

Answer to Essential Question 5.8: Let's first convert the speed from km/h to m/s, so all the units are SI units. The 120 km/h is equal to 33.3 m/s. Your apparent weight at the bottom of the loop is the normal force acting on you:

$$F_{N,bottom} = \frac{mv^2}{r} + mg = \frac{(50 \text{ kg})(33.3 \text{ m/s})^2}{30 \text{ m}} + 490 \text{ N} = +1850 \text{ N} + 490 \text{ N} = 2340 \text{ N}.$$

For the top of the loop, the speed of 60 km/h is equal to 22.2 m/s. Once again, your apparent weight is the normal force acting on you. Using the equation we found for the normal force at the top of the loop:

$$F_{N,top} = \frac{mv^2}{r} - mg = \frac{(50 \text{ kg})(22.2 \text{ m/s})^2}{30 \text{ m}} - 490 \text{ N} = +820 \text{ N} - 490 \text{ N} = 330 \text{ N}.$$

Chapter Summary

Essential Idea Regarding Applications of Newton's Laws

In this chapter we extended our understanding of what we can do with Newton's second law by applying it to situations involving friction and circular-motion situations.

Friction

The force of friction comes into play when objects are in contact. The force of friction is the component of the contact force that is parallel to the surfaces in contact (the normal force is the perpendicular component). The force of friction **opposes relative motion** between objects in contact. If there is relative motion between surfaces in contact (when one object is sliding over another), the friction force is the force of kinetic friction. The strength of the interaction is measured by the coefficient of kinetic friction, defined as:

$$\mu_K = \frac{F_K}{F_N} \quad \text{so} \quad F_K = \mu_K F_N. \quad (\text{Equation 5.1: The kinetic force of friction})$$

If the force of friction prevents relative motion between surfaces in contact, the friction force is the force of static friction. The maximum strength of this interaction is measured by the coefficient of static friction, defined as:

$$\mu_S = \frac{F_{S,max}}{F_N} \quad \text{so} \quad F_S \leq \mu_S F_N. \quad (\text{Equation 5.2 The static force of friction})$$

The coefficients of friction depend on the pair of interacting materials.

Be careful when working with static friction because, if the friction force that is required to ensure no relative motion is less than the maximum possible force of static friction, the static force of friction adjusts itself to whatever it needs to be to prevent relative motion. Two points to keep in mind about static friction are:

- we usually use Equation 5.2 with the equals sign only when we are certain we are dealing with a limiting case and the force of static friction is the maximum value;
- even the direction of the static force of friction can be counter-intuitive. A good rule of thumb is that the static force of friction opposes the relative motion that would occur if there were no friction.

A General Method for Solving a Problem Involving Newton's Laws, in Two Dimensions

The standard method of solving force problems involves splitting the forces into components, applying Newton's second law once for each direction, and combining the results. However, it should be kept in mind that some problems lend themselves to being solved with whole vectors. The steps in the standard method include:

1. Draw a diagram of the situation.
2. Draw one or more free-body diagrams, with each free-body diagram showing all the forces acting on an object.
3. For each free-body diagram, choose an appropriate coordinate system. Coordinate systems for different free-body diagrams should be consistent with one another. A good rule of thumb is to align each coordinate system with the direction of the acceleration.
4. Break forces into components that are parallel to the coordinate axes.
5. Apply Newton's second law twice to each free-body diagram, once for each coordinate axis. Put the resulting force equations together and solve.

Uniform Circular Motion – motion in a circle at constant speed

When an object travels with a speed v in a circular path of radius r , there is a centripetal acceleration directed toward the center of the circle, given by:

$$a_c = \frac{v^2}{r}. \quad (\text{Equation 5.3: Centripetal acceleration})$$

To solve a problem involving uniform circular motion, we apply the method we use for other problems involving Newton's laws. The only change is in the form of Newton's second law:

$$\sum \vec{F} = \frac{mv^2}{r}, \quad (\text{Eq. 5.4: Newton's Second Law for uniform circular motion})$$

where the acceleration is directed toward the center of the circle.

We avoid the term "centripetal force" because many people think of it as a new force that appears when an object travels in a circle - there is no such force! In uniform circular motion, there is a force directed toward the center of the circle but it is not a magical new force that arises just because something goes in a circle. Instead, the force is a familiar force, such as the force of gravity, the normal force, tension, or friction; or, the force is a force that we will investigate later in the book, such as the electric force between charged particles or the magnetic force.