Period 5 Activity Sheet Solutions: Forces and Newton's Laws

5.1 What Are the Four Fundamental Forces?

a) Based on your class activities and your instructor's explanation, give examples of each of the fundamental forces.

1) **Gravitational Force**

An attractive force between all objects. The gravitational force causes objects to roll downhill, causes dropped objects to fall toward the Earth, and holds the Earth in an orbit around the Sun. Example: an unsupported object falls to the ground.

2) **Electromagnetic Force**

An attractive force between particles of opposite charge, and a repulsive force between particles with like charge (both positive or both negative). The electromagnetic force holds atoms together and causes charged objects to attract or repel one another. Example: when the negatively charged styrofoam ring is repelled by the negatively charged rod, the ring floats above the rod.

3) **Strong Nuclear Force**

An attractive force that holds protons and neutrons together in the nuclei of atoms. The strong force acts only when particles are close together. Example: all matter consisting of atoms.

4) **Weak Nuclear Force**

The force responsible for radioactive decay of atomic nuclei, such as the decay that produces radon gas. Example: decay of radioactive samples.

b) The space between an atomic nucleus and its electron cloud is so great that the majority of the volume of an atom is empty space. Since atoms are mostly empty space, explain in terms of fundamental forces why a solid object sitting on a table does not fall through the table.

Electromagnetic forces between atoms lock atoms together to form a solid. In most solids, these forces are strong enough to prevent the solid from falling apart when subjected to a force.

c) Group Discussion Question: Since all objects contain positive and negative electrical charges, shouldn't we feel an electromagnetic force from every object we encounter? Explain why we do not.

5.2 How Do Newton's Laws of Motion Describe Forces?

a) **Newton's First Law:**

Your instructor will demonstrate a metal cart on an air track, which minimizes the amount of friction between the cart and the metal track.

1) As the cart moves along the track, is there a net force acting on the cart? __**Since there is very little friction between the cart and the track, the net force is essentially zero.**__

2) Is a net force required to keep the cart moving at a constant speed? _**No**_

   Explain why or why not.

   According to Newton's first law, a force must act on an object in motion to change the object's speed or direction. Since the cart moves at a constant speed along the track, its acceleration is zero and no net force is required.

b) **Newton's Second Law**: ***F = M a***

A Lamborghini Diablo sports car can accelerate from 0 MPH to 60 MPH in 4.3 seconds. The mass of the car is 1,580 kg. Calculate the force (in newtons) needed to accelerate the car. (We assume that its acceleration is constant.)

1) Convert 60 miles/hour into meters/second. Hint: 1 mile = 1,609 meters.

$$\frac{60 \text{ mi}}{\text{hr}} \times \frac{1{,}609 \text{ m}}{\text{mi}} \times \frac{1 \text{ hr}}{3{,}600 \text{ s}} = 26.8 \text{ m/s}$$

2) Find the acceleration of the car using $a = \frac{v_{final} - v_{initial}}{t}$

$$a = \frac{v_f - v_i}{t} = \frac{26.8 \text{ m/s} - 0 \text{ m/s}}{4.3 \text{ s}} = 6.24 \text{ m/s}^2$$

3) Use Newton's second law to find the force on the car during its acceleration.

$$F = M\,a = 1{,}580 \text{ kg} \times 6.24 \text{ m/s}^2 = 9{,}854 \text{ N} = 9.9 \times 10^3 \text{ N}$$

c) **Newton's Second Law applied to falling objects**: ***F = M g***

In Period 4, we found that the force of gravity acting on a falling rock is given by

$$F = \frac{G\,M_{rock}\,M_{planet}}{D^2} = M_{rock}\,g$$

Where ***D*** = the radius of the planet and ***g*** is the acceleration of gravity on that planet.

Calculate the acceleration of gravity on the surface of Mars. The mass of Mars = 6.42 x 10^{23} kg and the radius of Mars = 3.4 x 10^6 m

$$g = \frac{G\ M_{Mars}}{D^2} = \frac{(6.67 \times 10^{-11}\ N\ m^2/kg^2) \times (6.42 \times 10^{23}\ kg)}{(3.4 \times 10^6\ m)^2} =$$

$$\frac{(6.67 \times 10^{-11}\ N\ \cancel{m^2}/kg^{\cancel{2}}) \times (6.42 \times 10^{23}\ \cancel{kg})}{1.16 \times 10^{13}\ \cancel{m^2}} = 3.69\ N/kg = 3.69\ m/s^2$$

d) Calculate the gravitational force acting on a 5 kg rock that is dropped above the surface of Mars.

$F = M\,g$ = 5 kg x 3.69 m/s^2 = 18 kg m/s^2 = 18 N

5.3 Newton's Third Law

a) Your instructor will demonstrate a cart with a fan attached to it. Before you see each demonstration, predict the cart's motion.

1) When the fan is turned on, will the cart move in the direction the fan blows, move in the opposite direction that the fan blows, or not move?

Prediction: ____

Watch the demonstration and describe what happened. Explain the motion of the cart in terms of Newton's third law.

The cart moves in the opposite direction that the fan blows. The fan exerts a force on nearby air molecules, which exert a force back on the fan and cart, giving it a push.

2) Your instructor will place on the track a second cart with a metal "sail" attached. When the fan on the first cart is turned on, it blows against the sail on the second cart. Will either cart move when the fan is turned on?

Prediction: __________ Describe and explain what happened.

The carts move apart. The cart with the fan pushes air molecules against the sail, accelerating the sail cart. The sail pushes back against the air molecules that strike it. The air molecules exert a force on the fan cart, accelerating it. The forces are equal and opposite.

3) Next, we connect the two carts together. Will the carts move when the fan is turned on?

Prediction: __________ Describe and explain what happened.

The carts do not move. The fan exerts a force F on the air, blowing it toward the sail. The air exerts a force F back on the fan, pushing it away from the sail. When the air strikes the sail, it exerts a force F on the sail, pushing it away from the fan. Since the carts are connected,

the equal forces on the fan and sail cancel because they act in opposite directions.

4) Finally we put the fan and the sail on the same cart so that the fan blows against the sail. When the fan is turned on, will the cart move? If so, in which direction?

Prediction: _________ Describe and explain what happened.

The cart moves slowly in the direction away from the fan and toward the sail. When the fan is close to the sail, the wind from the fan does not just come to rest when it strikes the sail. Instead, some of the wind is reflected by the sail, creating a force on the sail that is larger than the force on the fan.

d) Group Discussion Question: You are sitting in a sailboat that is not moving because no wind is blowing. Could you move the boat by holding a powerful fan and pointing it at the sail?

5.4 Frictional Force - What Determines the Amount and Type of Friction?

a) Types of Friction: Static and Sliding. Your instructor will demonstrate a toy truck pulling a wooden block with a spring scale attached.

1) How much force does the scale measure just before the block starts to move? ____________

2) How much force does the scale measure while the block is moving? __________

3) Which of the two types of friction is greater? _ **Static friction** _

b) How Does the Amount of Force Pressing Surfaces Together Affect Friction?

1) Attach the spring scale to the screw eye on the front of the wooden cart. Drag the cart **upside down** at a constant velocity across the smooth board. How much force is required to move the cart at a constant velocity? _____________

2) Place a 1 kg mass on the cart and again drag the cart upside down at a constant velocity across the smooth board. How much force is required to move the cart with the 1 kg mass at a constant velocity? _______________

3) Explain how the amount of force pressing the cart against the board affects the amount of friction between the cart and the board.

The greater the mass of the cart, the more force it exerts on the board. The greater the force between the cart and the board, the more friction between their surfaces.

c) How Does Surface Smoothness Affect Friction? Compare the amount of friction between a wooden cart and the surfaces it slides across by calculating the coefficient of friction between the cart and the surfaces.

1) Find the weight in newtons of the wooden cart by suspending it from the blue spring scale. ________________

2) How much force is required to move the cart at a constant velocity across the **smooth** board? (Use your measurement from part 5.4.b.1) _________

3) Calculate the coefficient of friction between the cart and the smooth board by forming the ratio of the force required to drag the cart divided by the weight of the cart.

$$\textbf{Coefficient of friction} = \frac{\textbf{force to pull cart across smooth board}}{\textbf{weight of cart}}$$

4) Drag the cart upside down at a constant velocity across the **rough** board. How much force is required to move the cart at a constant velocity? ______

5) Calculate the coefficient of friction between the cart and the rough surface.

$$\textbf{Coefficient of friction} = \frac{\textbf{force to pull cart across rough board}}{\textbf{weight of cart}}$$

6) In which case is the coefficient of friction greater? Explain how the amount of friction is related to surface smoothness.

Dragging the cart across the rough surface results in a larger coefficient of friction than dragging it across the smooth surface. A rough surface produces more friction than a smooth surface.

7) Group discussion question: Which of the fundamental force(s) is/are responsible for the force of friction?

d) **Is friction always undesirable?**

1) Your instructor will demonstrate two toy cars moving up an incline. Explain the differences in the motion of the cars as they go up the incline.

As the cars go up the incline, the car with metal wheels slips sooner than the car with rubber band wheels because there is more friction between the rubber bands and the surface of the incline.

2) Balance a meter stick on two fingers. Start with one finger under each end of the meter stick. Slowly slide your fingers together while balancing the meter stick on them. Explain what happens to your fingers in terms of the downward force of the stick on your finger, the friction between the stick and your finger, and the center of mass of the meter stick.

First one finger slides along the meter stick and stops, then the other finger slides along and stops. Why does this happen? As one finger slides toward the center, more of the meter stick's weight hangs over the end of that finger and exerts a force on it. With this added force, eventually the force of friction between the sliding finger and the stick is greater than the force of static friction between the stationary finger and the stick.

At this point, your moving finger stops and the other finger slides in until the weight of the stick hanging over that finger causes the sliding friction to be greater than the static friction of the stationary finger. The process repeats until your fingers meet at the center of the meter stick.

3) Stack several pennies on a sheet of paper. Try to pull the paper out from under the pennies without toppling them. How high a stack of pennies can you pull the paper out from under? ___________

Explain why it is possible to pull the paper from under the pennies in terms of Newton's first law and the frictional forces acting between the bottom penny and the sheet of paper. Why does the height of the stack of pennies matter?

As Newton's first law states, stationary objects remain at rest unless a force acts on them. If you pull the paper out from under a small stack of pennies, the force of friction between the bottom penny and the paper is small enough that the pennies remain at rest.

The taller the stack of pennies, the greater the weight pressing down on the bottom penny and so the greater the force of friction between the bottom penny and the paper.