KINEMATICS

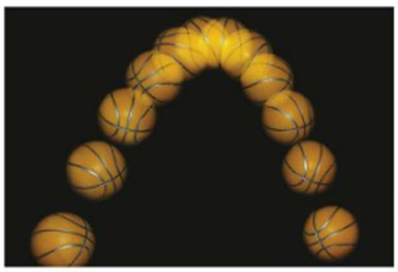
- **Kinematics** → mathematical description of motion.
  - The most simple way to view motion.
  - Kine is Greek for "motion."

MOTION

- **Motion** → change of an object's position or orientation.
  - the path along which an object moves is called its **trajectory**

Straight-line motion

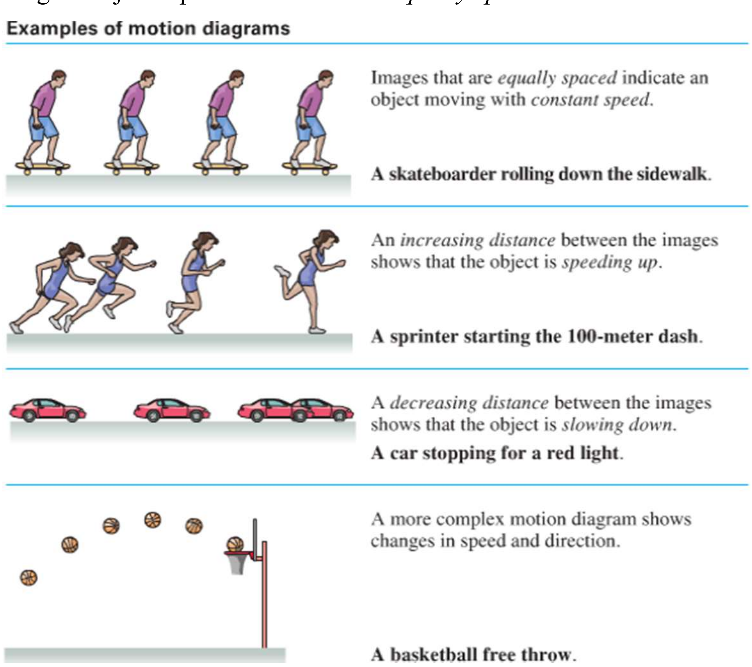
Circular motion



Projectile motion

Rotational motion

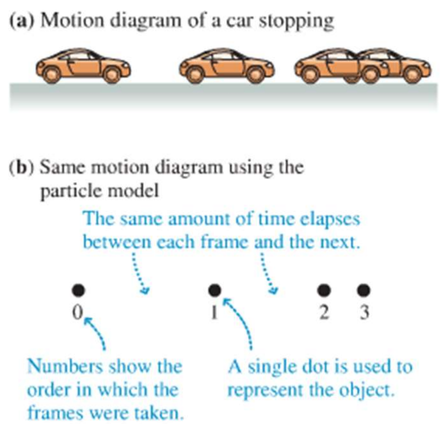
- An image showing an object's positions at several *equally spaced instants in time* is called a **motion diagram**.



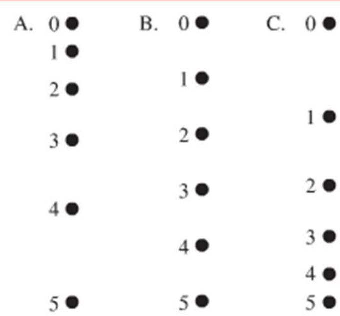
STOP TO THINK 1.1 Which car is going faster, A or B? Assume there are equal intervals of time between the frames of both videos.

- If you imagine the object's mass being contained within one single point of matter, you can make a **particle diagram**. It works the same way as a motion diagram.
  - ➢ It's an oversimplification of reality, but it allows us to focus on the object's movement as a whole without worrying about the extensions of the object.

FIGURE 1.4 Simplifying a motion diagram using the particle model.

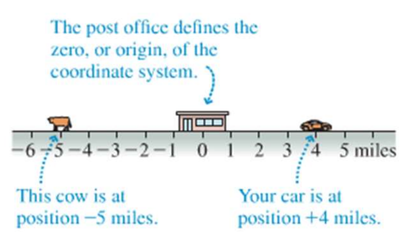


STOP TO THINK 1.2 Three motion diagrams are shown. Which is a dust particle settling to the floor at constant speed, which is a ball dropped from the roof of a building, and which is a descending rocket slowing to make a soft landing on Mars?



- **Position** → your location at any given point in time.
  - ➢ Describing a position requires an **origin**, or zero/reference point.
  - ➢ Ex: if you tell your friend your 4 miles from his house, you are using his house as a reference point.
  - ➢ If you said, "I'm 4 miles," your friend would not understand or think you were daft.
  - ➢ The origin is defined by us. But it must be defined.
  - ➢ Ex: In labs, we may define the vertical zero position as the ground. Or we may call the lab table zero. It depends on the circumstances. But we must define it.
  - ➢ +/- indicates the position relative to the origin.

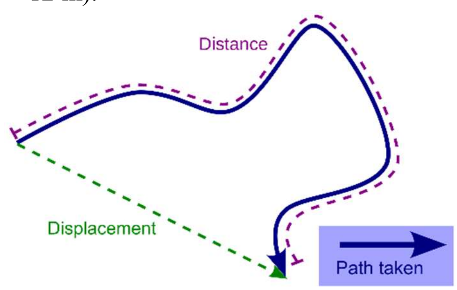
FIGURE 1.7 The coordinate system used to describe objects along a country road.



- **Vector Quantities** → have both magnitude and direction
  - Magnitude→ size, the amount of something
  - Ex: 60 mi/h East
- **Scalar Quantities** → have only magnitude (size)
  - Ex: 60 mi/h
  - You don't know what direction that car is heading.
- Common vector and scalar counterparts (fill in the definitions next to the terms):

Scalar	**Vector**
Distance	Displacement
Speed	Velocity
	Acceleration

- **Displacement** → change in position.
  - Ex: Sam ran from home (x_o = 0 m) to the end of the block (x = 12 m).
  - Displacement is Δx (change in position, final minus initial)
  - $\Delta x = x - x_o$
  - Can be negative or positive depending on the direction of displacement.
  - It's path independent.



- **Distance** → How far the object moved in total.
  - Can be much larger than the displacement of the object, but never smaller.
  - The total path taken by the object.

STOP TO THINK 1.3 Sarah starts at a positive position along the *x*-axis. She then undergoes a negative displacement. Her final position

A. Is positive. B. Is negative. C. Could be either positive or negative.

- **Speed** → How fast something is going.
  - A scalar quantity (no dir'n)
  - Ex: "That dude was doing at least 90 mph."
  - There's no indication of what direction he was heading
- **Velocity** → speed *and* direction
  - A vector quantity.
  - Ex: "That dude was doing at least 90 mph and heading north."
  - Much more descriptive.
- **Uniform Motion** → objects moving at a constant speed.

$$v = \frac{\Delta x}{\Delta t}$$

EXAMPLE 1.2 Finding the speed of a seabird

Albatrosses are seabirds that spend most of their lives flying over the ocean looking for food. With a stiff tailwind, an albatross can fly at high speeds. Satellite data on one particularly speedy albatross showed it 60 miles east of its roost at 3:00 PM and then, at 3:15 PM, 80 miles east of its roost. What was its velocity?

- **Instantaneous velocity** → the velocity of an object at any given instant in time.
- **Acceleration** → the rate at which an object speeds up, slows down or *changes direction*.
  - ➢ We only deal with avg acceleration in this course.

$$\Delta a_{avg} = \frac{\Delta v}{\Delta t}$$

- Kinematic units of measurement:

Variable	SI Unit
Displacement/Distance	Meters (m)
Velocity/Speed	Meters per second (m/s)
Acceleration	Meters per second squared (m/s^2)
Time	Seconds (s)
Mass	Kilograms (kg)

RELATIVE MOTION

- ***All motion is relative to the perspective of the observer.***
  - ➢ Imagine you're sitting in a lawn chair watching a train travel past you to the right at 50 m/s.
  - ➢ From your reference frame, a cup of water you see through the train's window is travelling at 50 m/s.
  - ➢ But, if you were on the train, the cup of water would seem at rest. And the guy on the lawn chair is travelling 50 m/s backwards.
- **Reference frame** → describes the location and velocity of the observer of an act.
  - ➢ Someone at rest on Earth is the most common reference frame.

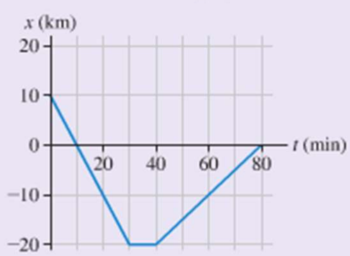
GRAPHING MOTION

- Position vs. Time graphs
  - ➢ Show an objects position over a time interval
  - ➢ The slope of this graph represents velocity.

CONCEPTUAL EXAMPLE 2.1 **Interpreting a car's position-versus-time graph**

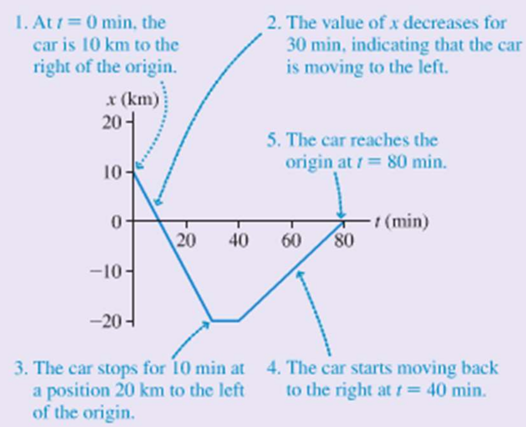
The graph in FIGURE 2.5 represents the motion of a car along a straight road. Describe (in words) the motion of the car.

FIGURE 2.5 Position-versus-time graph for the car.



REASON The vertical axis in Figure 2.5 is labeled "x (km)"; position is measured in kilometers. Our convention for motion along the x-axis given in Figure 2.1 tells us that x increases as the car moves to the right and x decreases as the car moves to the left. The graph thus shows that the car travels to the left for 30 minutes, stops for 10 minutes, then travels to the right for 40 minutes. It ends up 10 km to the left of where it began. FIGURE 2.6 gives a full explanation of the reasoning.

FIGURE 2.6 Looking at the position-versus-time graph in detail.



ASSESS The car travels to the left for 30 minutes and to the right for 40 minutes. Nonetheless, it ends up to the left of where it started. This means that the car was moving faster when it was moving to the left than when it was moving to the right. We can deduce this fact from the graph as well, as we will see in the next section.

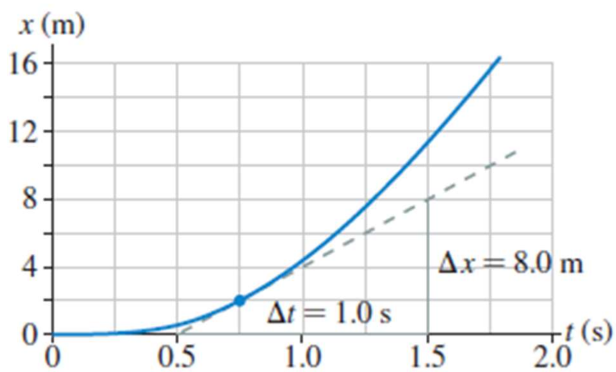
TACTICS BOX 2.1 Interpreting position-versus-time graphs

Information about motion can be obtained from position-versus-time graphs as follows:

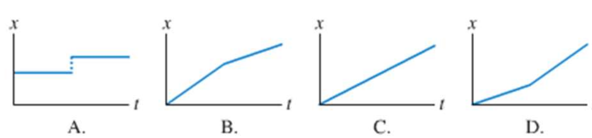
1. Determine an object's *position* at time *t* by reading the graph at that instant of time.
2. Determine the object's *velocity* at time *t* by finding the slope of the position graph at that point. Steeper slopes correspond to faster speeds.
3. Determine the *direction of motion* by noting the sign of the slope. Positive slopes correspond to positive velocities and, hence, to motion to the right (or up). Negative slopes correspond to negative velocities and, hence, to motion to the left (or down).

Exercises 2,3

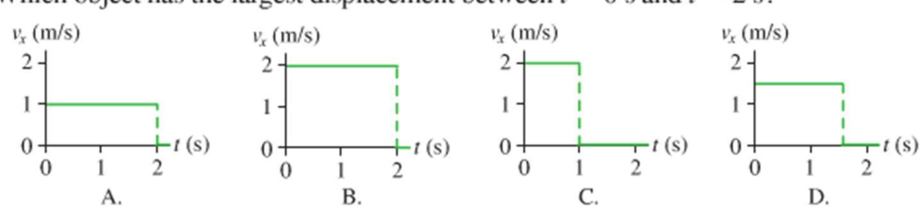
- Velocity vs. Time graphs
  - Shows an objects velocity over time.
  - When in the positive, it's moving forward, when in the negative, backward.
  - Slope represents acceleration.
  - Area under the curve represents displacement.
  - To find instantaneous velocity on a x v t graph that shows acceleration, find the slope of a line that is tangential to the curve at that moment in time.



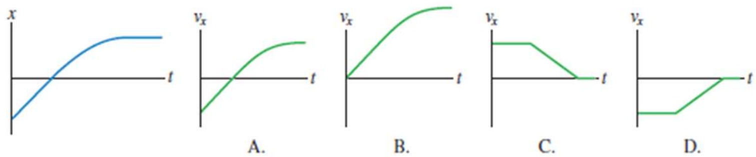
STOP TO THINK 2.1 Which position-versus-time graph best describes the motion diagram at left?



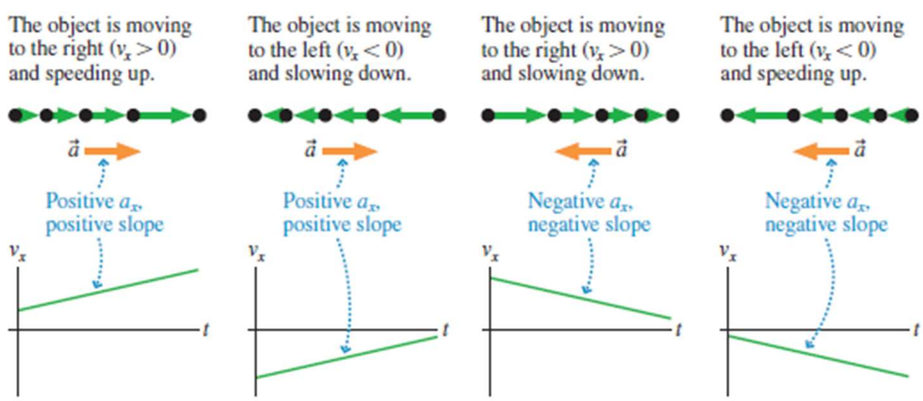
STOP TO THINK 2.2 Four objects move with the velocity-versus-time graphs shown. Which object has the largest displacement between $t = 0$ s and $t = 2$ s?



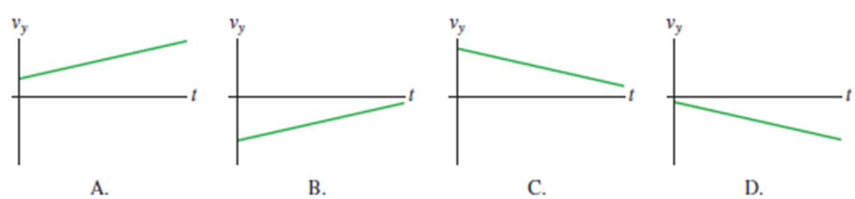
Which velocity-versus-time graph goes with the position-versus-time graph on the left?



- Determining the sign (+/-) for acceleration:



An elevator is moving downward. It is slowing down as it approaches the ground floor. Adapt the information in Figure 2.25 to determine which of the following velocity graphs best represents the motion of the elevator.



1-D KINEMATIC EQUATIONS

- If you derive our basic motion equations, we can come up with three to describe objects that accelerate in 1-dimension.

$$v = v_o + at$$

$$v^2 = v_o^2 + 2ax$$

$$x = v_o t + \frac{1}{2}at^2$$

Example:

A car has an initial velocity of 15.0 m/s and undergoes a constant acceleration of 6.0 m/s^2. What is the final velocity of the car after 18.0 s?

Free Fall

- **Free fall** → any scenario where the only acceleration present is the *acceleration due to gravity*.
  - ***Any two objects, regardless of mass, will fall at the SAME RATE.***
  - In free fall scenarios, we can assume gravitational acceleration to be constant.
  - Acceleration due to gravity → **g**
  - **g = 9.8 m/s^2** on Earth
  - It's often negative, since it is directed downwards (negatives indicate direction!).
- We can ignore air resistance if:
  - The object is relatively heavy compared to its size.
  - It falls for a relatively short amount of time
  - Its moving relatively slowly (i.e., it doesn't hit terminal velocity)

Acceleration of gravity, "g" in the Solar System			
At the surface of	**g (m/s^2) is**	**Mass (kg)***	**Radius (m)***
Sun[1]	275	1.99×10^{30}	6.95×10^{8}
Mercury	3.7	3.30×10^{23}	2.44×10^{6}
Venus	8.9	4.87×19^{24}	6.05×10^{6}
Earth	9.8	5.97×10^{24}	6.38×10^{6}
Moon (of Earth)	1.6	7.35×10^{22}	1.73×10^{6}
Mars	3.7	6.42×10^{23}	3.40×10^{6}
Phobos (moon of Mars)	6.0×10^{-3}	1.08×10^{16}	1.1×10^{4}
Deimos (moon of Mars)	3.3×10^{-3}	1.80×10^{15}	6×10^{3}
Jupiter[1]	25	1.90×10^{27}	7.15×10^{7}
Ganymede (moon of Jupiter)	1.4	1.48×10^{23}	2.63×10^{6}
Europa (moon of Jupiter)	1.3	4.80×10^{22}	1.57×10^{6}
Saturn[1]	10.4	5.68×10^{26}	6.03×10^{7}
Uranus[1]	8.9	8.68×10^{25}	2.56×10^{7}
Neptune[1]	11	1.02×10^{26}	2.48×10^{7}
Pluto	0.7	1.27×10^{22}	1.14×10^{6}

[1]Assuming that these objects actually *had* a surface...

Example:

John drops a rock down a 12 foot well. How long will it take to reach the bottom of the well? How long would it take if he were to do this same experiment on Pluto?