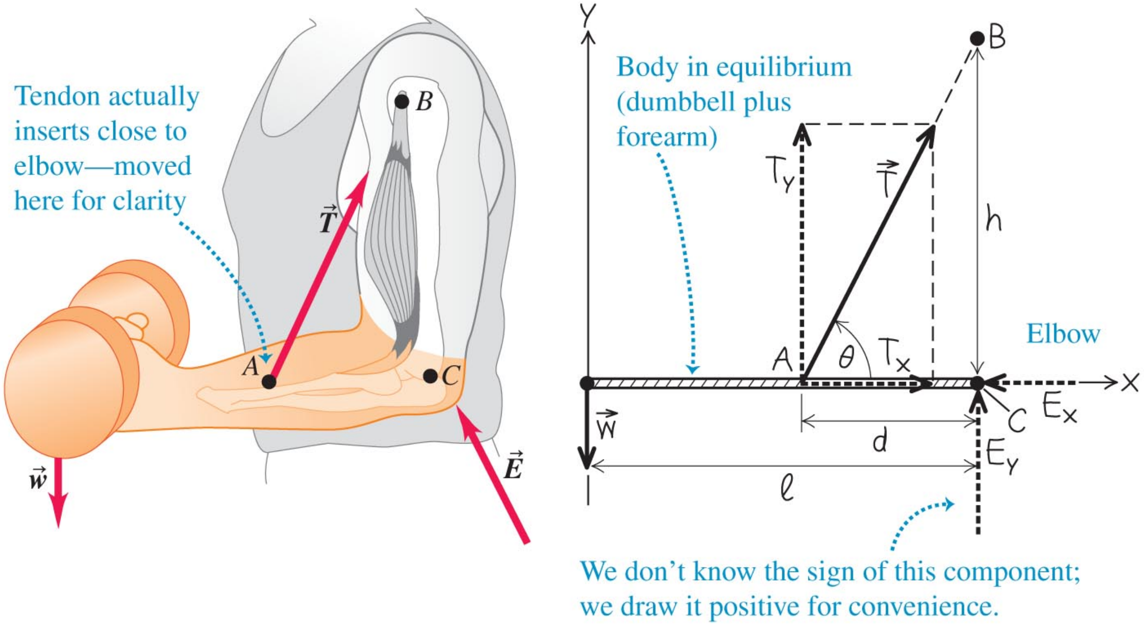
The Firefighter on the Ladder – Figure 10.27

- This problem is "classic" and appears in one form or another on most standardized exams.
- Refer to worked example on page 304.



Balanced Forces During Exercise – Figure 10.27

- Once again, a "classic" problem which always appears in some form on standardized exams.
- Refer to the worked example on page 305.



Tendon actually inserts close to elbow—moved here for clarity

Body in equilibrium (dumbbell plus forearm)

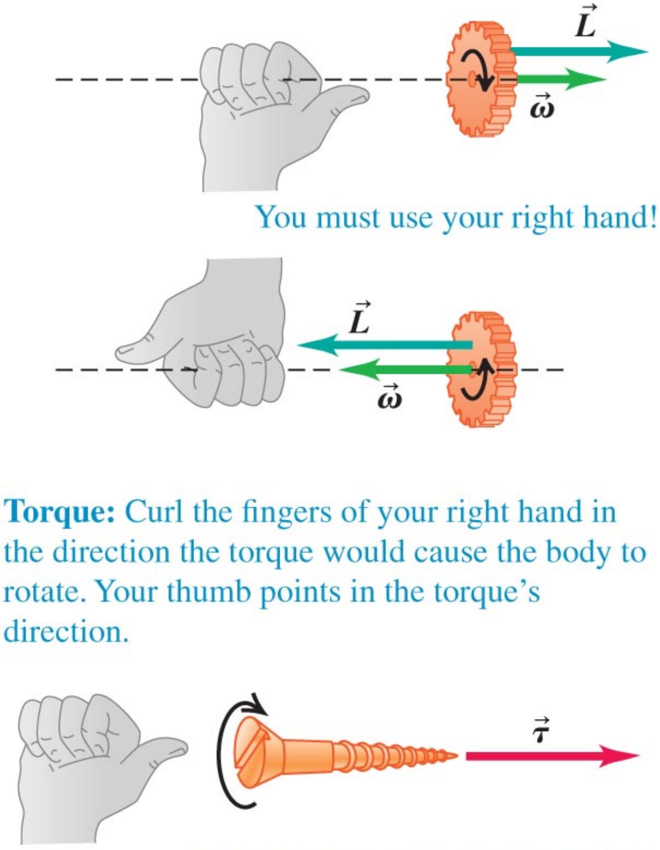
We don't know the sign of this component; we draw it positive for convenience.

(a)

(b)

Angular Quantities Are Vectors – Figure 10.29

- The "right-hand rule" gives us a vector's direction.



Angular velocity and angular momentum: Curl the fingers of your right hand in the direction of rotation. Your thumb then points in the direction of angular velocity and momentum.

You must use your right hand!

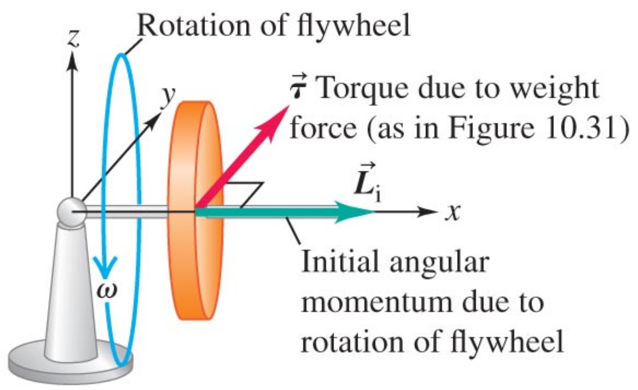
Torque: Curl the fingers of your right hand in the direction the torque would cause the body to rotate. Your thumb points in the torque's direction.

Right-hand screws are threaded so that they move in the direction of the torque applied to them.

Gyroscopes Can Add Stability – Figure 10.31

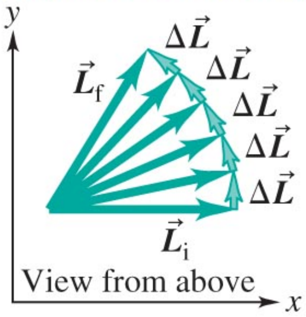
- The gyroscopic motion adds stability to bicycles, footballs, bullets and more.

When the flywheel is rotating, the system starts with an angular momentum $\vec{L}_i$ parallel to the flywheel's axis of rotation.



(a)

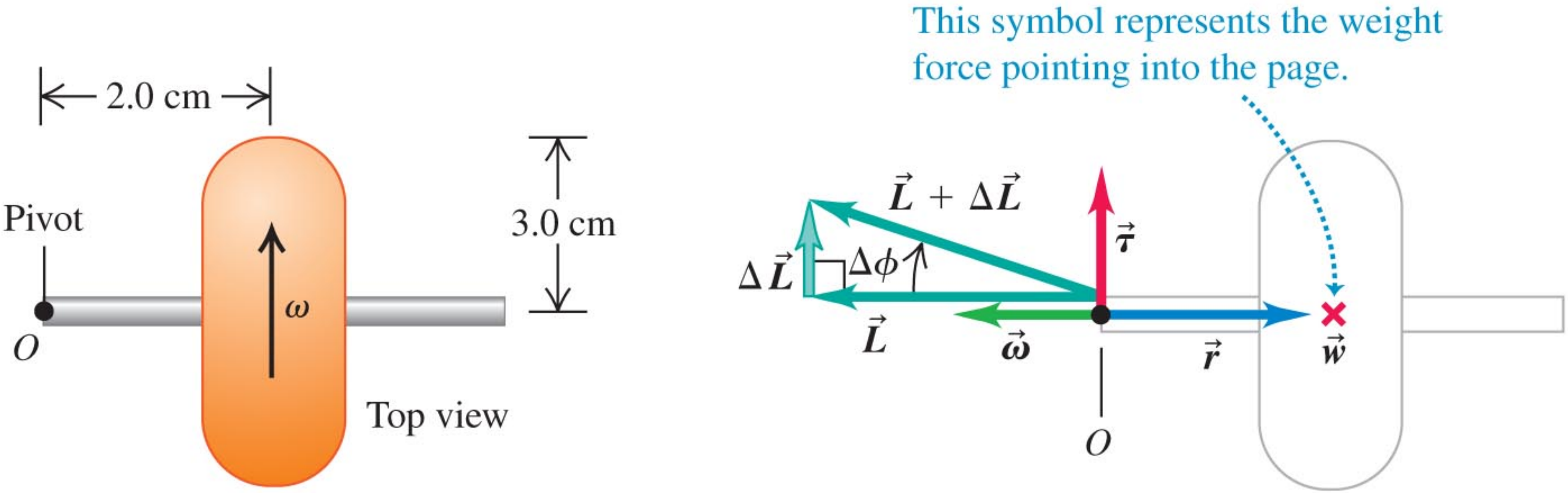
Now the effect of the torque is to cause the angular momentum to precess around the pivot. The gyroscope circles around its pivot without falling.



(b)

A Laboratory Gyroscope – Figure 10.33

- Refer to the worked example on page 309.



This symbol represents the weight force pointing into the page.

(a) Top view of spinning cylindrical gyroscope wheel

(b) Vector diagram