2.2.1 In Class or Homework Exercise

1. If you are in a car that is struck from behind, you can receive whiplash.

    (a) Using Newton's laws of motion, explain what happens.

    Your body is initially at rest; it therefore needs a force to accelerate it forward (1st Law). The back of the seat applies this force to your body, but your head is above the seat. In order for your head to accelerate forward at the same rate as your body, a force must be applied to it. This force must come from your neck, as nothing else is in contact with your head. This strain that your neck experiences applying this force is what results in the whiplash.

    (b) How does a headrest reduce whiplash?

    The headrest is in contact with your head and can therefore exert the force needed to accelerate your head with the rest of your body. Your neck does not have to apply the required force in this situation.

2. If you push forward on the back of an automobile, does that mean that its velocity has to be in the forward direction? Explain and give an example.
    No. If the force that you are exerting is the only horizontal force, this means that the net force is in the direction that you are pushing and the acceleration would have to be in that direction, not the velocity. The car could be moving toward you and slowing down.

    There could also be other forces acting on the car. For example, the car could be on a hill with you pushing up the hill. In this case, the net force could be down the hill even though you are pushing up the hill. In this case, the acceleration would not even be in the same direction that you are pushing.

3. According to legend, a horse learned Newton's laws. When told to pull a cart, he refused, saying that if he pulled the cart forward, according to Newton's Third Law there would be an equal force backwards. Thus, there would be balanced forces and, according to Newton's Second Law, the cart would not accelerate. How would you reason with this rather weird horse?
    Although there is an equal force backwards, the two forces are acting on different objects. The horse is exerting a force in the positive direction **on the cart**; the cart will exert a negative force **on the horse**. To determine if the cart accelerates, it is necessary to look at only the forces acting on the cart:
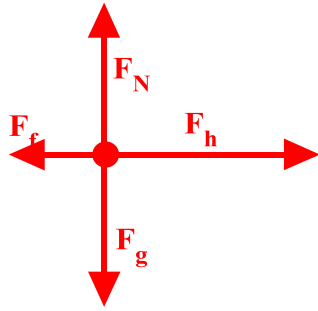
Since the only other horizontal force is friction, as long as the force that the horse is exerting is larger than the force of friction the cart will accelerate in the positive direction.

4. Suppose that you exert a force on a black block and measure its acceleration. You then exert the same force on a brown block. Its acceleration is three times that of the black block. What can you conclude about the masses of the blocks?

We will assume no friction in this explanation, so that the force that you are exerting is the net force in this situation. Since according to Newton's Second Law $\vec{a} = \dfrac{\vec{F}}{m}$, if the acceleration is 3 times as large (and the force stays the same) the mass must be only 1/3 as large.

5. A common trick involves covering a table with a cloth and placing dinnerware on the cloth. When the cloth is suddenly pulled horizontally, the dishes stay in position and drop onto the table.

   (a) Identify all forces acting on the dishes during the trick.

   Assuming that the cloth is being pulled to the left, the free body diagram on one of the dishes would look like this:
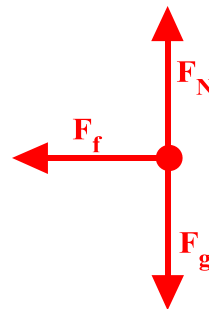
   Notice that the only horizontal force acting on the dishes is the force of friction between the dishes and the cloth. It is this force of friction that attempts to accelerate the dishes.

   (b) Explain how the trick works.

   When you pull the cloth, you are giving it an acceleration. The force of friction attempts to accelerate the dishes at the same rate, but because of inertia they attempt to stay at rest. The force of friction is limited by the coefficient of friction and the normal force, so there is

a maximum force of friction that the cloth can apply to the dishes; since there is a maximum force of friction, there is also a maximum acceleration that can be given to the dishes.

If the acceleration of the cloth is greater than the acceleration that can be provided to the dishes, the cloth will slide out from under the dishes and they will be left behind on the table. That is why the key to the trick is to pull the cloth quickly; pull it too slow and the dishes will keep up with the cloth and fall on the floor. This trick is also easier with a smaller coefficient of friction between the cloth and the dishes.

Demonstration: This trick can easily be demonstrated in class. If a dish and cloth are not available, a piece of paper and a mass can be used to show the same effect.

6. A stone hangs by a fine thread from the ceiling and a section of the same thread dangles from the bottom of the stone. If a person gives a sharp pull on the dangling thread, where is the thread likely to break, below the stone or above it? What if the person gives a slow and steady pull? Explain your answers.

A demonstration is easy to do to answer what happens in this situation. Simply tie a two threads to a mass (500 g or so). Use one thread to hold the mass in the air, and pull on the other thread hanging below.

Quick Pull: A quick pull should result in the thread breaking below the mass. The mass has a tendency to stay at rest (Newton's First Law), so does not move much (or attempt to move) initially. The pull on the bottom thread attempts to accelerate the mass (Newton's Second Law). If the pull is quick enough and large enough, the tension in the bottom thread is large enough to break it before the force is transferred to the top thread.

Slow Pull: A slow pull should result in the thread breaking above the mass. As most trainees may have predicted, the top thread is subjected to both the pull on the bottom thread and the weight of the mass. The bottom thread does not have to support the weight of the mass and is only subjected to the pull on the thread. Since there is more tension in the top thread, it is more likely to break.

7. A force of 9000. *N* is used to stop a 1500 *kg* car traveling at 20.0 *m/s*. What braking distance is needed to bring the car to a halt?
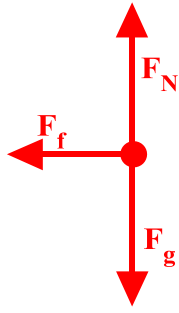
Using the forward direction as the positive direction,

$$\vec{F}_{net} = -9000.N$$
$$m = 1500kg$$
$$\vec{v}_i = 20.0m/s$$
$$\vec{v}_f = 0$$

$$\vec{F}_{net} = m\vec{a}$$
$$-9000. = 1500\vec{a}$$
$$\vec{a} = -6.0m/s^2$$

$$\Delta\vec{d} = \frac{v_f^2 - v_i^2}{2\vec{a}}$$
$$= \frac{0^2 - 20.0^2}{2(-6.0)}$$
$$= \boxed{33m}$$

8. When you drop a 0.40 *kg* apple, Earth exerts a force on it that causes it to accelerate at 9.8 *m/s*^{2}. According to Newton's third law, the apple must exert an equal and opposite force on Earth. If the mass of the Earth is 5.98×10^{24} *kg*, what is the Earth's acceleration?

Looking at the apple first, we can see that the only force acting on it is the force of gravity

$$m = 0.40kg$$
$$\vec{a} = 9.8m/s^2$$
$$\vec{F}_g = ?$$

$$\vec{F}_{net} = m\vec{a}$$
$$\vec{F}_g = m\vec{a}$$
$$= (0.40)(9.8)$$
$$= 3.92N$$

According to Newton's Third Law, there will be an equal and opposite force upward on the Earth:

$$m = 5.98\times10^{24}kg$$
$$\vec{F}_g = -3.92N$$
$$\vec{a} = ?$$

$$\vec{F}_{net} = m\vec{a}$$
$$-3.92 = (5.98\times10^{24})\vec{a}$$
$$\vec{a} = \boxed{-6.6\times10^{-25}m/s^2}$$