Answer to Essential Question 3.4: In this case, we can use the definition of acceleration to write Equation 3.1 as $\vec{F}_{net} = m\vec{a} = m\Delta\vec{v} / \Delta t$. The net force acting on the ball, the ball's mass, and the time interval over which the force is applied are the same in this situation as in Example 3.4, so the ball's change in velocity, +15 m/s, must also be the same. Because the ball's initial velocity is –8.0 m/s, adding the change of +15 m/s results in a final velocity of +7.0 m/s.

3-5 Newton's Laws of Motion

Sir Isaac Newton (1642 – 1727) made many contributions to mathematics and science, including three laws of motion. Previously, we looked at several situations involving objects at rest and objects moving with constant velocity. We found that, in all such cases, the net force on the object was zero. In contrast, whenever an object's velocity was changing we found that there was a non-zero net force acting on the object. These observations are summarized by:

Newton's First Law - If no net force acts on an object, the object's velocity is unchanged: the object either remains at rest or it keeps moving with constant velocity. If there is a non-zero net force acting, then the object's velocity changes.

Recall that the net force is the sum of all the forces acting on an object. Always remember to add forces as vectors. The net force can be symbolized by $\sum \vec{F}$.

When there is a non-zero net force acting on an object, Newton's first law is a rather qualitative statement. It tells us that the velocity of the object changes, but it does not tell us how the velocity changes. This is where Newton's second law comes in.

$$\vec{a} = \frac{\sum \vec{F}}{m}. \qquad \text{(Equation 3.1: \textbf{Newton's Second Law})}$$

Equation 3.1 is often re-arranged to the following form, but it's the same equation!

$$\sum \vec{F} = m\vec{a} \qquad \text{(Equation 3.1: \textbf{Newton's Second Law})}$$

Thus, if we know all the forces that act on an object, and we also know the object's mass, we can determine the object's acceleration. Once we know the acceleration we can go on to analyze the object's motion using the methods, and constant-acceleration equations, of Chapter 2.

How quickly an object's velocity changes when a net force is applied depends on the magnitude of the net force as well as the object's inertia. The more mass an object has, the harder it is to change the object's velocity. In other words, an object's inertia is determined by its mass.

Newton's third law is simple to state but it can be rather counter-intuitive. This law follows from the fact that forces are associated with interactions, and both objects involved in an interaction experience a force of the same magnitude because of that interaction.

Newton's Third Law - When one object exerts a force on a second object, the second object exerts a force equal in magnitude, and opposite in direction, on the first object.

Note that Newton's laws apply for observers who are not accelerating while observing a system. For instance, you can use Newton's laws to explain the motion of an apple being tossed up and down by a person on a bus if you are at rest on the sidewalk watching the bus go by, or even if you are on the bus while the bus is moving at constant velocity. Newton's laws give an incomplete picture if you are on the bus, analyzing the motion of the apple while the bus accelerates. A non-accelerating reference frame is known as an inertial frame of reference.

Question: A fast-moving train collides with a small car that stalled as it crossed the railroad tracks. (Fortunately, the driver was able to run to safety before the collision.) Which object exerts more force on the other during the collision? Justify your answer.

Answer: Despite the fact that the train has much more mass than the car, the force the train exerts on the car is always equal in magnitude, and opposite in direction, to the force the car exerts on the train. Newton's third law addresses the fact that a force comes from an interaction, and the interacting objects are always equal partners in that interaction in the sense that they experience forces of equal magnitude.

So, why do many people think that the train exerts more force on the car than the car exerts on the train? The issue is that while the forces may be equal-and-opposite, the accelerations are different. Because the train's mass is much larger than the car's mass, the train's acceleration (the net force divided by the mass) is much less than the car's. Because the car experiences a large acceleration, so does a person in the car, and the forces exerted on a person in the car can be large enough to cause serious injury or death. Conversely, because the train experiences a small acceleration, someone on the train experiences a modest force and a person on the train may hardly even notice a collision occurred (until the engineer applies the brakes, at least). Thus, although the forces are equal-and-opposite, the effects of the forces differ greatly.

Although Newton's third law can be counter-intuitive, it is easy to verify. One way to verify it is to mount force sensors on carts and set up collisions between the carts, or have one cart push or pull the other. No matter what the situation, even if the carts have different masses and/or one of the carts is initially stationary, the result is that the force that the first cart exerts on the second is always equal in magnitude, and opposite in direction, to the force the second cart exerts on the first. A result from an actual experiment is shown in Figure 3.12, showing graphs of the force, as a function of time, experienced by two carts being pushed together.

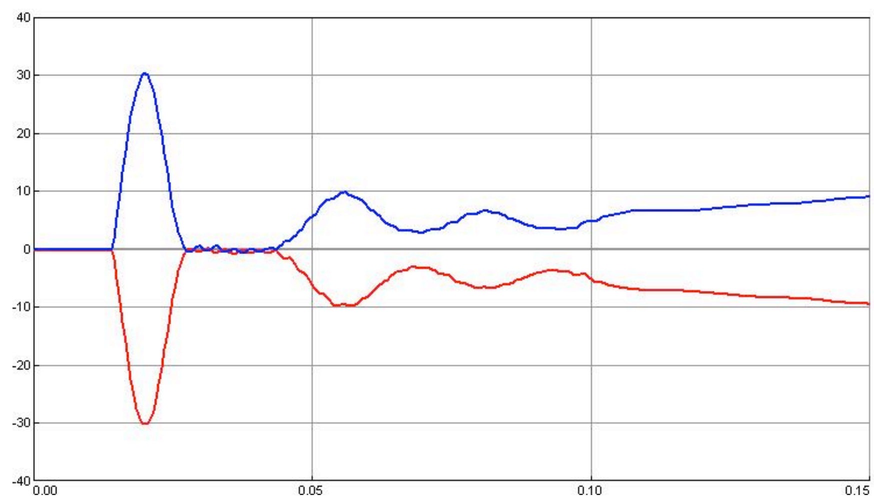

Figure 3.12: The top graph shows the force, in newtons, as a function of time, in seconds, that cart A exerts on cart B. The bottom graph shows the force cart B exerts on cart A. Such graphs are always mirror images, providing experimental evidence of Newton's third law.

Related End-of-Chapter Exercises: 56 and 57.

Essential Question 3.5: Does the Sun exert more force on the Earth, or does the Earth exert more force on the Sun?