Summary

THE BIG IDEA **An object will remain upright if its center of mass is above the area of support.**

11.1 Torque

To make an object turn or rotate, apply a torque.

- **Torque** is produced by a turning force and tends to produce rotational acceleration.
- Force and torque are different; forces tend to make things accelerate whereas torques produce rotation.
- A torque is produced when a force is applied with "leverage." You use leverage when you use a screwdriver to open the lid of a paint can.
- The **lever arm** is the distance from the turning axis to the point of contact.
- Torque can be calculated using the following equation:

$$\text{torque} = \text{force}_{\perp} \times \text{lever arm}$$

11.2 Balanced Torques

When balanced torques act on an object, there is no change in rotation.

- Children of unequal weight can balance on a seesaw by sitting at different distances from the pivot point.
- Scale balances with sliding weights are based on balanced torques.

11.3 Center of Mass

The center of mass of an object is the point located at the object's average position of mass.

- The point where all of the mass of an object can be considered concentrated is called the **center of mass.**
- For a symmetrical object, the center of mass is at the geometric center of the object. For irregularly shaped objects, the location of the center of mass varies.
- Spin can be applied to an object by applying a force that does not pass through the object's center of mass. Kicking a football in the middle, for example, will make it travel without rotating. Kicking the football above or below its center will make it rotate.

11.4 Center of Gravity

For everyday objects, the center of gravity is the same as the center of mass.

- The **center of gravity,** or CG, is the average position of all of the particles of *weight* that make up an object. For most objects on and near Earth, the terms *center of mass* and *center of gravity* are interchangeable.

- If you throw a wrench so that it rotates as it moves through the air, you'll see it wobble about its CG. The center of gravity itself would follow a parabolic path.
- An object's CG is its balance point; supporting the CG supports the entire object. A meter stick can be balanced by applying a force at its geometric midpoint—the location of its CG.
- Any object suspended at a single point will hang with its CG directly below the point of suspension.

11.5 Torque and Center of Gravity

If the center of gravity of an object is above the area of support, the object will remain upright.

- If the CG extends outside the area of support, an unbalanced torque exists, and the object will topple.
- The Leaning Tower of Pisa does not topple because its CG does not extend beyond its base.
- It is difficult to balance a broom upright in the palm of your hand because the support base is very small and far beneath the CG.

11.6 Center of Gravity of People

The center of gravity of a person is not located in a fixed place, but depends on body orientation.

- When you stand erect with your arms at your sides, your CG is within your body.
- The CG is slightly lower in women than in men because women tend to be proportionally larger in the pelvis and smaller in the shoulders.
- Raising your arms vertically over your head raises your CG by several centimeters.
- When you stand, your CG is somewhere above your support base, which is the area bounded by your feet.

11.7 Stability

When an object is toppled, the center of gravity of that object is raised, lowered, or unchanged.

- An object balanced so that any displacement lowers its center of mass is in **unstable equilibrium.**
- An object balanced so that any displacement raises its center of mass is in **stable equilibrium.** Raising the CG of an object in stable equilibrium requires increasing the object's potential energy, which requires work.
- An object balanced so that any small movement neither raises nor lowers its center of gravity is in **neutral equilibrium.**
- An object with a low CG is usually more stable than an object with a relatively high CG.