Activity 2 Push or Pull—Adding Vectors

GOALS

In this activity you will:

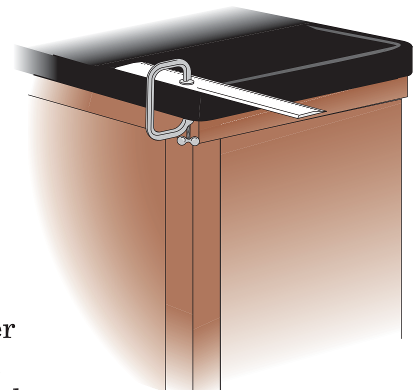
- Recognize that a force is a push or a pull.
- Identify the forces acting on an object.
- Determine when the forces on an object are either balanced or unbalanced.
- Calibrate a force meter in arbitrary units.
- Use a force meter to apply measured amounts of force to objects.
- Compare amounts of acceleration semiquantitatively.
- Understand and apply Newton's Second Law of Motion.
- Understand and apply the definition of the newton as a unit of force.
- Understand weight as a special application of Newton's Second Law.

What Do You Think?

Moving a football one yard to score a touchdown requires strategy, timing, and many forces.

- **What is a force?**
- **Can the same force move a bowling ball and a ping-pong ball?**

Record your ideas about these questions in your *Active Physics* log. Be prepared to discuss your responses with your small group and the class.



For You To Do

1. Use a flexible ruler as a "force meter". Use washers to make a scale of measurement for (that is, to calibrate) the meter inpennyweights. The force you are using to calibrate the meter is gravity, the force with which Earth pulls downward

on every object near its surface. *Carefully* clamp the plastic strip into position as shown in the diagram on the previous page.

2. Draw a line on a piece of paper. Hold the paper next to the plastic strip so that the line is even with the edge of the strip. Mark the position of the end of the strip on the reference line and label the position as the "zero" mark.

3. Place one washer on the top surface of the strip near the strip's outside end. Notice that the strip bends downward and then stops. Hold the paper in the original position and mark the new position of the end of the strip. Label the mark as "1 pennyweight."

4. Repeat **Step 3** for two, three, and four coins placed on the strip. In each case mark and label the new position of the end of the strip.

   a) Copy the reference line and the calibration marks from the piece of paper into your log.

5. Practice holding one end of the "force meter" (plastic strip) in your hand and pushing the free end against an object until you can bend the strip by forces of 1, 2, 3, and 4-pennyweight amounts. To become good at this, you will need to check the amount of bend in the strip against your calibration marks as you practice.

6. Use the force meter to push an object such as a tennis ball with a continuous 1-pennyweight force. You will need to keep up with the object as it moves and to keep the proper bend in the force meter. You may need to practice a few times to be able to do this.

   a) In your log, record the amount of force used, a description of the object, and the kind of motion the object seemed to have.

7. Repeat **Step 6** three more times, pushing on the same object with steady (constant) 2, 3, and 4-pennyweight amounts of force.

   a) Record the results in your log for each amount of force.

8. Based on your observations, complete the statement: "The greater the constant, unbalanced force pushing on an object,..."

   a) Write the completed statement in your log.

9. Select an object that has a small mass. Use the force meter to push on the object with a rather large, steady force such as 3- or 4-pennyweight amounts.

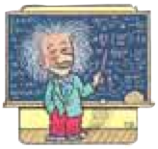
   a) Record the amount of force used, a description of the object pushed (especially including its mass, compared to the other objects to be pushed) and the kind of motion the object seemed to have.

10. Repeat **Step 9** using the same amount of force to push objects of greater and greater mass.

    a) Record the results in your log for each object.

11. Based on your observations, complete the statement: "When equal amounts of constant, unbalanced force are used to push objects having different masses, the more massive object..."

    a) Write the completed statement in your log.



Physics Words

Newton's Second Law of Motion: if a body is acted upon by an external force, it will accelerate in the direction of the unbalanced force with an acceleration proportional to the force and inversely proportional to the mass.

weight: the vertical, downward force exerted on a mass as a result of gravity.

PHYSICS TALK

Newton's Second Law of Motion

Based on observations from experiments similar to yours, Isaac Newton wrote his **Second Law of Motion**:

The acceleration of an object is directly proportional to the unbalanced force acting on it and is inversely proportional to the object's mass. The direction of the acceleration is the same as the direction of the unbalanced force.

If 1 N (newton) is defined as the amount of unbalanced force that will cause a 1-kg mass to accelerate at 1 m/s^2 (meter per second every second), the law can be written as an equation:

$$F = ma$$

where F is expressed in newtons (symbol N), mass is expressed in kilograms (kg), and acceleration is expressed in meters per second every second (m/s^2).

By definition, the unit "newton" can be written in its equivalent form: $(kg)m/s^2$.

Newton's Second Law can be arranged in three possible forms:

$$F = ma \qquad a = \frac{F}{m} \qquad m = \frac{F}{a}$$

FOR YOU TO READ

Weight and Newton's Second Law

Newton's Second Law explains what "weight" means, and how to measure it. If an object having a mass of 1 kg is dropped, its free fall acceleration is roughly 10 m/s^2.

Using Newton's Second Law,

$$F = ma$$

the force acting on the falling mass can be calculated as

$$\begin{aligned} F &= ma \\ &= 1 \text{ kg} \times 10 \text{ m/s}^2 \text{ or } 10 \text{ N} \end{aligned}$$

The 10-N force causing the acceleration is known to be the gravitational pull of Earth on the 1-kg object. This gravitational force is given the special name **weight**. Therefore, it is correct to say, "The weight of a 1-kg mass is ten newtons."

What is the weight of a 2-kg mass? If dropped, a 2-kg mass also would accelerate due to gravity (as do all objects in free fall) at about 10 m/s^2. Therefore, according to Newton's Second Law, the weight of a 2-kg mass is equal to

$$2 \text{ kg} \times 10 \text{ m/s}^2 \text{ or } 20 \text{ N}$$

In general, to calculate the numerical value of an object's weight in newtons, it is necessary only to multiply the numerical value of its mass by the numerical value of the g (acceleration due to gravity), which is about 10m/s^2.

$$\text{Weight} = mg$$

The preceding equation is the "special case" of Newton's Second Law that must be applied to any situation in which the force causing an object to accelerate is Earth's gravitational pull.

Where There's Acceleration, There Must Be an Unbalanced Force

There are lots of different everyday forces. You just read about the force of gravity. There is also the force of a spring, the force of a rubber band, the force of a magnet, the force of your hand, the force of a bat hitting a ball, the force of friction, the buoyant force of water, and many more. Newton's Second Law tells you that accelerations are caused by unbalanced external forces. It doesn't matter what kind of force it is or how it originated. If you observe an acceleration (a change in velocity), then there must be an unbalanced force causing it.

When you apply a force, if the object has a small mass, the acceleration may be quite large for a given force. If the object has a large mass, the acceleration will be smaller for the same applied force. Occasionally, the mass is so large that you are not even able to measure the acceleration because it is so small.

If you push on a go-cart with the largest force possible, the cart will accelerate a great deal. If you push on a car with that same force, you

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will measure a much smaller acceleration. If you were to push on the Earth, the acceleration would be too small to measure. Can you convince someone that a push on the Earth moves the Earth? Why should you believe something that you can't measure? If you were to assume that the Earth does not accelerate when you push on it, then you would have to believe that Newton's Second Law stops working when the mass gets too big. If that were so, you would want to determine how big is "too big." When you conduct such experiments, you find that the acceleration gets less and less as the mass gets larger and larger. Eventually, the acceleration gets so small that it is difficult to measure. Your inability to measure it doesn't mean that it is zero. It just means that it is smaller than your best measurement. In this way, you can assume that Newton's Second Law is always valid.

All of these statements are summarized in Newton's Second Law as you read in **Physics Talk**:

$$F = ma$$

or in forms that emphasize the acceleration and the mass

$$a = \frac{F}{m} \text{ and } m = \frac{F}{a}$$

Sample Problem 1

A tennis racket hits a ball with a force of 150 N. While the 275-g ball is in contact with the racket, what is its acceleration?

Strategy: Newton's Second Law relates the force acting on an object, the mass of the object, and the acceleration given to it by the force. Use the form of the equation that emphasizes acceleration to find the acceleration. The force unit, the newton, is defined as the amount of force needed to give a mass of 1.0 kg an acceleration of 1.0 m/s^2. Therefore, you will need to change the grams to kilograms.

Givens:

$F = 150.0$ N

$m = 275$ g

Solution:

$$275 \text{ g} = 0.275 \text{ kg}$$

$$a = \frac{F}{m}$$

$$= \frac{150 \text{ N}}{0.275 \text{ kg}}$$

$$= 545 \text{ m/s}^2$$

Sample Problem 2

As the result of a serve, a tennis ball ($m_t = 58$ g) accelerates at 43 m/s^2.

a) What force is responsible for this acceleration?

b) Could an identical force accelerate a 5.0-kg bowling ball at the same rate?

Strategy: Newton's Second Law states that the acceleration of an object is directly proportional to the applied force and indirectly proportional to the mass ($F = ma$).

Givens:

$a = 43$ m/s^2

$m_t = 58$ g $= 0.058$ kg

$m_b = 5.0$ kg

Solution:

a)

$$F = m_t a$$

$$= 0.058 \text{ kg} \times 43 \text{ m/s}^2$$

$$= 2.494 \text{ N or } 2.5 \text{ N}$$

b) Since the mass of the bowling ball is much greater than that of the tennis ball, an identical force will result in a smaller acceleration.
(You can calculate the acceleration.)

$$a = \frac{F}{m_b}$$

$$= \frac{2.5\ \text{N}}{5.0\ \text{kg}}$$

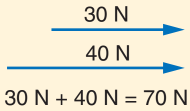
$$= 0.50\ \text{m/s}^2$$

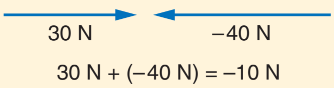
Adding Vectors

A vector is a quantity that has both magnitude and direction. Velocity is a vector. In the previous activity you found that the direction in which an object was traveling and the speed at which it was moving are equally important.

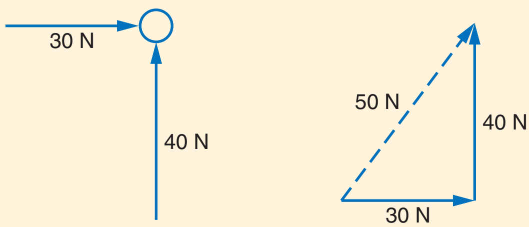
Force is also a vector because you can measure how big it is (its magnitude) and its direction. Acceleration is also a vector. The equation for acceleration reminds you that the force and the acceleration must be in the same direction.

Often, more than one force acts on an object. If the two forces are in the same direction, the sum of the forces is simply the addition of the two forces. A 30-N force by one person and a force of 40 N by a second person (pushing in the same direction) on the same desk provides a 70-N force on the desk. If the two forces are in opposite directions, then you give one of the forces a negative value and add them again. If one student pushes on a desk to the right with a force of 30 N and a second student pushes on the same desk to the left with a force of 40 N, the net force on the desk will be 10 N to the left. Mathematically, you would state that 30 N + (–40 N) = – 10 N where the negative sign denotes "to the left."





Occasionally, the two forces acting on an object are at right angles. For instance, one student may be kicking a soccer ball with a force of 30 N ahead toward the goal, while the second student kicks the same soccer ball with a force of 40 N toward the sideline. To find the net force on the ball and the direction the ball will travel, you must use vector addition. You can do this by using a vector diagram or the Pythagorean Theorem.



In the vector diagram shown above, the two force vectors are shown as arrows acting on the soccer ball. The magnitudes of the vectors are drawn to scale. The 30-N force may be drawn as 3.0 cm and the 40-N force may be drawn as 4.0 cm, if the scale is 10 N = 1 cm. To add the vectors, slide them so that the tip of the 30-N vector can be placed next to the tail of the 40-N vector (tip to tail method). The sum of the two vectors is then drawn from the tail of the 30-N vector to the tip of the 40-N vector. This *resultant* vector is measured and is found to be 5.0 cm, which is equivalent to 50 N. The angle is measured with a protractor and is found to be 53°.

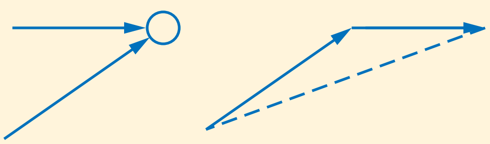
A second method of finding the resultant vector is to recognize that the 30-N and 40-N force vectors form a right triangle. The resultant is the hypotenuse of this triangle. Its length can be found by the Pythagorean Theorem.

$$a^2 + b^2 = c^2$$
$$30\ \text{N}^2 + 40\ \text{N}^2 = c^2$$
$$900\ \text{N}^2 + 1600\ \text{N}^2 = c^2$$
$$c = \sqrt{2500}\ \text{N}^2$$
$$c = 50\ \text{N}$$

The angle can be found by using the tangent function.

$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{40\ \text{N}}{30\ \text{N}} = 1.33$$
$$\theta = 53°$$

Adding vector forces that are not perpendicular is a bit more difficult mathematically, but no more difficult using scale drawings and vector diagrams. Two other players are kicking a soccer ball in the direction shown in the diagram. The resultant vector force can be determined using the tip to tail approach.



The two arrows in the left diagram correspond to the two players kicking the ball at different angles. The diagram at the right shows the two vectors being added "tip to tail." The resultant vector (shown as a dotted line) represents the net force and is the direction of the acceleration of the soccer ball.

Sample Problem 3

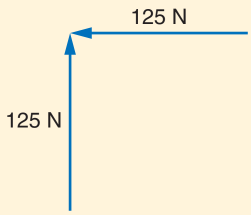
One player applies a force of 125 N in a north direction. Another player pushes with a force of 125 N west. What is the magnitude and direction of the resultant force?

Strategy: Since the forces are acting at right angles, you can use the Pythagorean Theorem to find the resultant force. The direction of the force can be found using the tangent function.

Givens:

$$F_1 = 125\ \text{N}$$
$$F_2 = 125\ \text{N}$$

Solution:



$$F_R^2 = F_1^2 + F_2^2$$
$$F_R = \sqrt{125\ \text{N}^2 + 125\ \text{N}^2}$$
$$= \sqrt{31{,}250\ \text{N}^2}$$
$$= 177\ \text{N}$$
$$\tan\theta = \frac{\text{opposite}}{\text{adjacent}} = \frac{125\,\text{N}}{125\,\text{N}} = 1$$
$$\theta = 45°$$

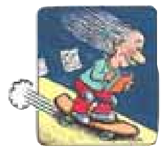
The resultant force is 177 N, 45° west of north.

Reflecting on the Activity and the Challenge

What you learned in this activity really increases the possibilities for interpreting sports events in terms of physics. Now you can explain why accelerations occur in terms of the masses and forces involved. You know that forces produce accelerations. Therefore, if you see an acceleration occur, you know to look for the forces involved. You can apply this to the sport that you will describe.

Also, you can explain, in terms of mass and weight, why gravity has no "favorite" athletes; in every case of free fall in sports, g has the same value, about 10 m/s^2.

Physics To Go



1. Copy and complete the following table using Newton's Second Law of Motion. Be sure to include the unit of measurement for each missing item.

Newton's Second Law:	F =	m ×	a
Sprinter beginning 100-meter dash	?	70 kg	5 m/s^2
Long jumper in flight	800 N	?	10 m/s^2
Shot put ball in flight	70 N	7 kg	?
Ski jumper going down hill before jumping	400 N	?	5 m/s^2
Hockey player "shaving ice" while stopping	−1500 N	100 kg	?
Running back being tackled	?	100 kg	−30 m/s^2

2. The following items refer to the table in **Question 1**:

   a) In which cases in the table does the acceleration match "g," the acceleration due to gravity 10 m/s^2?
   Are the matches to g coincidences or not? Explain.

   b) The force on the hockey player stopping is given in the table as a negative value. Should the player's acceleration also be negative? What do you think it means for a force or an acceleration to be negative?

   c) The acceleration of the running back being tackled also is given as negative. Should the unbalanced force acting on him also be negative? Explain.

d) In your mind, "play" an imagined video clip that illustrates the event represented by each horizontal row of the preceding table. Write a brief voice-over script for each video clip that explains how Newton's Second Law of Motion is operating in the event. Use appropriate physics terms, equations, numbers, and units of measurement in the scripts.

3. What is the acceleration of a 0.30-kg volleyball when a player uses a force of 42 N to spike the ball?

4. What force would be needed to accelerate a 0.040-kg golf ball at 20.0 m/s^2?

5. Most people can throw a baseball farther than a bowling ball, and most people would find it less painful to catch a flying baseball than a bowling ball flying at the same speed as the baseball. Explain these two apparent facts in terms of:
   a) Newton's First Law of Motion.
   b) Newton's Second Law of Motion.

6. Calculate the weight of a new fast-food sandwich that has a mass of 0.1 kg. Think of a clever name for the sandwich that would incorporate its weight.

7. In the United States, people measure body weight in pounds. Write down the weight, in pounds, of a person who is known to you. (This could be your weight or someone else's.)
   a) Convert the person's weight in pounds to the international unit of force, newtons. To do so, use the following conversion equation:
   Weight in newtons = Weight in pounds × 4.38 newtons/pound
   b) Use the person's body weight, in newtons, and the equation
   $$\text{Weight} = mg$$
   to calculate the person's body mass, in kilograms.

8. Imagine a sled (such as a bobsled or luge used in Olympic competitions) sliding down a 45° slope of extremely slippery ice. Assume there is no friction or air resistance (not really possible). Even under such ideal conditions, it is a fact that gravity could cause the sled to accelerate at a maximum of only 7.1 m/s^2. Why would the "ideal" acceleration of the sled not be g, 10 m/s^2? Your answer is expected only to suggest reasons why, on a 45° hill, the ideal free fall acceleration is "diluted" from 10 m/s^2 to about 7 m/s^2; you are not expected to give a complete explanation of why the "dilution" occurs.

9. If you were doing the voice-over for a tug-of-war, how would you explain what was happening? Write a few sentences as if you were the science narrator of that athletic event.
10. You throw a ball. When the ball is many meters away from you, is the force of your hand still acting on the ball?
11. Carlo and Sara push on a desk in the same direction. Carlo pushes with a force of 50 N, and Sara pushes with a force of 40 N. What is the total resultant force acting on the desk?
12. A car is stuck in the mud. Four adults each push on the back of the car with a force of 200 N. What is the total force on the car?
13. During a football game, two players try to tackle another player. One player applies a force of 50.0 N to the east. A second player applies a force of 120.0 N to the north. What is the total applied force? (Since force is a vector, you must give both the magnitude and direction of the force.)
14. In auto racing, a crash occurs. A red car hits a blue car from the front with a force of 4000 N. A yellow car also hits the blue car from the side with a force of 5000 N. What is the total force on the blue car? (Since force is a vector, you must give both the magnitude and direction of the force.)
15. A baseball player throws a ball. While the 700.0-g ball is in the pitcher's hand, there is a force of 125 N on it. What is the acceleration of the ball?
16. If the acceleration due to gravity at the surface of the Earth is approximately 9.8 m/s^2, what force does the gravitational attraction of the Earth exert on a 12.8-kg object?
17. A force of 30.0 N acts on an object. At right angles to this force, another force of 40.0 N acts on the same object.
    a) What is the net force on the object?
    b) What acceleration would this give a 5.6-kg wagon?
18. Bob exerts a 30.0 N force to the left on a box (m = 100.0 kg). Carol exerts a 20.0 N force on the same box, perpendicular to Bob's.
    a) What is the net force on the box?
    b) Determine the acceleration of the box.
    c) At what rate would the box accelerate if both forces were to the left?