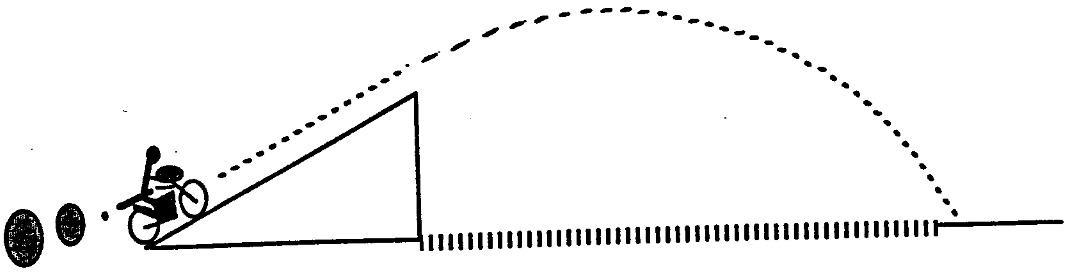
# I. KINEMATICS KIT



# CONSTRUCTING MOTION DIAGRAMS FOR LINEAR MOTION

When first applying kinematic (motion) principles there is a tendency to use the wrong kinematic quantity—to inappropriately interchange quantities such as position, velocity, and acceleration. Constructing a motion diagram should reduce this confusion and should provide a better intuitive understanding of the meaning of these quantities.

A motion diagram represents the position, velocity, and acceleration of an object at several different times. The times are usually separated by equal time intervals. At each position, the object's velocity and acceleration are represented by arrows. If the acceleration is constant throughout the motion, one arrow can represent the acceleration at all positions shown on the diagram.

The motion diagrams for three common types of linear motion are described below.

**Constant Velocity:** The first motion diagram, shown in Fig. 1.3, is for an object moving at a constant speed toward the right. The motion diagram might represent the changing position of a car moving at constant speed along a straight highway. Each dot indicates the position of the object at a different time. The times are separated by equal time intervals. Because the object moves at a constant speed, the displacements from one dot to the next are of equal length. The velocity of the object at each position is represented by an arrow with the symbol $\vec{v}$ under it. The velocity arrows are of equal length (the velocity is constant). *The acceleration is zero because the velocity does not change*.

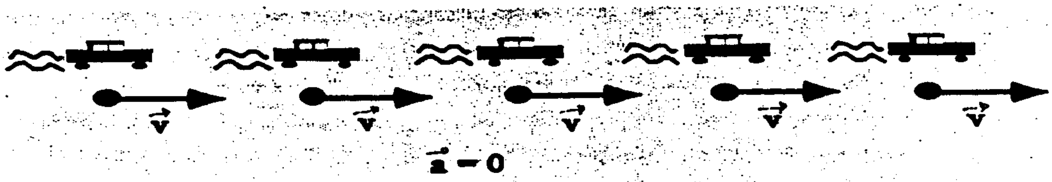



**Fig. 1.3** The motion diagram for an object moving with a constant velocity. The acceleration is zero because the velocity is not changing.

**Constant Acceleration in the Direction of Motion:** The motion diagram in Fig. 1.4 represents an object that undergoes constant acceleration toward the right in the same direction as the initial velocity. This occurs when your car accelerates to pass another car or when a race car accelerates (speeds up) while traveling along the track. Once again the dots represent schematically the positions of the object at times separated by equal time intervals $\Delta t$. Because the object accelerates toward the right, its velocity arrows increase in length toward the right as time passes. The product $\vec{a}(\Delta t) = \Delta\vec{v}$ represents the increase in length (the increase in speed) of the velocity arrow in each time interval $\Delta t$. The displacement between adjacent positions increases as the object moves right because the object moves faster as it travels right.

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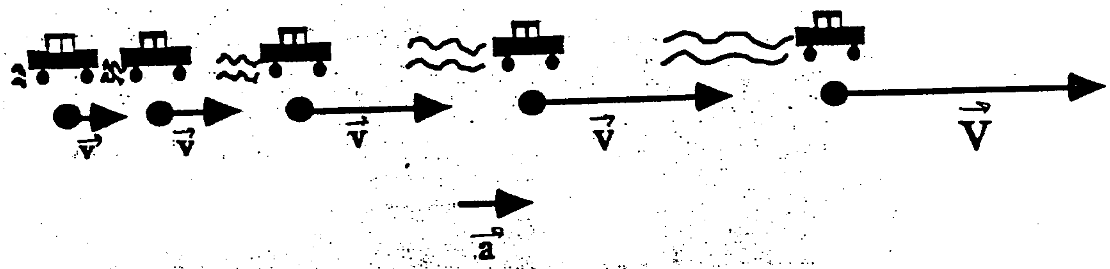




Fig. 1.4 A motion map for an object that is accelerating in the direction of its velocity. The velocity increases as time progresses.

**Constant Acceleration Opposite the Direction of Motion:** The motion diagram in Fig. 1.5 represents an object that undergoes constant acceleration opposite the direction of the initial velocity / to
(this is sometimes called deceleration—a slowing of the motion). For this case the acceleration
/to arrow points left, opposite the direction of motion. This type of motion occurs when a car skids to /can
a stop. The dots represent schematically the positions of the object at equal time intervals. Because
the acceleration points left opposite the motion, the object's velocity arrows decrease by the same //lengths the
amount from one position to the next. We are now subtracting $\Delta\vec{v} = \vec{a}(\Delta t)$ from the velocity during each time interval $\Delta t$. Because the object moves slower as it travels right, the displacment between adjacent positions decreases as the object moves right.

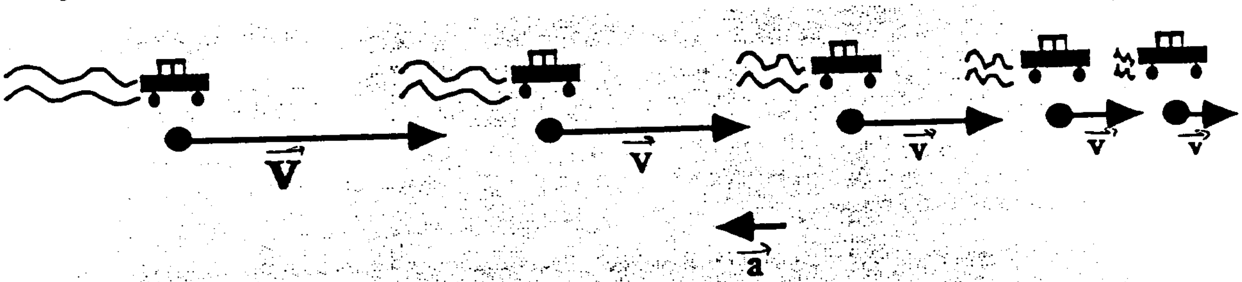
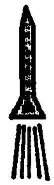




Fig. 1.5 A motion diagram for an object whose acceleration points opposite the velocity. The magnitude of the velocity decreases as time progresses.

You should become so familiar with these motion diagrams that you can read a linear-motion problem and draw a reasonable diagram that represents the motion described in the problem. When you complete the mathematical solution to a kinematic problem later in the semester, you can see if your answer is consistent with the motion diagram.

# Motion Diagrams—1

| (a) Construct a motion diagram for a car traveling toward the left at decreasing speed.  | (b) Construct a motion diagram for a bottle rocket whose burning fuel causes it to move vertically upward at increasing speed.  | (c) Construct a motion diagram for the bottle rocket described in (b) after its fuel is burned and while it still moves upward but now at decreasing speed.  |
|---|---|---|
| | | |
| | Save spaces below for answers. | |

# Motion Diagrams—2

Construct a motion diagram for a skier moving at decreasing speed up an incline.

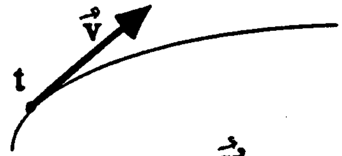
Construct a motion diagram for a car moving at increasing speed down an incline.

A block sits on a compressed spring. When the spring is released, the block is first pushed upward at increasing speed. After the block leaves contact with the spring, it moves upward at decreasing speed. Construct a motion diagram for the block's trip. (You will need two diagrams, one for each part of the trip.)

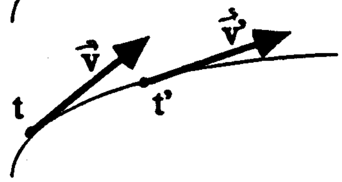
Use the space below the line for the answer.

# GRAPHICALLY SUBTRACTING $\vec{v}$'s TO FIND DIRECTION OF $\vec{a}$

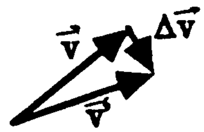
The direction of an object's acceleration at some arbitrary time $t$ can be determined if we know its velocity at two different times separated by a short time interval $\Delta t$. The procedure is outlined and illustrated below.



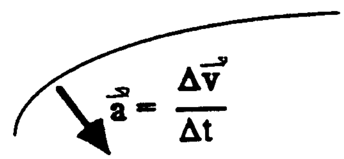

**Original velocity:** Draw an arrow representing the velocity $\vec{v}$ of the object at time $t$.




**New velocity:** Draw another arrow representing the velocity $\vec{v}'$ of the object a short time interval $\Delta t$ later at time $t'$.



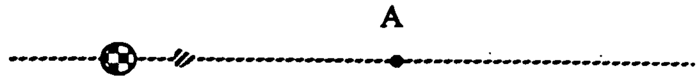

**Velocity change:** To find the change in velocity $\Delta\vec{v}$ during the time interval $\Delta t$, place the tails of $\vec{v}$ and $\vec{v}'$ together. The change in velocity $\Delta\vec{v}$ is a vector that points from the head of $\vec{v}$ to the head of $\vec{v}'$. Notice in the figure at the right that $\vec{v} + \Delta\vec{v} = \vec{v}'$ or rearranging, $\Delta\vec{v} = \vec{v}' - \vec{v}$ (that is, $\Delta\vec{v}$ is the change in velocity).




**Acceleration:** The acceleration equals the velocity change $\Delta\vec{v}$ divided by the time interval $\Delta t$ needed for that change; that is, $\vec{a} = \Delta\vec{v}/\Delta t$. If you do not know the time interval, you can at least determine the direction of the acceleration because it points in the same direction as $\Delta\vec{v}$.

# Graphically Subtracting v's to find direction of a—1

A ball moves with decreasing speed toward the right along a straight line. Determine the direction of the ball's acceleration when at position A.




**Earlier velocity:** Draw an arrow representing the velocity $\vec{v}$ of the ball at a time t when the position of the ball is just before A.

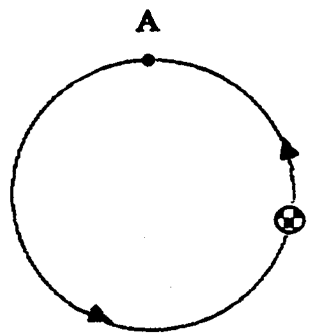

**Later velocity:** Draw an arrow representing the velocity $\vec{v}'$ of the ball at a time t' when the position of the ball is just after A

**Velocity Change:** Subtract the two velocity vectors to find the change in velocity $\Delta\vec{v} = \vec{v}' - \vec{v}$. To find the change in velocity $\Delta\vec{v}$ during the time interval $\Delta t = t' - t$, place the tails of $\vec{v}$ and $\vec{v}'$ together. Then, $\Delta\vec{v}$ is a vector that points from the head of **v** to the head of $\vec{v}'$.

**Acceleration:** The acceleration equals the velocity change $\Delta\vec{v}$ divided by the time interval $\Delta t$ needed for that change—that is, $\vec{a} = \Delta\vec{v}/\Delta t$. In this example we do not know the time interval. However, you can determine the direction of the acceleration since it points in the same direction as $\Delta\vec{v}$.

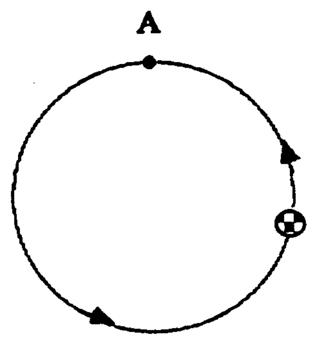
# Graphically Subtracting v's to find a—2

A ball moves at a constant speed in a counter-clockwise direction along a circular path. Determine the direction of the ball's acceleration when at position A. The direction of the velocity at each point along the circle is tangent to the circle.




**Earlier velocity:** Draw an arrow representing the velocity $\vec{v}$ of the ball at a time t when the position of the ball is just before A.

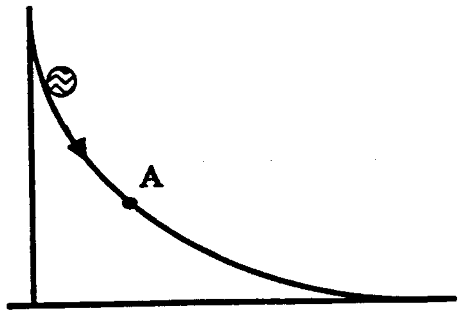
**Later velocity:** Draw an arrow representing the velocity $\vec{v}'$ of the ball at a time t' when the position of the ball is just after A




**Velocity Change:** Subtract the two velocity vectors to find the change in velocity $\Delta\vec{v} = \vec{v}' - \vec{v}$ during the time interval $\Delta t = t' - t$. To do this, place the tails of $\vec{v}$ and $\vec{v}'$ together. Then, $\Delta\vec{v}$ is a vector that points from the head of $\vec{v}$ to the head of $\vec{v}'$.

**Acceleration:** The acceleration equals the velocity change $\Delta\vec{v}$ divided by the time interval $\Delta t$ needed for that change—that is, $\vec{a} = \Delta\vec{v}/\Delta t$. In this example we do not know the time interval. However, you can determine the direction of the acceleration since it points in the same direction as $\Delta\vec{v}$.

A marble passes point A as it rolls along the slide with increasing speed (see sketch at right). Determine the direction of the marble's acceleration when at position A. The direction of the velocity at each point along the slide is tangent to the slide.




**Earlier Velocity:** Draw an arrow representing the velocity $\vec{v}$ of the marble at time $t$ when at a position just above point A on the slide.

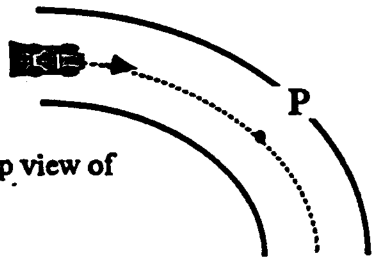
**Later Velocity:** Draw another arrow representing the velocity $\vec{v}'$ of the marble at time $t'$ when at a position just below point A.

**Velocity Change:** Subtract the two velocity vectors to find the change in velocity $\Delta\vec{v} = \vec{v}' - \vec{v}$ during the time interval $\Delta t = t' - t$. To do this, place the tails of $\vec{v}$ and $\vec{v}'$ together. Then, $\Delta\vec{v}$ is a vector that points from the head of $\vec{v}$ to the head of $\vec{v}'$.

**Acceleration:** The acceleration equals the velocity change $\Delta\vec{v}$ divided by the time interval $\Delta t$ needed for that change—that is, $\vec{a} = \Delta\vec{v}/\Delta t$. In this example we do not know the time interval. However, you can determine the direction of the acceleration since it points in the same direction as $\Delta\vec{v}$.

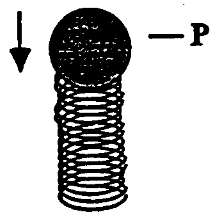
# Graphically Subtracting v's to find a—4

A car travels with decreasing speed along a horizontal, curved road. Determine the acceleration at point P .




(top view of

A large mass is attached to an oscillating spring. Determine the acceleration of the mass at point P when it is moving downward with decreasing speed.

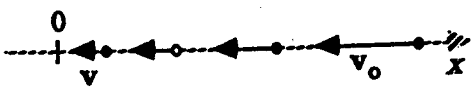



A ball is thrown vertically upward. Determine the acceleration of the ball at it's highest point.

Leave space below line vacant for comments about solution.

# Signs of Kinematic Quantities

A motion diagram that represents the motion of a car is shown below. Determine the sign (+, 0, or –) of the position, velocity, and acceleration of the car at the position of the open circle.




Position: + , 0 , –

Explain:

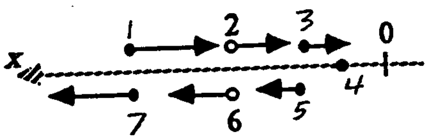
Velocity: + , 0 , –

Explain:

Acceleration: + , 0 , –

Explain:

A motion diagram that represents the motion of a ball is shown below. Determine the sign (+, 0, or –) of the position, velocity, and acceleration of the ball at the positions of each open circle. Determine the signs of the displacement and change in velocity as the ball moves from position two to position six.




Position Two: + , 0 , –

Position Six: + , 0 , –

Velocity Two: + , 0 , –

Velocity Six : + , 0 , –

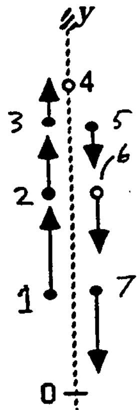
Acceleration Two: + , 0 , –

Acceleration Six: + , 0 , –

Displacement 2 → 6: + , 0 , –

Velocity Change 2 → 6: + , 0 , –

A motion diagram that represents the motion of a ball is shown below. Determine the sign (+, 0, or –) of the position, velocity, and acceleration of the ball at the positions of each open circle. Determine the signs of the displacement and change in velocity as the ball moves from position four to position six.




Position Four: + , 0 , –

Position Six: + , 0 , –

Velocity Four: + , 0 , –

Velocity Six + , 0 , –

Acceleration Four: + , 0 , –

Acceleration Six: + , 0 , –

Displacement 4 → 6: + , 0 , –

Velocity Change 4 → 6: + , 0 , –

Save space below for comments about the answers.

## CONSTRUCTING A PICTORIAL REPRESENTATION OF A PROBLEM

Most students that have trouble with physics say that they understand the material but do not know how to get started on a problem. Constructing a pictorial representation that clearly and explicitly identifies its individual parts is the way experienced physicists start most problems, and the way we hope you will learn to start solving physics problems.

To construct this representation, picture yourself in the situation described in the problem. Try to recreate the sequence of events that occurs. As you recreate the problem in you mind, make a sketch that indicates on paper the major steps in the process. In dynamics, the problem is usually divided into parts separated by instants at which the acceleration changes. These are instants when the forces acting on an object change abruptly. For example, the forces on a golf ball sitting on a tee change abruptly at the instant the club first contacts the ball. The forces change again when the ball leaves contact with the club—the ball is now a projectile.

Each part of the problem involves a description of the motion while the acceleration is approximately constant. The next part of the problem starts when the acceleration has changed because forces acting on the object have changed. (In the real world, the acceleration changes in a continuous fashion and not abruptly from one value to another.)

Some problems involve two objects that move either together or move independently. Just as the characteristics of two people are described differently, the characteristics of these objects must be described separately. Different symbols are used to indicate the position, velocity, acceleration, mass and other properties of each object.

Consider an example of constructing a pictorial representation for a problem that is broken in two distinct parts.

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**EXAMPLE 5.2** A person in a car traveling at a constant 16-m/s speed (35 mi/h) on a through street suddenly sees a truck in front that has entered from a side street and that now blocks the car's path. What is the shortest stopping distance for the car assuming the reaction time of the driver is 0.75 s. The car's maximum acceleration is 6.0 m/s². Construct a pictorial model for the problem but do not solve it.

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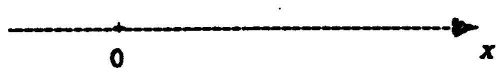
**SOLUTION** Think about the situation described in the problem. Picture yourself in the driver's seat and try to recreate in slow motion the complete sequence of events that occurs. Turn these thoughts into a sketch on paper. Start the pictorial representation by placing a coordinate axis with an origin on a sheet of paper (sometimes two perpendicular axes are needed).

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