Chapter 1. Concepts of Motion

The universe we live in is one of change and motion. Although we all have intuition about motion, based on our experiences, some of the important aspects of motion turn out to be rather subtle.

Chapter Goal: To introduce the fundamental concepts of motion.

Chapter 1. Concepts of Motion

Topics:

- Motion Diagrams
- The Particle Model
- Position and Time
- Velocity
- Linear Acceleration
- Motion in One Dimension
- Solving Problems in Physics
- Units and Significant Figures

Chapter 1. Reading Quizzes

What is a "particle"?

A. Any part of an atom
B. An object that can be represented as a mass at a single point in space
C. A part of a whole
D. An object that can be represented as a single point in time
E. An object that has no top or bottom, no front or back

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What quantities are shown on a complete motion diagram?

A. The position of the object in each frame of the film, shown as a dot

B. The average velocity vectors (found by connecting each dot in the motion diagram to the next with a vector arrow)

C. The average acceleration vectors (with *one* acceleration vector linking each *two* velocity vectors)

D. All of the above

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D. All of the above

An acceleration vector

A. tells you how fast an object is going.

B. is constructed from two velocity vectors.

C. is the second derivative of the position.

D. is parallel or opposite to the velocity vector.

E. Acceleration vectors weren’t discussed in this chapter.

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The pictorial representation of a physics problem consists of

A. a sketch.
B. a coordinate system.
C. symbols.
D. a table of values.
E. all of the above.

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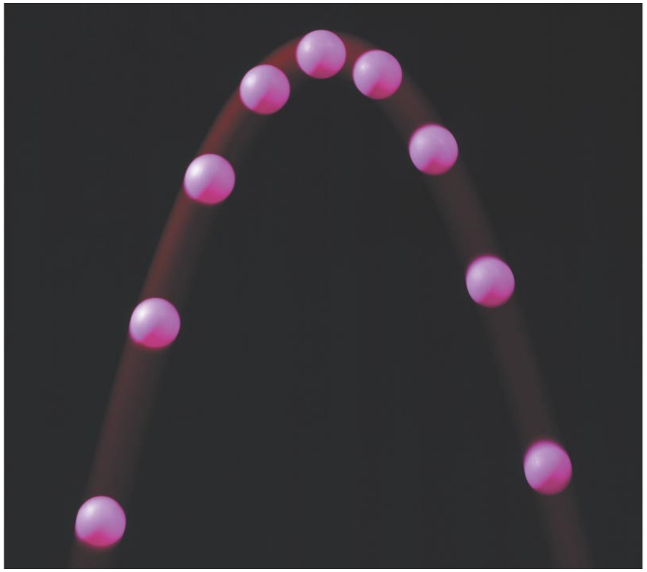
✔ **E. all of the above.**

Chapter 1. Basic Content and Examples

Translational Motion

Circular Motion



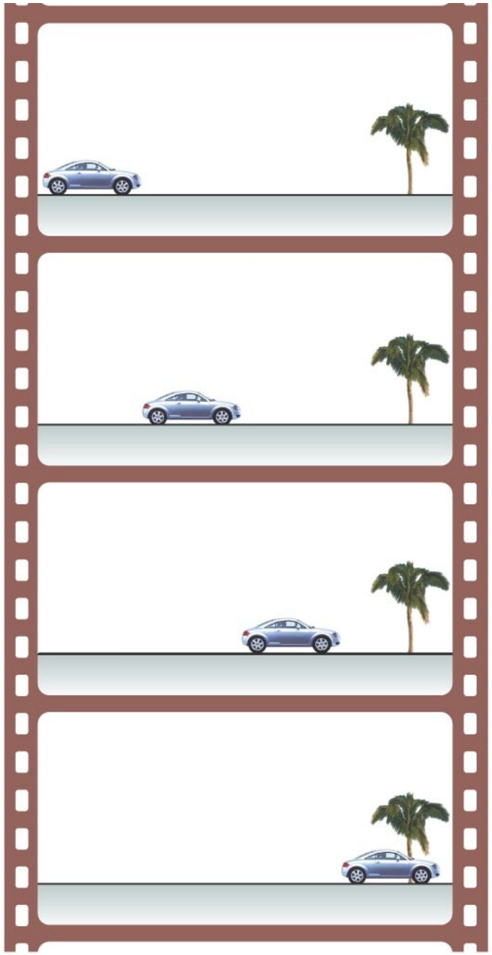
Projectile Motion

Rotational Motion

Making a Motion Diagram

An easy way to study motion is to make a movie of a moving object. A movie camera takes photographs at a fixed rate, typically 30 photographs every second. Each separate photo is called a frame, and the frames are all lined up one after the other in a filmstrip, as shown. The car is in a somewhat different position in each frame.

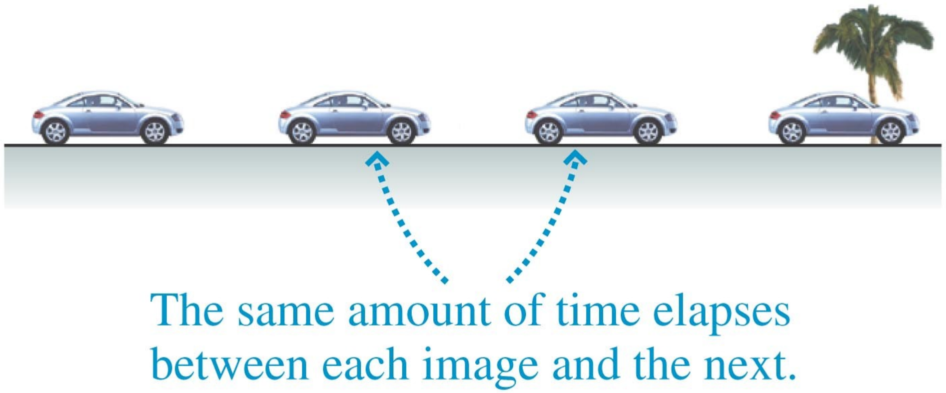
FIGURE 1.2 Four frames from the movie of a car.



Making a Motion Diagram

Suppose we cut the individual frames of the filmstrip apart, stack them on top of each other, and project the entire stack at once onto a screen for viewing. The result is shown. This composite photo, showing an object's position at several equally spaced instants of time, is called a motion diagram.

FIGURE 1.3 A motion diagram of the car shows all the frames simultaneously.



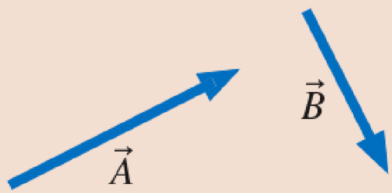
The Particle Model

If we restrict our attention to objects undergoing translational motion, which is the motion of an object along a trajectory, we can consider the object as if it were just a single point, without size or shape. We can also treat the object as if all of its mass were concentrated into this single point. An object that can be represented as a mass at a single point in space is called a particle. A particle has no size, no shape, and no distinction between top and bottom or between front and back.

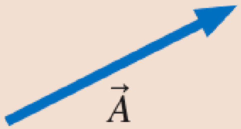
Tactics: Vector Addition

TACTICS BOX 1.1 **Vector addition**

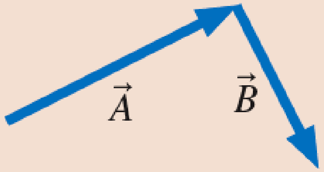
To add $\vec{B}$ to $\vec{A}$:



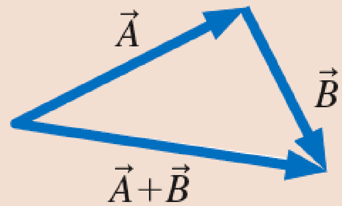
❶ Draw $\vec{A}$.



❷ Place the tail of $\vec{B}$ at the tip of $\vec{A}$.



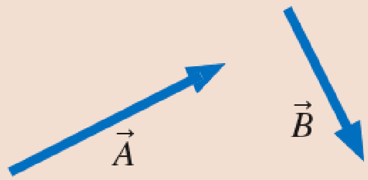
❸ Draw an arrow from the tail of $\vec{A}$ to the tip of $\vec{B}$. This is vector $\vec{A} + \vec{B}$.



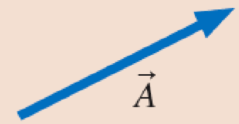
Tactics: Vector Subtraction

TACTICS BOX 1.2 **Vector subtraction**

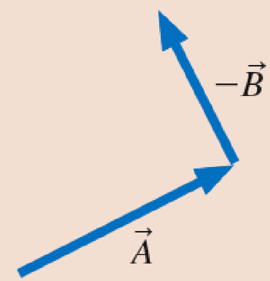
To subtract $\vec{B}$ from $\vec{A}$:



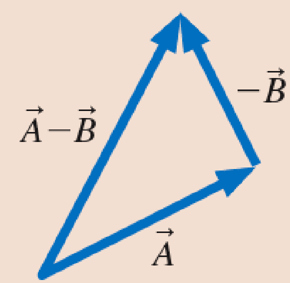
❶ Draw $\vec{A}$.



❷ Place the tail of $-\vec{B}$ at the tip of $\vec{A}$.



❸ Draw an arrow from the tail of $\vec{A}$ to the tip of $-\vec{B}$. This is vector $\vec{A} - \vec{B}$.



EXAMPLE 1.1 Headfirst into the snow

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Alice is sliding along a smooth, icy road on her sled when she suddenly runs headfirst into a large, very soft snowbank that gradually brings her to a halt. Draw a motion diagram for Alice. Show and label all displacement vectors.

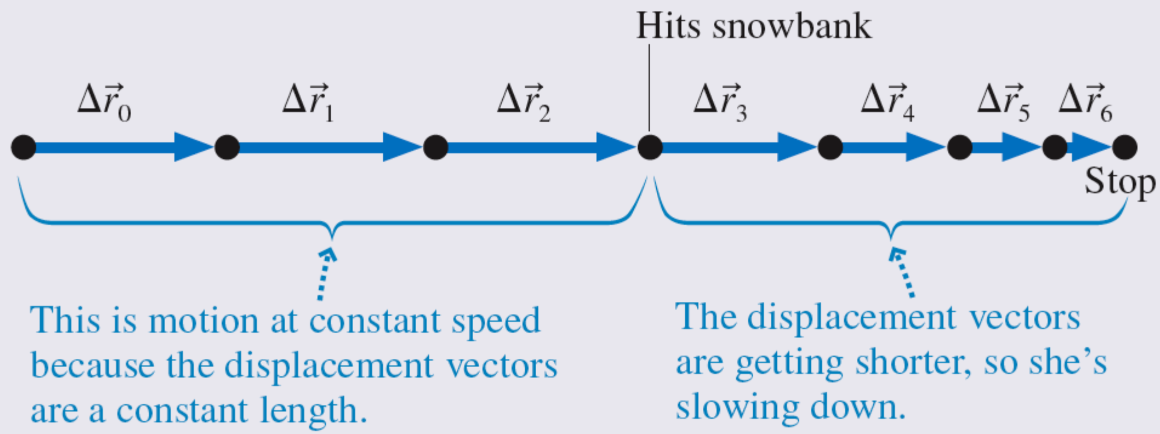
EXAMPLE 1.1 Headfirst into the snow

MODEL Use the particle model to represent Alice as a dot.

EXAMPLE 1.1 Headfirst into the snow

VISUALIZE **FIGURE 1.11** shows Alice's motion diagram. The problem statement suggests that Alice's speed is very nearly constant until she hits the snowbank. Thus her displacement vectors are of equal length as she slides along the icy road. She begins slowing when she hits the snowbank, so the displacement vectors then get shorter until she stops. It is reasonable to assume that her stopping distance in the snow is less than the distance she had slid along the road, but we do not want to make her stop *too* quickly.

FIGURE 1.11 Alice's motion diagram.



Average Speed, Average Velocity

To quantify an object's fastness or slowness, we define a ratio as follows:

$$\text{average speed} = \frac{\text{distance traveled}}{\text{time interval spent traveling}}$$

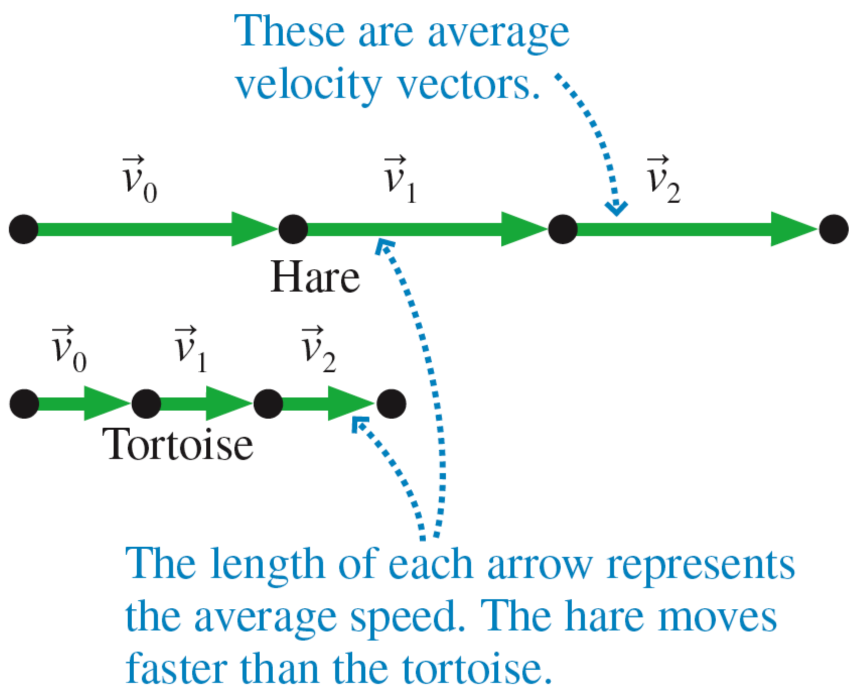
Average speed does not include information about direction of motion. Average velocity does include direction. The average velocity of an object during a time interval Δt, in which the object undergoes a displacement $\Delta \boldsymbol{r}$, is the vector

$$\vec{v}_{\text{avg}} = \frac{\Delta \vec{r}}{\Delta t}$$

Motion Diagrams with Velocity Vectors

The velocity vector, as we've defined it, points in the same direction as the displacement $\Delta\vec{r}$, and the length of $\vec{v}$ is directly proportional to the length of $\Delta\vec{r}$. Consequently, the vectors connecting each dot of a motion diagram to the next, which we previously labeled as displacement vectors, could equally well be identified as velocity vectors.

FIGURE 1.13 Motion diagram of the tortoise racing the hare.



EXAMPLE 1.2 Accelerating up a hill

EXAMPLE 1.2 Accelerating up a hill

The light turns green and a car accelerates, starting from rest, up a 20° hill. Draw a motion diagram showing the car's velocity.

EXAMPLE 1.2 Accelerating up a hill

MODEL Use the particle model to represent the car as a dot.

EXAMPLE 1.2 Accelerating up a hill

VISUALIZE The car's motion takes place along a straight line, but the line is neither horizontal nor vertical. Because a motion diagram is made from frames of a movie, it will show the object moving with the correct orientation—in this case, at an angle of 20°. **FIGURE 1.14** shows several frames of the motion diagram, where we see the car speeding up. The car starts from rest, so the first arrow is drawn as short as possible and the first dot is labeled "Start." The displacement vectors have been drawn from each dot to the next, but then they have been identified and labeled as average velocity vectors $\vec{v}$.

Linear Acceleration

Because velocity is a vector, it can change in two possible ways.

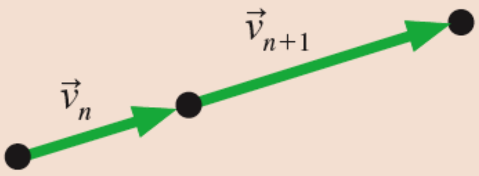
1. The magnitude can change, indicating a change in speed, or
2. The direction can change, indicating that the object has changed direction.

We will concentrate for now on the first case, a change in speed.

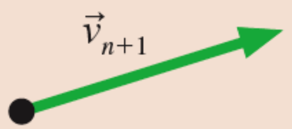
Tactics: Finding the acceleration vector

TACTICS BOX 1.3 **Finding the acceleration vector**

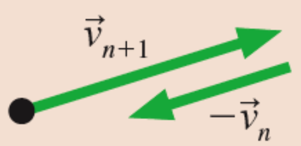
To find the acceleration as the velocity changes from $\vec{v}_n$ to $\vec{v}_{n+1}$:



❶ Draw the velocity vector $\vec{v}_{n+1}$.

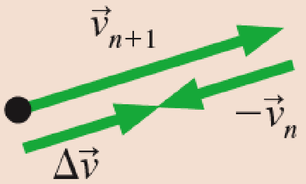


❷ Draw $-\vec{v}_n$ at the tip of $\vec{v}_{n+1}$.

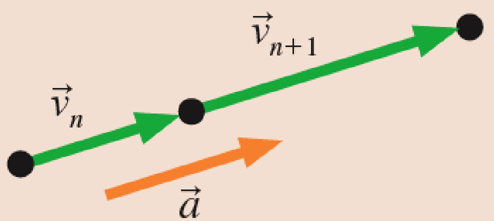


Tactics: Finding the acceleration vector

❸ Draw $\Delta\vec{v} = \vec{v}_{n+1} - \vec{v}_n$
$= \vec{v}_{n+1} + (-\vec{v}_n)$
This is the direction of $\vec{a}$.



❹ Return to the original motion diagram. Draw a vector at the middle point in the direction of $\Delta\vec{v}$; label it $\vec{a}$. This is the average acceleration at the midpoint between $\vec{v}_n$ and $\vec{v}_{n+1}$.



Problem-Solving Strategy: Motion Diagrams

PROBLEM-SOLVING STRATEGY 1.1 **Motion diagrams** MP

MODEL Represent the moving object as a particle. Make simplifying assumptions when interpreting the problem statement.

Problem-Solving Strategy: Motion Diagrams

VISUALIZE A complete motion diagram consists of:

- The position of the object in each frame of the film, shown as a dot. Use five or six dots to make the motion clear but without overcrowding the picture. More complex motions may need more dots.
- The average velocity vectors, found by connecting each dot in the motion diagram to the next with a vector arrow. There is *one* velocity vector linking each *two* position dots. Label the row of velocity vectors $\vec{v}$.
- The average acceleration vectors, found using Tactics Box 1.3. There is *one* acceleration vector linking each *two* velocity vectors. Each acceleration vector is drawn at the dot between the two velocity vectors it links. Use $\vec{0}$ to indicate a point at which the acceleration is zero. Label the row of acceleration vectors $\vec{a}$.

EXAMPLE 1.5 Skiing through the woods

EXAMPLE 1.5 Skiing through the woods

A skier glides along smooth, horizontal snow at constant speed, then speeds up going down a hill. Draw the skier's motion diagram.

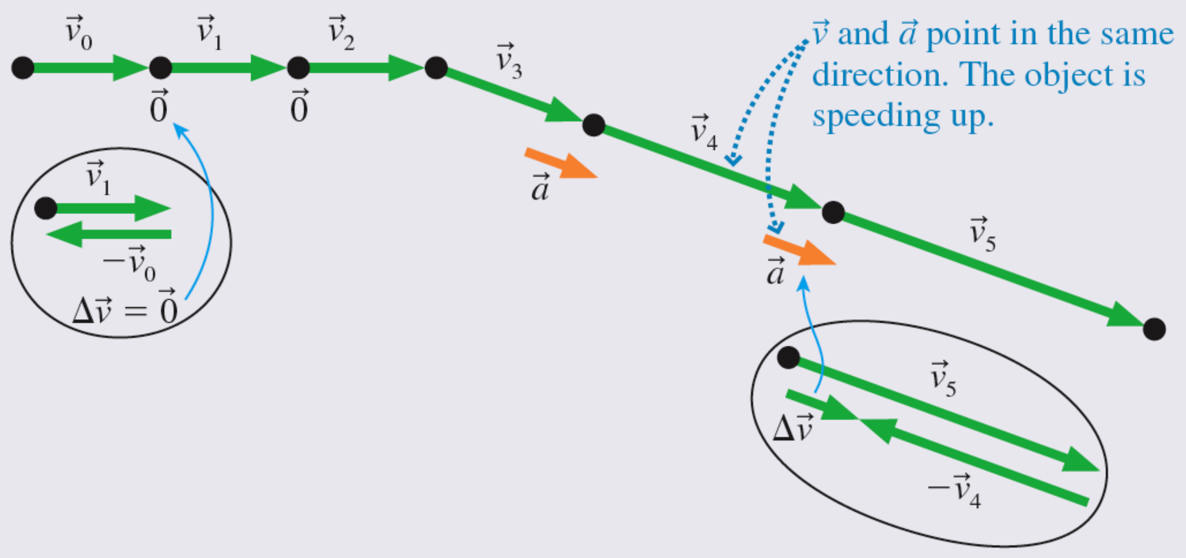
EXAMPLE 1.5 Skiing through the woods

MODEL Represent the skier as a particle. It's reasonable to assume that the downhill slope is a straight line. Although the motion as a whole is not linear, we can treat the skier's motion as two separate linear motions.

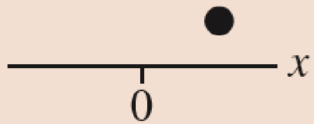
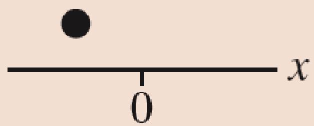
EXAMPLE 1.5 Skiing through the woods

VISUALIZE **FIGURE 1.17** shows a complete motion diagram of the skier. The dots are equally spaced for the horizontal motion, indicating constant speed; then the dots get farther apart as the skier speeds up down the hill.

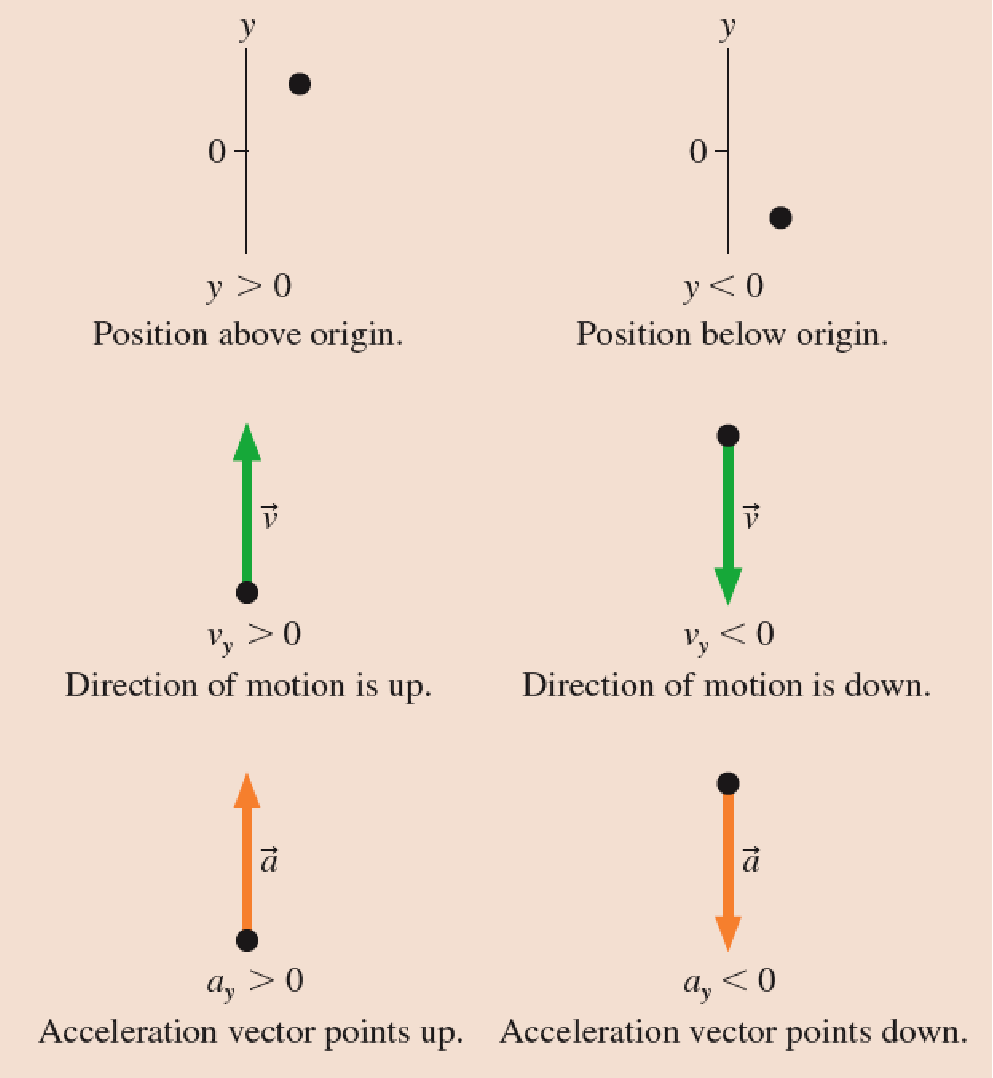
FIGURE 1.17 Motion diagram of a skier.



Tactics: Finding the acceleration vector

	$x > 0$	Position to right of origin.
	$x < 0$	Position to left of origin.
	$v_x > 0$	Direction of motion is to the right.
	$v_x < 0$	Direction of motion is to the left.
	$a_x > 0$	Acceleration vector points to the right.
	$a_x < 0$	Acceleration vector points to the left.

Tactics: Finding the acceleration vector



Tactics: Finding the acceleration vector

- The sign of position (x or y) tells us *where* an object is.
- The sign of velocity (v_x or v_y) tells us *which direction* the object is moving.
- The sign of acceleration (a_x or a_y) tells us which way the acceleration vector points, *not* whether the object is speeding up or slowing down.

EXAMPLE 1.7 Interpreting a position graph

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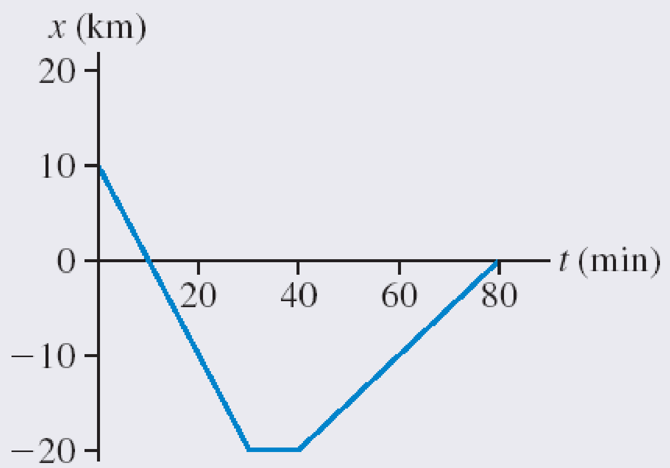
The graph in **FIGURE 1.22a** represents the motion of a car along a straight road. Describe the motion of the car.

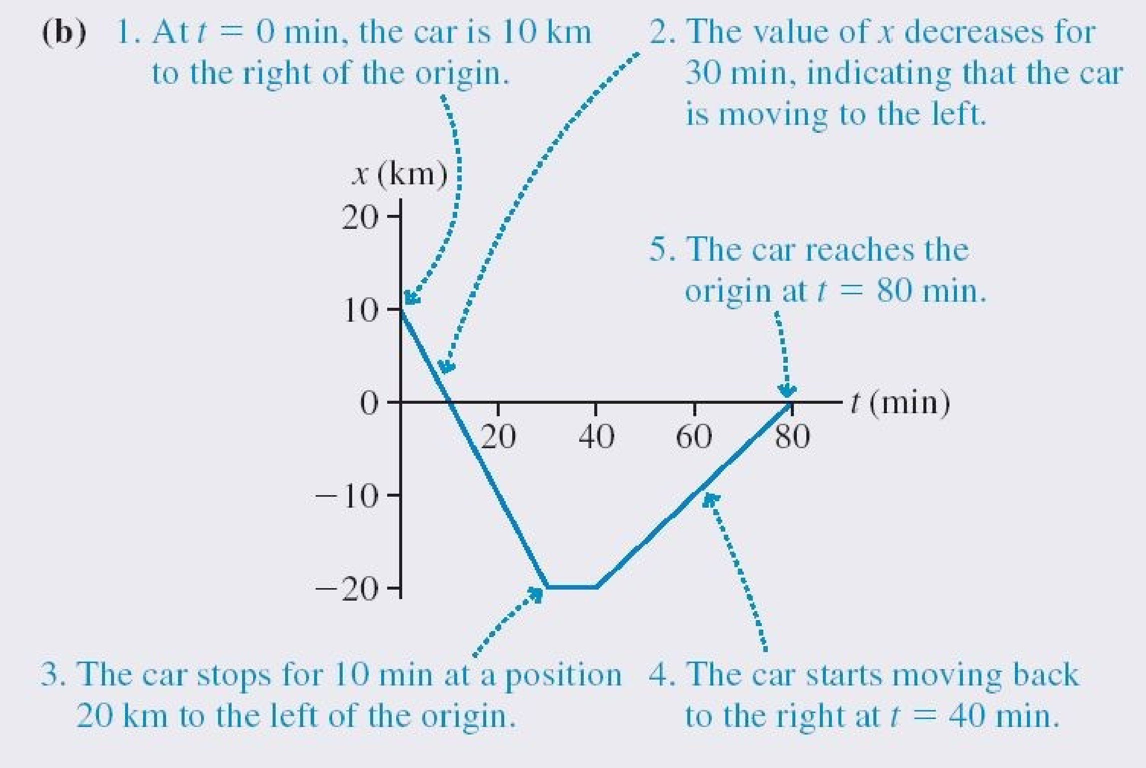
(a)



EXAMPLE 1.7 Interpreting a position graph

MODEL Represent the car as a particle.

VISUALIZE As **FIGURE 1.22b** shows, the graph represents a car that travels to the left for 30 minutes, stops for 10 minutes, then travels back to the right for 40 minutes.



Tactics: Drawing a pictorial representation

TACTICS BOX 1.5 **Drawing a pictorial representation**

MP

1. **Draw a motion diagram.** The motion diagram develops your intuition for the motion and, especially important, determines whether the signs of v and a are positive or negative.
2. **Establish a coordinate system.** Select your axes and origin to match the motion. For one-dimensional motion, you want either the x-axis or the y-axis parallel to the motion.
3. **Sketch the situation.** Not just any sketch. Show the object at the *beginning* of the motion, at the *end,* and at any point where the character of the motion changes. Show the object, not just a dot, but very simple drawings are adequate.

Tactics: Drawing a pictorial representation

4. **Define symbols.** Use the sketch to define symbols representing quantities such as position, velocity, acceleration, and time. *Every* variable used later in the mathematical solution should be defined on the sketch. Some will have known values, others are initially unknown, but all should be given symbolic names.
5. **List known information.** Make a table of the quantities whose values you can determine from the problem statement or that can be found quickly with simple geometry or unit conversions. Some quantities are implied by the problem, rather than explicitly given. Others are determined by your choice of coordinate system.
6. **Identify the desired unknowns.** What quantity or quantities will allow you to answer the question? These should have been defined as symbols in step 4. Don't list every unknown, only the one or two needed to answer the question.

General Problem-Solving Strategy

General Problem-Solving Strategy

MP

MODEL It's impossible to treat every detail of a situation. Simplify the situation with a model that captures the essential features. For example, the object in a mechanics problem is usually represented as a particle.

General Problem-Solving Strategy

VISUALIZE This is where expert problem solvers put most of their effort.

- Draw a *pictorial representation*. This helps you visualize important aspects of the physics and assess the information you are given. It starts the process of translating the problem into symbols.
- Use a *graphical representation* if it is appropriate for the problem.
- Go back and forth between these representations; they need not be done in any particular order.

General Problem-Solving Strategy

SOLVE Only after modeling and visualizing are complete is it time to develop a *mathematical representation* with specific equations that must be solved. All symbols used here should have been defined in the pictorial representation.

General Problem-Solving Strategy

ASSESS Is your result believable? Does it have proper units? Does it make sense?

FIGURE 1.25 Determining significant figures.

Leading zeros locate the decimal point. They are not significant.

$$0.00620 = \boxed{6.20} \times 10^{-3}$$

A trailing zero is reliably known. It is significant.

The number of significant figures is the number of digits when written in scientific notation.

- The number of significant figures ≠ the number of decimal places.
- Changing units shifts the decimal point but does not change the number of significant figures.

Tactics: Drawing a pictorial representation

TACTICS BOX 1.6 **Using significant figures**

1. When multiplying or dividing several numbers, or taking roots, the number of significant figures in the answer should match the number of significant figures of the *least* precisely known number used in the calculation.
2. When adding or subtracting several numbers, the number of decimal places in the answer should match the *smallest* number of decimal places of any number used in the calculation.
3. It is acceptable to keep one or two extra digits during intermediate steps of a calculation, as long as the final answer is reported with the proper number of significant figures. The goal is to minimize round-off errors in the calculation. But only one or two extra digits, not the seven or eight shown in your calculator display.

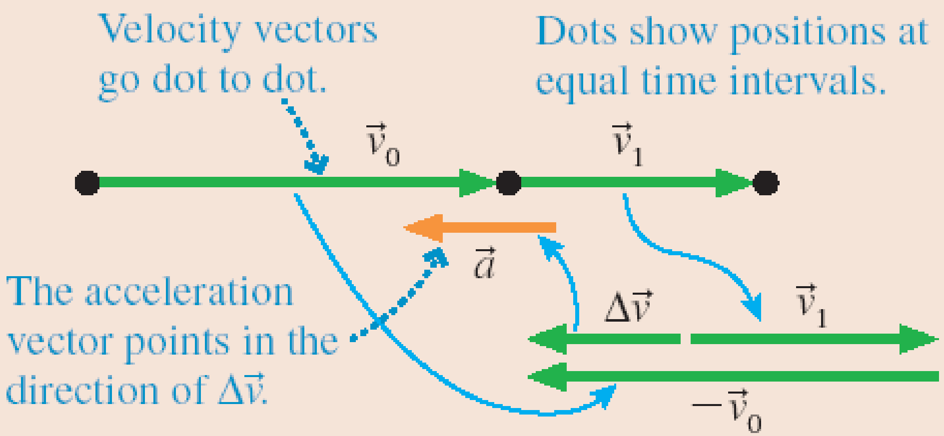
Exercises 38–39

Chapter 1. Summary Slides

General Strategy

Motion Diagrams

- Help visualize motion.
- Provide a tool for finding acceleration vectors.



▶ These are the average velocity and the average acceleration vectors.

General Strategy

Problem Solving

MODEL Make simplifying assumptions.

VISUALIZE Use:

- **Pictorial representation**
- **Graphical representation**

SOLVE Use a **mathematical representation** to find numerical answers.

ASSESS Does the answer have the proper units? Does it make sense?

Important Concepts

The particle model represents a moving object as if all its mass were concentrated at a single point.

Important Concepts

Position locates an object with respect to a chosen coordinate system. Change in position is called displacement.

Velocity is the rate of change of the position vector $\vec{r}$.

Acceleration is the rate of change of the velocity vector $\vec{v}$.

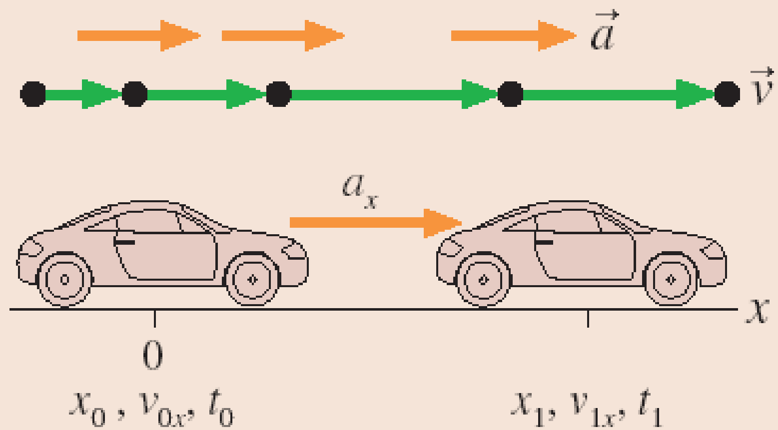
An object has an acceleration if it

- Changes speed and/or
- Changes direction.

Important Concepts

Pictorial Representation

1. Draw a motion diagram.
2. Establish coordinates.
3. Sketch the situation.
4. Define symbols.
5. List knowns.
6. Identify desired unknown.



Known

$x_0 = v_{0x} = t_0 = 0$

$a_x = 2.0 \text{ m/s}^2 \quad t_1 = 2.0 \text{ s}$

Find

x_1

Applications

For **motion along a line:**

- Speeding up: $\vec{v}$ and $\vec{a}$ point in the same direction, v_x and a_x have the same sign.
- Slowing down: $\vec{v}$ and $\vec{a}$ point in opposite directions, v_x and a_x have opposite signs.
- Constant speed: $\vec{a} = \vec{0}$, $a_x = 0$.

Acceleration a_x is positive if $\vec{a}$ points right, negative if $\vec{a}$ points left. The sign of a_x does *not* imply speeding up or slowing down.

Applications

Significant figures are reliably known digits. The number of significant figures for:

- **Multiplication, division, powers** is set by the value with the fewest significant figures.
- **Addition, subtraction** is set by the value with the smallest number of decimal places.

The appropriate number of significant figures in a calculation is determined by the data provided.

Chapter 1. Clicker Questions

Which car is going faster, A or B? Assume there are equal intervals of time between the frames of both movies.

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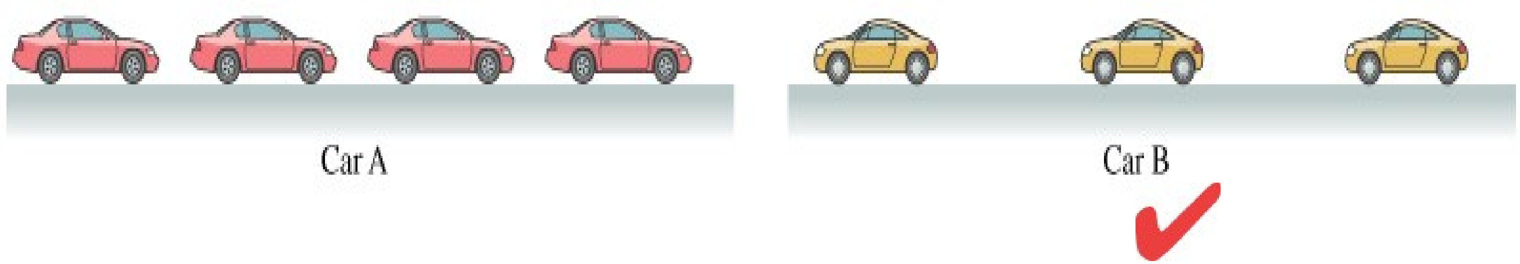
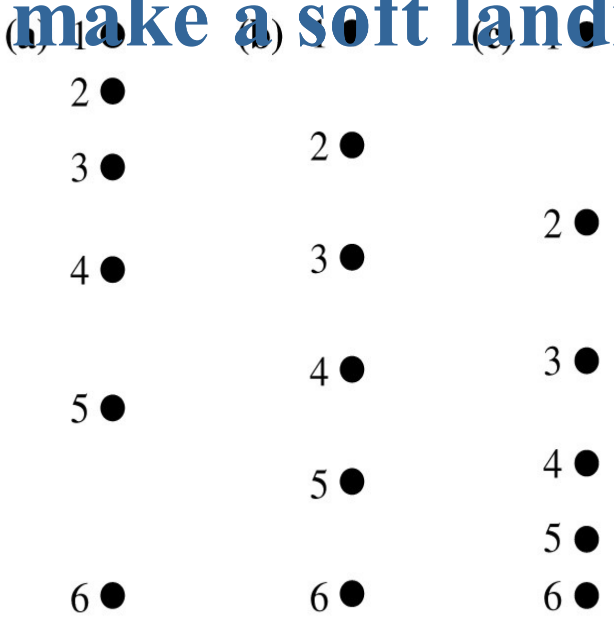


B is going faster.

Three motion diagrams are shown. Which is a dust particle settling to the floor at constant speed, which is a ball dropped from the roof of a building, and which is a descending rocket slowing to make a soft landing on Mars?



A. (a) is ball, (b) is dust, (c) is rocket

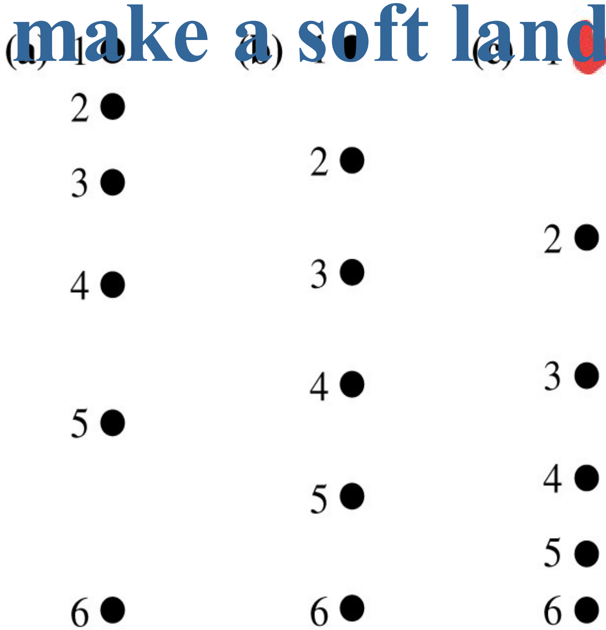
B. (a) is ball, (b) is rocket, (c) is dust

C. (a) is rocket, (b) is dust, (c) is ball

D. (a) is rocket, (b) is ball, (c) is dust

E. (a) is dust, (b) is ball, (c) is rocket

Three motion diagrams are shown. Which is a dust particle settling to the floor at constant speed, which is a ball dropped from the roof of a building, and which is a descending rocket slowing to make a soft landing on Mars?



A. (a) is ball, (b) is dust, (c) is rocket

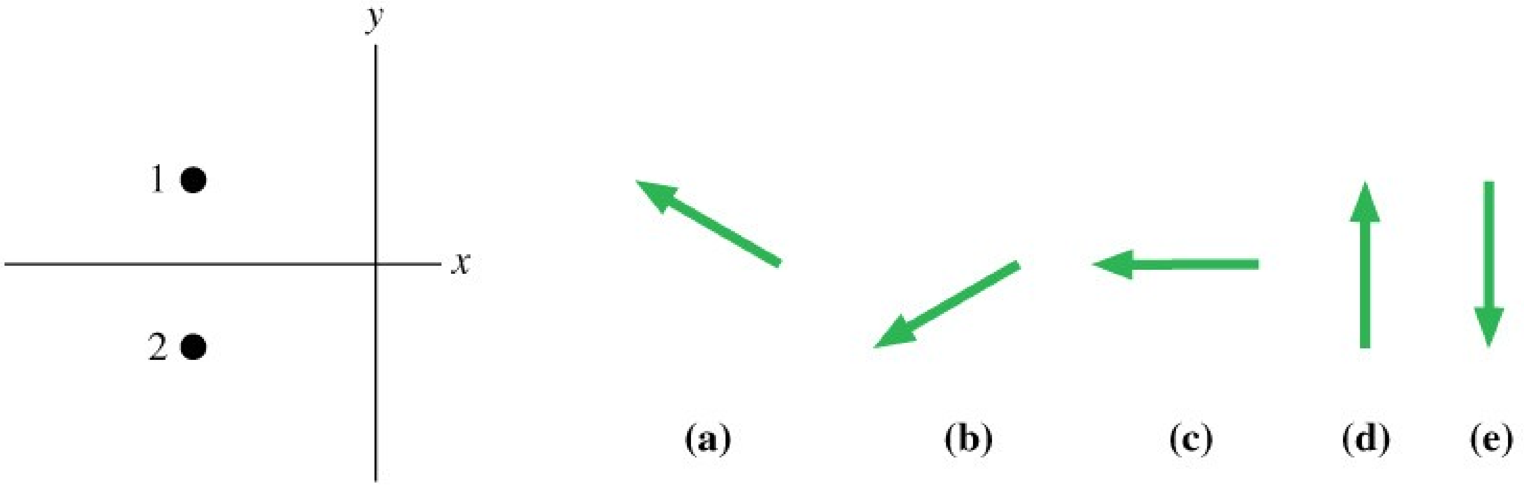
B. (a) is ball, (b) is rocket, (c) is dust

C. (a) is rocket, (b) is dust, (c) is ball

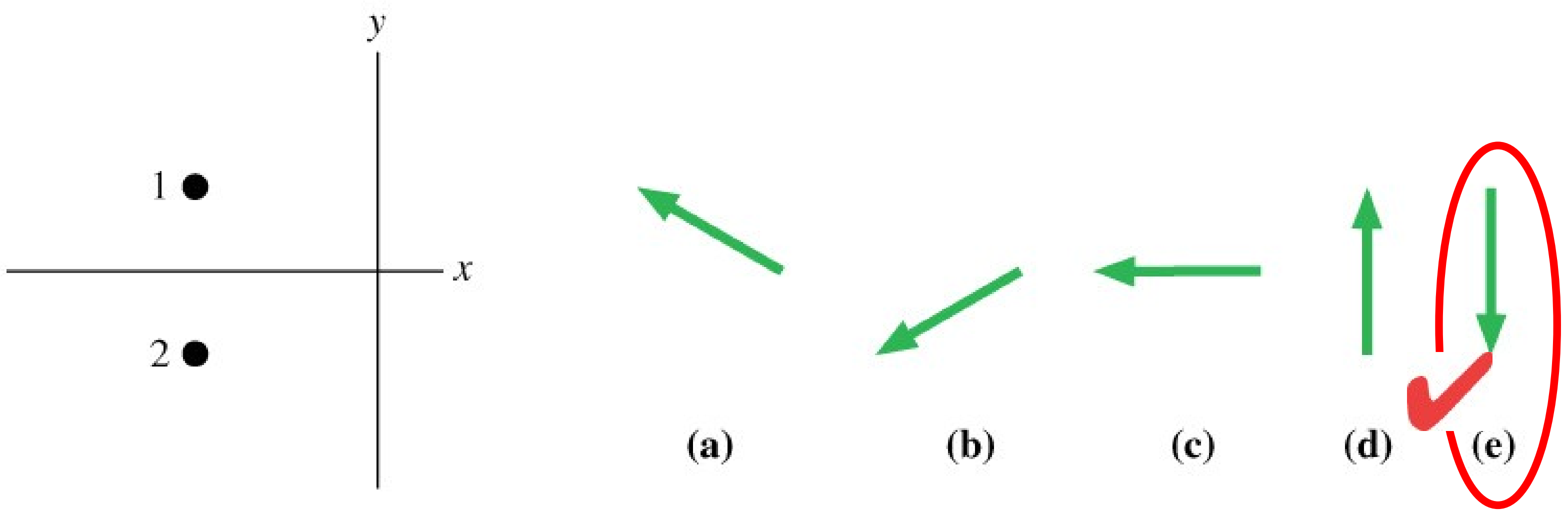
D. (a) is rocket, (b) is ball, (c) is dust

E. (a) is dust, (b) is ball, (c) is rocket

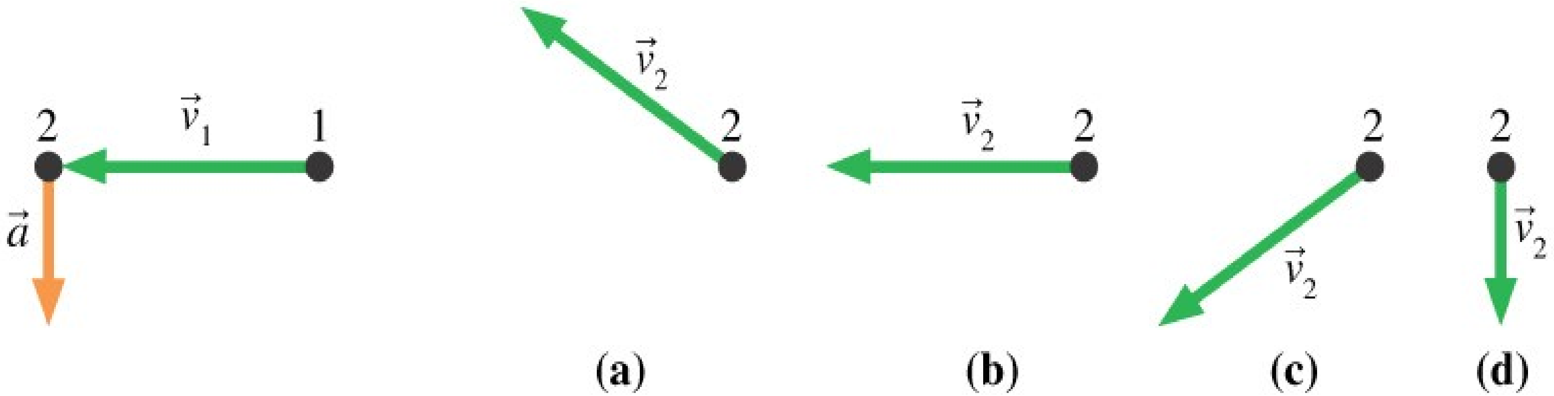
A particle moves from position 1 to position 2 during the interval Δt. Which vector shows the particle's average velocity?



A particle moves from position 1 to position 2 during the interval Δt. Which vector shows the particle's average velocity?



A particle undergoes acceleration $\vec{a}$ while moving from point 1 to point 2. Which of the choices shows the velocity vector $\vec{v}_2$ as the object moves away from point 2?



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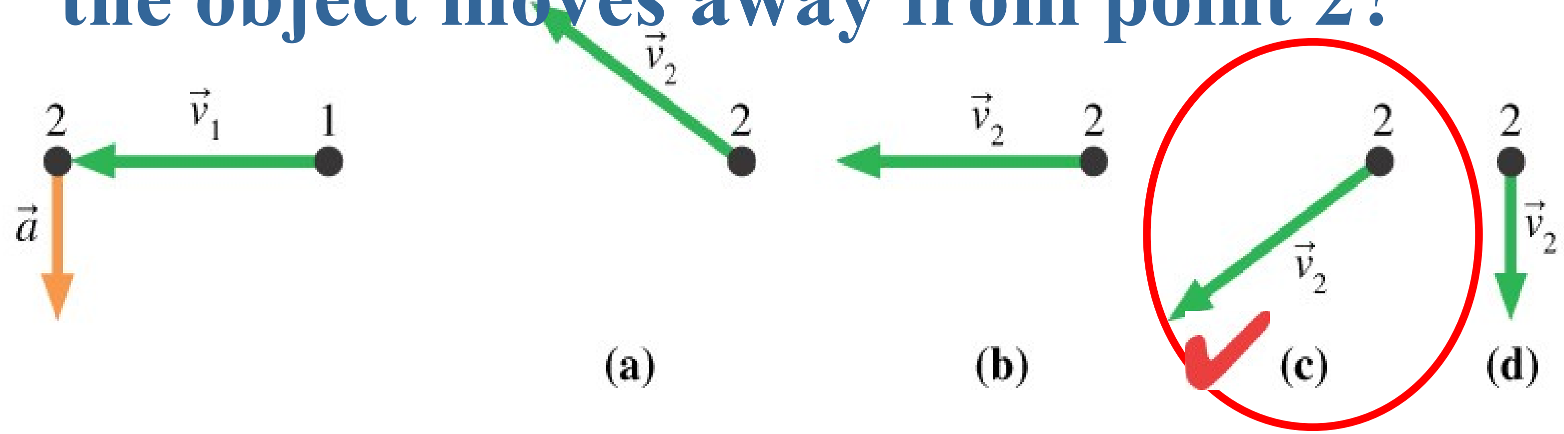

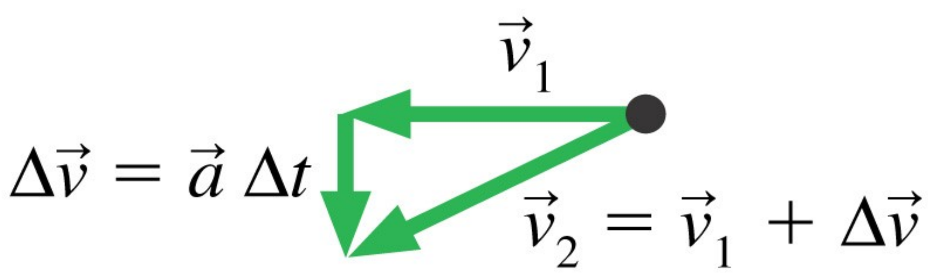

Rank in order, from the most to the least, the number of significant figures in the following numbers. For example, if b has more than c, c has the same number as a, and a has more than d, you could give your answer as b > c = a > d.

a. 8200 b. 0.0052 c. 0.430 d. 4.321×10^{-10}

A. a = b = d > c
B. b = d > c > a
C. d > c > b = a
D. d > c > a > b
E. b > a = c = d

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