Any object that is dropped, thrown, or shot is called a projectile. The study of projectile motion is called ballistics. Examples include a batted baseball arcing to the outfield, an egg dropping to the floor, and a shell fired from a cannon. In all these cases, once the object is released, the only significant force acting on it is gravity. Under these conditions an object is said to be in free flight.

The motion of a projectile is usually separated into horizontal and vertical components. Like the x- and y-axes of the Cartesian coordinate system that we use to describe vectors. Near the earth's surface, gravity acts only downward, perpendicular to the surface of the earth. It therefore has no effect on the horizontal motion of an object parallel to the surface of the earth. In free flight there are no forces acting horizontally, so the projectile moves with constant horizontal velocity. This fact agrees with Newton's First Law, which states that an object will maintain a constant velocity unless acted upon by an outside force. This velocity is whatever horizontal velocity the object started with when it began in free flight. If we view the object from above so that the vertical motion is not seen, the object does not appear to speed up or slow down during the flight.

In some cases the slowing effect of air resistance, a form of friction, must be considered. If air resistance is significant, as in testing a paper airplane or a Frisbee, the problem is no longer one of ballistics, but of aerodynamics. Under ordinary earthbound conditions, free flight does not last very long. Eventually, the object collides with something or is subjected to other forces, and the free flight is over.

**Materials**
- Two coins (quarters)
- A small flat stick, such as a tongue depressor or ice cream pop stick, or a piece of thin, stiff cardboard cut about 10 to 15 cm long and 1 cm wide
- Wooden or stiff plastic ruler
- Hardcover book
- Table, desk, counter, or bench

**Procedure**

1. Hold the stick flat on the table with about two thirds of its length hanging past the edge of the table. Place the book on top of the other end of the stick to hold it in place.

2. Place one coin flat on the stick about midway between the tip of the stick and the edge of the table, extending a bit past both sides of the stick. Place a second coin on the tip of the stick, bashed balanced and ready to fall off. See Figure 1.

3. Hold the ruler in a hanging position above the stick so that when you swing the ruler, it will hit the first coin squarely and propel it forward. See Figure 2. Be sure there are unobstructed paths for the coins to reach the floor without hitting anything. Swing the ruler away from the stick, and then swing it sharply forward to strike the first coin to propel it in the desired direction. Try to avoid giving it any velocity upward or downward. The second coin should drop straight down to the floor. Observe and record which coin hits the floor first, or if it is a tie.

4. Repeat step 3 twice for a total of three trials. Try varying the force with which you strike the first coin.

**Data Collection and Analysis**

Check which coin strikes the floor first (three trials):
- First coin
- Second coin
- Tie

1. Which coin (the one struck by the ruler or the one dropping straight down) hits the floor first? Why:

2. Think of the second coin (the one that drops straight down) as a timer against which to compare the first coin's flight time until it hits the floor. Does the time it takes for the first coin to hit the floor depend on how far it flies across the room? Why or why not?

**Questions**

1. Why is motion of an object in free flight usually separated into horizontal and vertical components?
2. True or false. The faster you throw a ball horizontally, the longer it will take to hit the floor.
3. What is the effect of air resistance on an object in free flight?
4. Which of the following are examples of ballistics, and which are not?
   - (a) a space shuttle lifting off from a launch pad
   - (b) an egg falling after it rolls off a table
   - (c) a leaf rustling on the ground
   - (d) a basketball arcing upward toward the hoop
Understanding Mass and Gravity

There are two very important factors that affect gravitational force.
1. The larger the mass of an object, the greater the gravitational force.
2. The closer objects are, the greater the gravitational force.

Answer the following questions.

1. An individual was weighed on Earth before flying to various altitudes. The scale registered 150 pounds on Earth. Place a plus (+) beside the statements below that are true. Place a minus (-) beside the statements that are false. On the blank below each statement, write why the statement is true or false.

   (a) The same individual in a plane flying at an altitude of 30,000 feet will weigh less than 150 pounds.
   (b) The mass of the individual at 30,000 feet is different than the mass of the individual on the earth's surface.
   (c) The weight of the individual on the surface of the earth and at 30,000 feet will be 150 pounds.
   (d) The weight of the individual will be less at 40,000 feet than at 30,000 feet.
   (e) The masses of the individual and the earth will not change.

Circle the correct choices:

2. A man weighs 180 pounds. He walks up a mountain to an elevation of 15,000 feet. His weight at 15,000 feet will:
   (a) increase/decrease because he is moving
   (b) away from/howard the earth's center.
   The man (c) will not lose matter as he reaches the 15,000-foot elevation.

3. The diagram below represents a female astronaut on the surface of the earth at point "a". The astronaut is part of a crew that will fly a space mission on a given day. Below are five numbers that represent the weight of the female astronaut on the day of the given space mission. Place the numbers in order in the appropriate rectangles to represent the changing weight of the astronaut as the flight leaves Earth.

   140 lbs. 90 lbs. 120 lbs. 100 lbs. 80 lbs.

   (a) 
   (b) 
   (c) 
   (d) 
   (e) 

   Earth's Surface

Circle the correct choices:

4. A rectangular piece of iron weighs 96 pounds on the surface of the earth. The piece of iron is transported to the moon and weighed. The weight of the rectangular piece of iron on the moon's surface is 16 pounds.

   (a) The mass of the moon is (more/less) than the earth.
   (b) The force of gravity is (less/more) than on Earth.
   (c) The mass of the iron on the moon is (different than/the same as) on Earth.
   (d) The weight of the iron on the moon is (a) 1/4 (b) 1/2 (c) 1/6 (d) 1/10 of the weight on earth.
   (e) The gravitational force on the moon is (a) 1/4 (b) 1/2 (c) 1/6 (d) 1/10 of the gravitational force on earth.
   (f) Gravitational force and weight (are/are not) related.
QUESTIONS ABOUT GRAVITY

Sir Isaac Newton developed the law of gravitation. According to Newton's law, every object in the universe attracts every other object. He called the force of attraction between objects gravitational attraction. The amount of gravitational attraction between objects depends on how much mass the objects have and how far apart the objects are.

In the study of science, it is important to ask questions. Trying out various possibilities for answers is part of the scientific method. Seldom are the answers to scientific problems found on the first trial. Isaac Newton spent a great deal of time wondering and thinking about why objects fall before he developed his three laws about gravity.

The exercises that follow is a "What do you think?" exercise. Following each question, write what you think the answer might be.

1. Do all objects have a gravitational attraction? (yes/no) because

2. If objects have a mutual attraction, does gravity pull them toward each other? (yes/no) because

3. If two objects are attracted, do they both move? (yes/no) because

4. When a rock is thrown off a cliff, does the rock fall to earth? (yes/no) because

5. Does the earth move toward the rock? (yes/no) because

6. Does a tennis ball fall faster than a baseball? (yes/no) because

FORCE AND ACCELERATION

A force is a push or a pull. To calculate force, we use the following formula:

\[ F = ma \]

where \( F \) = force in newtons
\( m \) = mass in kg
\( a \) = acceleration in m/sec²

Example: With what force will a rubber ball hit the ground if it has a mass of 0.25 kg?

Answer: \( F = (0.25 \text{ kg}) (9.8 \text{ m/s}^2) \)

\( F = 2.45 \text{ N} \)

Solve the following problems.

1. With what force will a car hit a tree if the car has a mass of 3,000 kg and it is accelerating at a rate of 2 m/s²?

   Answer: __________

2. A 10 kg bowling ball would require what force to accelerate it down an alleyway at a rate of 3 m/s²?

   Answer: __________

3. What is the mass of a falling rock if it hits the ground with a force of 147 newtons?

   Answer: __________

4. What is the acceleration of a softball if it has a mass of 0.50 kg and hits the catcher's glove with a force of 25 newtons?

   Answer: __________

5. What is the mass of a truck if it is accelerating at a rate of 5 m/s² and hits a parked car with a force of 14,000 newtons?

   Answer: __________
**The Force of Gravity**

**Exercise 15**

Name ___________________________ Date ____________

**Use the facts below to answer the questions.**

**Fact 1:** All objects that have mass are attracted to each other. This attraction is a force called gravity. The more mass the objects have, the greater the force of gravity.

**Fact 2:** The strength of gravitational force depends on the mass of objects. Objects with less mass have less gravitational pull.

**Fact 3:** Weight is the measure of the force of gravity on an object. The stronger the pull, the greater the weight.

**Fact 4:** An object's mass stays the same but weight may change, depending on the force of gravity.

**Fact 5:** Weight can change because of the distance between two objects. The farther you get away from the center of the earth, the less you will weigh.

**Fact 6:** The force of gravity is weaker near the equator than it is near the north and south poles.

1. An object would weigh slightly less at which part of the world? __________________________

2. You take the elevator up to the top of the Sears Tower in Chicago, one of the tallest buildings in the world. What happens to your weight? Why? __________________________

3. The moon has less mass than the earth. Would you expect it to have a greater gravitational force than the earth? Why? __________________________

4. Based on your answer in number 3, would you expect to weigh less or more on the moon? __________________________

5. Even though you weigh less in these situations, your clothes still fit the same (a little too tight). Why? __________________________

**The Forces of Nature**

**Exercise 21**

Name ___________________________ Date ____________

Look at each picture below. Decide which force or law of nature is at work. Write centrifugal, gravity, friction, or inertia under each picture.

1. __________________________

2. __________________________

3. __________________________

4. __________________________

5. __________________________

6. __________________________

7. __________________________

8. (Hint: name two forces here.) __________________________
Physical Science: Critical Thinking

Gravity and Its Effects

Name __________________________ Date ________________

A. Imagine that you are playing softball. Use what you have learned about physics to help you answer the following questions.

1. You have hit the ball as hard as you can. It is going very, very far, but it finally falls to the ground. What force pulls the ball to the ground?

2. What would happen to your ball if after you hit it there was suddenly no gravity?

3. What would happen if you hit a softball as hard as you could on a planet with much stronger gravity than Earth?

B. Imagine that you and a friend are a part of a research team traveling in a space ship. You are studying gravity in outer space. Fill in the blanks to complete your research report.

First we studied the Earth. We knew that the force of

(1) ____________________ was allowing us to stay in Earth's orbit. As we got farther away from Earth, we felt

(2) ____________________ (more/less) strongly pulled toward it.

Then we headed toward the moon. When we got on the scale, we found that we weighed (3) ____________________, (more/less) when we were closer to the Earth and (4) ____________________, (more/less) when we were closer to the moon. The moon also has a force of (5) ____________________, but the moon is (6) ____________________ (more/less) massive than the Earth.

Exercise 16

Putting Gravity and Friction to Work

Name __________________________ Date ________________

Physical Science: Critical Thinking

Use what you know about gravity and friction to answer the following questions.

1. Janet is a paratrooper. When she jumps from the plane, she drops quickly, free falling through the air at great speeds that would kill her if she hit the ground. When she opens her parachute, she slows down and lands safely on the ground.

a. What in this story shows the effects of gravity?

b. Explain how friction works in this story.

c. Without gravity, what would happen to Janet when she jumped out of the plane?

d. Without friction, what would happen to Janet when she opened her parachute?

2. Parker runs river rafting trips on Western rivers. Usually his trips start up in the mountains, then end on flatter lands. He loves to ride down steep rapids. When he gets going too fast, he instructs his passengers to put their oars in the water and hold them steady against the strong current.

a. What in this story shows the effects of gravity?

b. Explain how friction works in this story.

c. Without gravity, what would happen to the rivers that Parker runs his trips on?

d. Without friction, what would happen to rafters as they headed down the river?
Section 1: Newton's Second Law
Section 2: Gravity

Directions: In the blank at the left, write the letter of the term that correctly completes each statement.

1. Every object in the universe exerts a force on every other object. This force is called ________.
   a. friction  
   b. gravity

2. The measure of the gravitational force exerted by Earth on an object is the object's ________.
   a. weight  
   b. mass

3. The amount of gravitational force between two objects depends on their ________.
   a. color and density  
   b. mass and distance

4. Weight is measured in units called ________.
   a. newtons  
   b. kilograms

5. The greater an object's ________ the stronger the gravitational force on it.
   a. mass  
   b. velocity

6. Mass is measured in units called ________.
   a. newtons and kilonewtons  
   b. grams and kilograms

7. A weight reading on a scale shows the ________ exerted by the scale.
   a. upward force  
   b. downward force

8. Earth exerts a stronger gravitational force than the Moon because Earth has more ________.
   a. mass  
   b. density

9. The masses of your hand and your notebook are quite small, so the force of attraction between them is ________.
   a. zero  
   b. weak

10. An object transported from the surface of Earth to the surface of the Moon has its weight ________.
    a. decreased  
    b. stay the same

Gravity

Directions: Answer the following questions on the lines provided.

1. What is gravity?
2. What are two things that the amount of gravitational force between two objects depends on?

3. Why does Earth exert a stronger gravitational force than the Moon?

4. If an object weighs 40 N on Earth, would it weigh more than 40 N on the Moon? Explain.

5. What is the centripetal force that allows a car to move around a sharp curve in a roadway?

6. Draw an arrow on the bottom diagram to show the movement of the car if the centripetal force of the road and car is not enough to overcome the car's inertia when it reaches point B.

7. Explain how you know the car is accelerating when it reaches point A in the first diagram.