TOPIC 14

Force and Motion

14-1 Displacement and Velocity

Key Concepts

- What is needed to describe motion completely?
- How are distance and displacement related?
- How are average speed and instantaneous speed different?
- How can you determine speed using a distance-time graph?

Key Terms

• frame of reference • relative motion • displacement • vector • speed • average speed • instantaneous speed • velocity

DEFINE

frame of reference _____

relative motion _____

displacement _____

vector _____

An object is in motion when its distance from another object is changing. However, all motion is relative. For example, as a train moves past a platform, people on the platform see those on the train speeding by. When the people on the train look at each other, they do not seem to be moving at all.

Relative Motion **To describe motion accurately and completely, a frame of reference is needed.** A **frame of reference** can be described as a system of objects that are not moving with respect to one another. **Relative motion** is movement in relation to a frame of reference. Choosing a proper frame of reference allows you to describe motion in a meaningful manner.

Distance and Displacement When an object moves in a straight line, the distance is the length of the line. On the other hand, **displacement** is the length and direction of the line from the starting point to the ending point. **Displacement gives information both about how far and in what direction an object moves from a starting point.** Displacement is an example of a vector. A **vector** is a quantity that has magnitude and direction. Distance is the magnitude of displacement.

Vector addition involves combining vector magnitudes and directions. When displacements represented by two vectors have the same direction, the resultant vector is simply the sum of the displacement magnitudes. If two displacements are in opposite directions, the magnitudes are subtracted from each other. When two or more displacement vectors have different directions, their resultant may be determined by graphing the vectors.

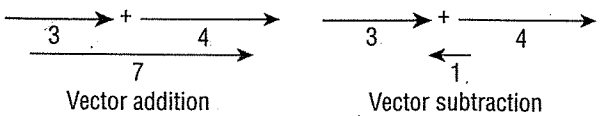

Figure 14-1
Vector math

Speed and Velocity Speed is the ratio of the distance an object moves to the amount of time it is moving. Typically, there are two ways to describe the speed of an object: average speed and instantaneous speed.

Average speed is the total distance traveled divided by the entire time that it takes to travel that distance. During the time an object is moving, its speed may change, but this equation tells you the average speed over the entire trip. By contrast, **instantaneous speed** is the rate at which an object is moving at a given moment in time. **Average speed is computed for the entire time of a trip, and instantaneous speed is measured at a particular instant.**

$$\text{average speed} = \frac{\text{total distance}}{\text{total time}}$$

Velocity is a vector that indicates the speed and direction in which an object is moving. Sometimes the motion of an object involves two or more directions relative to a reference point. For example, an airplane that is lifting off from the runway has both an upward velocity and a forward velocity. As with displacement, velocity vectors can be combined using vector addition.

Graphing Motion A distance-time graph is a good way to describe motion. On a line graph, the slope is the change in the vertical axis value divided by the change in the horizontal axis value. **The slope of a line on a distance-time graph is speed, or the distance moved from the start point to the end point divided by the amount of time it takes.**

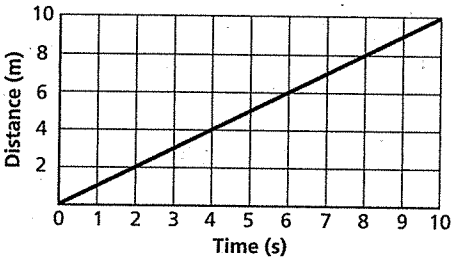

Figure 14-2
The slope of the distance-time graph is speed.

DEFINE

speed _____

average speed _____

instantaneous speed _____

velocity _____

Section 14-1 Assessment

1. ***Applying Concepts*** Suppose you are riding in a car, and the highway is parallel to a railroad. The car is passing alongside a train. Why is the train a poor frame of reference by which to determine the motion of the car? Explain your answer.

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2. ***Problem Solving*** You begin walking at a speed of 4 kilometers per hour (km/h) for 1 hour. You rest for 0.5 hour, then resume walking at 4 km/h for another 0.5 hour. What is your average speed?

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14-2 Acceleration and Force

Key Concepts

- How are changes in velocity described?
- How is average acceleration calculated?
- How do forces affect the motion of an object?
- What is the difference between balanced forces and unbalanced forces?

Key Terms

• acceleration • free fall • constant acceleration • force • friction • gravity • projectile motion

The velocity of an object can change due to a change in speed, a change in direction, or both. The rate at which velocity changes is called **acceleration**. Like velocity, acceleration is a vector.

Acceleration Acceleration applies to any change in an object's velocity. It can be caused by an increase in speed (positive change) or by a decrease in speed (negative change). **Free fall** is the movement of an object toward Earth solely because of gravity. Near Earth's surface, the acceleration due to gravity is 9.8 meters per second per second or meters per second squared (m/s^2).

However, acceleration isn't always the result of changes in speed. A horse on a carousel is traveling at a constant speed, but it is accelerating because its direction is constantly changing. It is moving in a circle. Sometimes acceleration is characterized by changes in both speed and direction, such as when the spin of a carousel increases in speed.

The velocity of an object moving in a straight line changes at a constant rate when the object is experiencing a constant acceleration. **Constant acceleration** is a steady change in velocity. **Average acceleration for straight-line motion is calculated by dividing the change in velocity by the total time.**

$$\text{acceleration} = \frac{\text{final velocity} - \text{initial velocity}}{\text{total time}}, \text{ or } a = \frac{v_f - v_i}{t}$$

Notice in this equation that if velocity increases, the numerator is positive, and so acceleration is positive. If velocity decreases, then the numerator is negative, and so acceleration is negative.

You can use a graph to calculate constant acceleration. The slope of a line in speed-time graph, in which the speed of an object is plotted against time, is acceleration. This same motion, when plotted on a distance-time graph, appears as a curved line.

Force A force is a push or a pull that acts on an object. **A force can cause a resting object to accelerate, or it can accelerate a moving object by changing the object's speed, direction, or both.** Force is measured in newtons (N). One newton is the force that causes a mass of 1 kilogram (kg) to accelerate at a rate of 1 m/s^2.

DEFINE

acceleration _____

free fall _____

constant acceleration _____

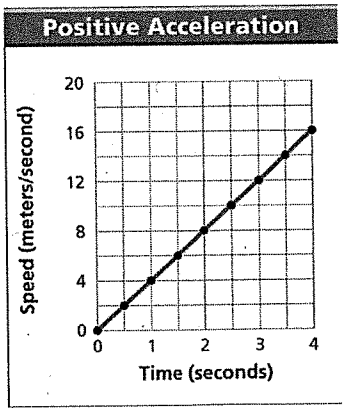

Figure 14-3
The slope of a speed-time graph is acceleration.

Force is a vector. Thus, forces in the same direction add together, while forces in opposite directions are subtracted from one another. The net force is the overall force acting on an object. Balanced forces are forces that combine to produce a net force of zero. Unbalanced forces result in a net force that is not equal to zero acting on the object. **When the forces on an object are balanced, there is no change in the object's motion, whereas unbalanced forces acting on an object cause the object to accelerate.**

Friction and Gravity **Friction** is a force that opposes the motion of objects that touch as they move relative to each other. Friction acts at the surface where the objects are in contact. Static friction is the frictional force that acts on an object that is not moving. Sliding friction is a force that opposes the motion of an object as it slides over a surface. Rolling friction is the frictional force that works on rolling objects. Fluid friction is the frictional force that opposes the motion of an object through a fluid, such as water or air.

Gravity is an attractive force that acts between any two masses. The gravitational attraction of Earth's mass on other objects near Earth's surface causes free fall. Both gravity and the fluid friction of air affect the motion of a falling object. Gravity causes an object to accelerate downward, but the fluid friction of air acts in the direction opposite the downward motion, making the net acceleration smaller. Terminal velocity is the constant velocity of a falling object when the forces of gravitation and air friction are balanced.

Projectile motion is the curved path of an object through the air. It is a combination of horizontal motion and vertical motion. The horizontal motion is at constant velocity. However, the vertical motion undergoes constant acceleration due to gravity, so the vertical component of velocity is always changing. This accounts for the curved path of all projectile motion.

DEFINE

force _____

friction _____

gravity _____

projectile motion _____

Section 14-2 Assessment

1. ***Classifying*** What are three ways in which velocity can be changed?

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2. ***Calculating*** What is the average acceleration of a train if its initial velocity is 45 m/s in the forward direction and its final velocity 10 s later is 25 m/s in the forward direction?

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3. ***Applying Concepts*** How does the force causing the acceleration in the previous question affect the motion of the train?

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_____

14-3 Laws of Motion

Key Concepts

- What is Newton's first law of motion?
- What is Newton's second law of motion?
- What is Newton's third law of motion?
- How is momentum conserved?

Key Terms

• inertia • mass • weight • momentum
• gravitational force • centripetal force

The Italian scientist Galileo Galilei concluded that moving objects not subjected to friction or any other force would continue to move indefinitely. The English scientist Isaac Newton summarized Galileo's observations about force and motion in the three laws of motion.

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inertia _____

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mass _____

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weight _____

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Newton's Laws of Motion **According to Newton's first law of motion, the state of motion of an object does not change as long as the net force acting on the object is zero.** Thus, unless unbalanced forces act on an object, it stays at rest if it is already at rest, or it stays in motion with the same speed and direction if it is already in motion. Newton's first law of motion is sometimes called the law of inertia. **Inertia** is the tendency of an object to resist a change in its motion.

According to Newton's second law of motion, the acceleration of an object is equal to the net force acting on it divided by the object's mass. A net force causes an object's velocity to change, so that the object accelerates. The acceleration of an object caused by the net force also depends on the object's mass. **Mass** is the amount of matter the object contains.

$$\text{acceleration} = \frac{\text{net force}}{\text{mass}}, \text{ or } a = \frac{F}{m}$$

Force and acceleration are vectors, therefore the acceleration of an object is always in the same direction as the net force.

A special case of Newton's second law occurs when acceleration is due to gravity. For objects at a given distance from massive objects, such as Earth, the force of gravity on the object is its **weight**.

According to Newton's third law of motion, whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object. The two forces are called action and reaction forces. Note that these two forces do not act on the same object, so that even though the forces are equal, the acceleration of each object depends on its mass. This is why, when you jump upward from Earth's surface, the Earth appears not to move. The mass of Earth is so much greater than your mass that the acceleration on it is infinitesimally small. Your mass is small enough, however, that the equal and opposite force from the one that you exert on Earth is able to accelerate you upward over a measurable distance.

Momentum and Momentum Conservation Momentum is the product of an object's mass and its velocity. Because changing the momentum of an object involves changing its motion, the greater the momentum that an object has, the harder it is to stop.

Momentum is calculated by multiplying an object's mass (in kilograms) and its velocity (in meters per second). The units for momentum are kilogram-meters per second (kg•m/s).

$$\text{momentum} = \text{mass} \times \text{velocity, or } p = m \times v$$

Under certain conditions, collisions of objects obey the principle of conservation of momentum, which means that the total momentum of objects before a collision occurs is equal to the total momentum of the objects after the collision. Momentum is conserved when no external net force acts on the objects. **In the absence of unbalanced applied forces, the loss of momentum of one object equals the gain in momentum of the other object when the objects collide, so that momentum is conserved.**

Gravitation Gravity is the weakest of the fundamental universal forces, which include the strong and weak nuclear forces and the electromagnetic force. **Gravitational force** is an attractive force that acts between any two masses. Newton's law of universal gravitation states that every object in the universe attracts every other object. The gravitational force between two objects is proportional to their masses. The greater the mass of either object, the greater the gravitational force is between them. Gravitational force decreases with the square of the distance between objects. If the distance between two masses is doubled, the strength of the gravitational force decreases by a fourth.

Gravity keeps the moon in orbit around Earth and the planets in orbit around the Sun by acting as a type of centripetal force. A **centripetal force** is a center-directed force that continuously changes the direction of an object to make it move along a circular path. The friction that holds a car in a circular path on a curve also acts as a centripetal force.

DEFINE
momentum _____
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gravitational force _____
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_____
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centripetal force _____
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_____

Section 14-3 Assessment

1. ***Observing*** Suppose you release a stone from a ledge. What will you observe that makes you think that an unbalanced force is acting on the stone?

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2. ***Classifying*** What is a necessary condition for the conservation of momentum?

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