Reflect

Look at the picture of people running across a field. What words come to mind? Maybe you think about the word speed to describe how fast the people are running. You might think of the word acceleration to describe the way in which the runners gain speed. Some people might even use the word velocity to explain the direction in which the people are running.

But, what do these words actually mean? They all relate to motion, but what is the difference between speed, acceleration, and velocity?

Frame of Reference

When discussing terms that relate to motion, it is important to begin by discussing what is called a frame of reference. Motion describes a change in an object's position, direction, or location. Speed, velocity, and acceleration all describe the motion of an object relative to some other point. This point is the frame of reference.

When looking at a passing train from the window of another train, it is hard to tell which train is moving unless you have a frame of reference.

For example, suppose you are sitting in a motionless vehicle and looking out the window at another motionless vehicle. One of the vehicles starts to move, and for an instant, you cannot tell which vehicle is moving. The experience is especially confusing in the case of side-by-side trains. You might resolve the confusion by looking across to the windows on the other side of the train car and seeing the train station. In this situation, the train station is the frame of reference.

Without a frame of reference, it is impossible to determine which of two objects is moving. They are simply moving relative to each other. In general, our frame of reference is Earth's surface. If you are sitting in a chair, you are motionless because Earth's surface is motionless. But, what happens if you choose the solar system as your frame of reference? Now, you are traveling in orbits around Earth's axis as you travel around the Sun in a larger orbit.

Reflect

Speed

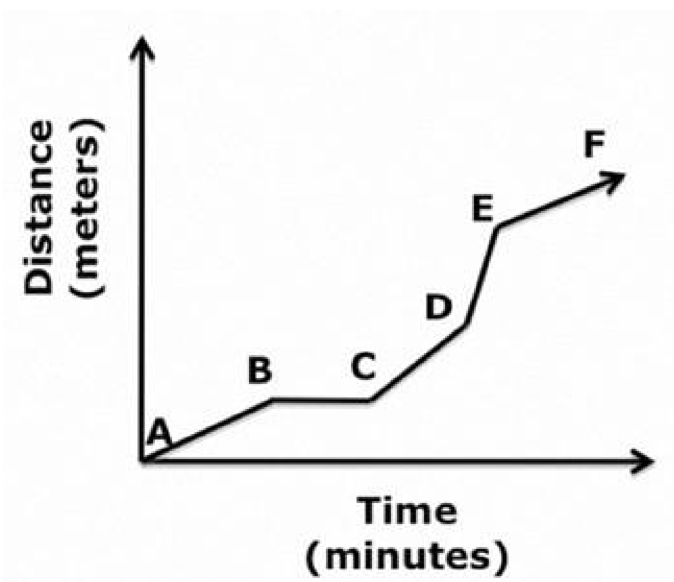
Speed is used to measure how fast an object moves. It is calculated by the distance an object travels divided by the time it takes the object to travel that distance. The formula for speed is $s = d/t$, where s represents speed, d represents distance, and t represents time.

In the United States, speed is usually measured in miles per hour (mph) or feet per second (ft/s.) The "/" symbol represents the word "per." For scientific purposes, we will use metric units for distance: meters (m) and kilometers (km.) For perspective, 1 m/s = 2.24 mph, and 1 km/hr = 0.62 mph.

Motion often occurs at varying speeds. In these situations, average speed can be calculated if the distance traveled and the time elapsed are known. Suppose you rode in a car across town in stop-and-go traffic. The distance traveled was 40 km, and the trip took 2 hr. The average speed of the car was 40 km divided by 2 hr, or 20 km/hr.

Average speed of car = distance/time
= 40 km/2 hr
= 20 km/hr

Graphs are often used to represent speed. Distance is typically plotted on the y-axis and time is plotted on the x-axis. The steeper the line on the graph, the greater the speed of the object. A horizontal line represents an object that has stopped moving since its distance on the graph does not change. Take a look at the graph below. It represents the speed of a car traveling through a city. The steepest part of the line is between points D and E. This represents the time at which the car was moving at the greatest speed.

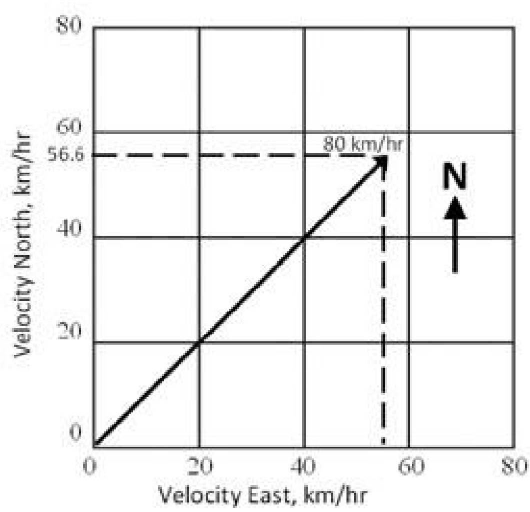


What Do You Think?

If a car is moving at a constant speed of 100 km/hr, how far does the car travel each hour? If the car moves for three hours, what is the total distance it will travel? You can check your answers on the next page.

Velocity

Velocity is measured in the same units as speed, but the direction of motion is also given. Direction may be described, for example, as north, south, east, west, left, or right. Velocity is said to be a vector quantity, meaning both magnitude (distance from one point to another) and direction are specified. Speed is said to be a scalar quantity, meaning it is a number with no indication of direction. An arrow on a grid often represents a vector quantity. The length of the arrow indicates the magnitude, and the point of the arrow shows the direction; the vector on the graph on the right shows that a car is traveling northeast at 80 km/hr.



Look Out!

If the speed of a moving object changes, its velocity also changes. The reverse statement, however, is *not* true. Velocity can change while speed remains unchanged. This is true because a change in direction at constant speed is a change in velocity. A car turning a corner at constant speed is changing its velocity.

Acceleration

Acceleration is the rate of velocity change during a certain period of time. Since the unit for velocity has time in the denominator (m/s for example), and velocity is divided by units of time (s for example) to calculate acceleration, the unit of time is given in the denominator twice. So, the units for acceleration are m/s^2, which is stated as “meters per second per second” or “meters per second squared.” In everyday usage, acceleration is usually thought of as change in speed. However, it is important to remember that acceleration is change in velocity. So, even if an object is moving at a constant speed, if it changes direction, the object is accelerating.

Most people think of acceleration as an increase in speed. However, slowing down is also considered acceleration. In everyday terms, this is called *deceleration,* but the scientific term is *negative* acceleration. An object traveling in a perfect circle at constant speed has uniform acceleration, called *radial acceleration*. The object is constantly changing direction as it travels around and around.

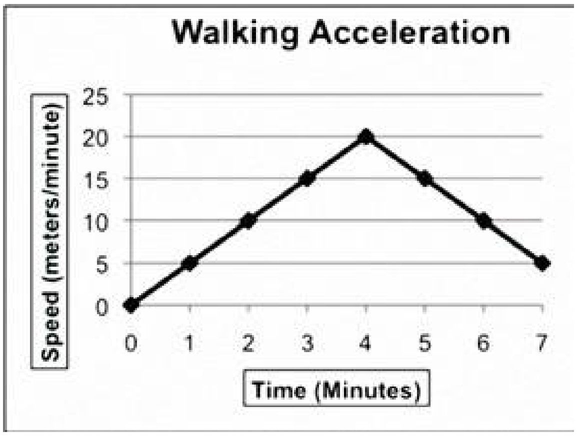
Look Out!

Acceleration can be calculated if the change in velocity and time for the velocity to change are known. For example, if a car moving south accelerates from 25 m/s to 50 m/s over a time of 10 seconds, the change in velocity is 25 m/s (50 m/s – 25 m/s) and the time period is 10 seconds. Divide 25 m/s by 10 s, and the acceleration of the car is 2.5 m/s^2.

Acceleration of car = change in velocity/ time period of velocity change
= (50 m/s – 25 m/s) / 10 s
= 25 m/s / 10s
= 2.5 m/s^2 south

What Do You Think?

The graph on the right shows the acceleration of a student as she walked home from soccer practice. During which time frame did the student travel with positive acceleration? When did she travel with negative acceleration? You can check your answer at the bottom of this page.



Getting Technical: Escape Velocity

Rockets were invented long before the first satellite was launched into space. Why was this the case? The answer has to do with escape velocity, which refers to the minimum velocity an object must reach before it can break free of Earth's gravitational pull. An object traveling at escape velocity can orbit Earth at the same velocity or head off into space.

Escape velocity for Earth is approximately 11,100 m/s (25,000 mph) in a direction away from Earth's surface. This means that an object, like a rocket, must move away from Earth's surface at a velocity of at least 11,100 m/s in order to travel into space. The main factor that postponed space exploration was the amount of time it took to develop a rocket that could exert enough force to accelerate an object to such an enormous velocity. In 1959, the Russian satellite, Luna 1, was the first object made by humans to attain escape velocity. This was the beginning of the space age!

This stamp commemorates Luna 1, the first human-made object to reach escape velocity.

What Do You Think?

Check your answers to the previous problems:

1. A car moving at a constant speed of 100 km/hr (km per hr) travels 100 kilometers each hour. In 3 hours, the car will have traveled 100 km/hr × 3 hr = 300 km.
2. The student traveled with positive acceleration from 0–4 min; during this interval, her speed continually increased. The student traveled with negative acceleration from 4–7 min; during this interval, her speed continually decreased.

What do you know?

The chart below lists examples of different types of motion. Choose one of the following terms that **best** describes each example. Note there may be more than one possible answer, but you may only use each word once:

3. Negative acceleration
4. Velocity
5. Average speed
6. Constant speed

Motion	Matching Description
A truck traveled southward on a road at 60 km/hr.	
A student rode her bike to a friend's house. She traveled 30 meters in 5 minutes and stopped one time along the way.	
A dog ran at a speed of 5 m/s for 5 min. Then, the dog changed its speed to 3 m/s.	
A car traveled at the same speed of 110 km/hr around an oval track.	

Connecting With Your Child

Design a Velocity Experiment

To help your child learn more about speed, velocity, and acceleration, work together to design an experiment that can be used to test factors that affect an object's velocity.

Begin by brainstorming ideas for the experiment, focusing on everyday equipment you can use. Develop a question that you and your child will attempt to answer. Suggestions include, "How does the mass of a toy car affect its velocity?" or "How does the surface of a ramp affect the velocity of a rubber ball?"

Once you have decided on a question, make a list of materials needed and have your child make a prediction. For example, if you are going to test the effect of mass on velocity, your child should predict how greater mass will affect velocity.

Next, gather the materials and set up the experiment. Make sure you are only changing one variable in your experiment. For instance, if you are testing the effect of mass on velocity by using toy cars and a ramp, make sure that the only thing you change in the experiment is the mass of the car. Keep the ramp and all other factors the same. If possible, conduct multiple trials, and find the average velocity for each mass you test.

Once you have completed the experiment, have your child write a conclusion, such as, "Objects with greater mass move with greater velocity."

Here are some questions to discuss with students after the experiment:

1. How did you calculate the velocity of the objects in your experiment?
2. What other factors could you test to determine their affect on velocity?
3. How might these kinds of experiments with velocity be useful to engineers and other scientists?