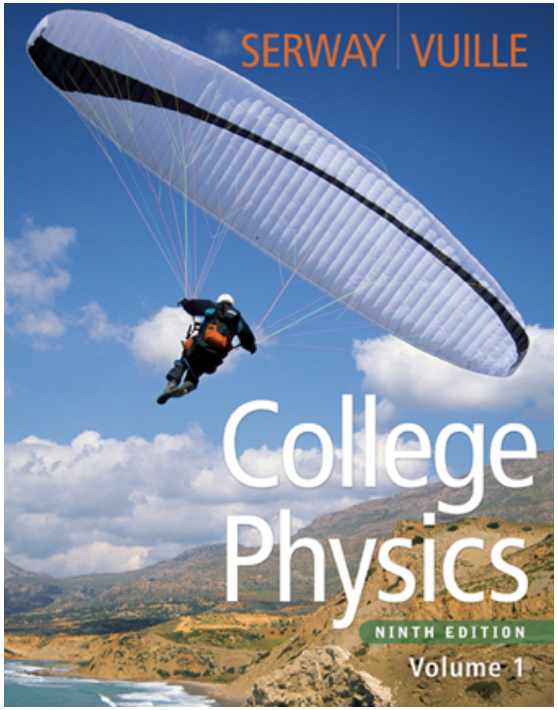

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Chapter Two

Motion in One Dimension

Dynamics

- The branch of physics involving the motion of an object and the relationship between that motion and other physics concepts
- ***Kinematics*** is a part of dynamics
  - In kinematics, you are interested in the *description* of motion
  - *Not* concerned with the cause of the motion

Quantities in Motion

- Any motion involves three concepts
  - Displacement
  - Velocity
  - Acceleration
- These concepts can be used to study objects in motion

Brief History of Motion

- Sumaria and Egypt
  - Mainly motion of heavenly bodies
- Greeks
  - Also to understand the motion of heavenly bodies
  - Systematic and detailed studies
  - Geocentric model

“Modern” Ideas of Motion

- Copernicus
  - Developed the heliocentric system
- Galileo
  - Made astronomical observations with a telescope
  - Experimental evidence for description of motion
  - Quantitative study of motion

Position

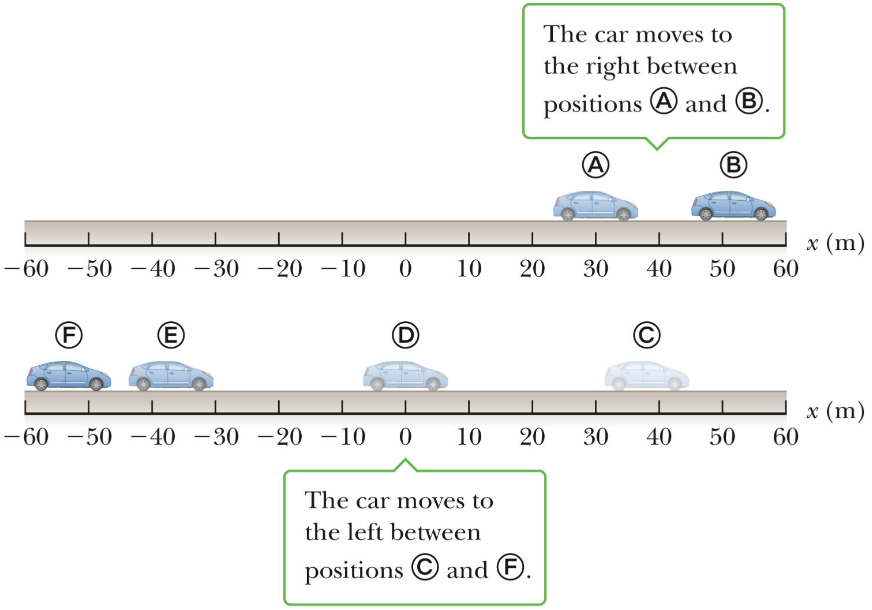
- Defined in terms of a **frame of reference**
  - A choice of coordinate axes
  - Defines a starting point for measuring the motion
    - Or any other quantity
  - One dimensional, so generally the x- or y-axis

Displacement

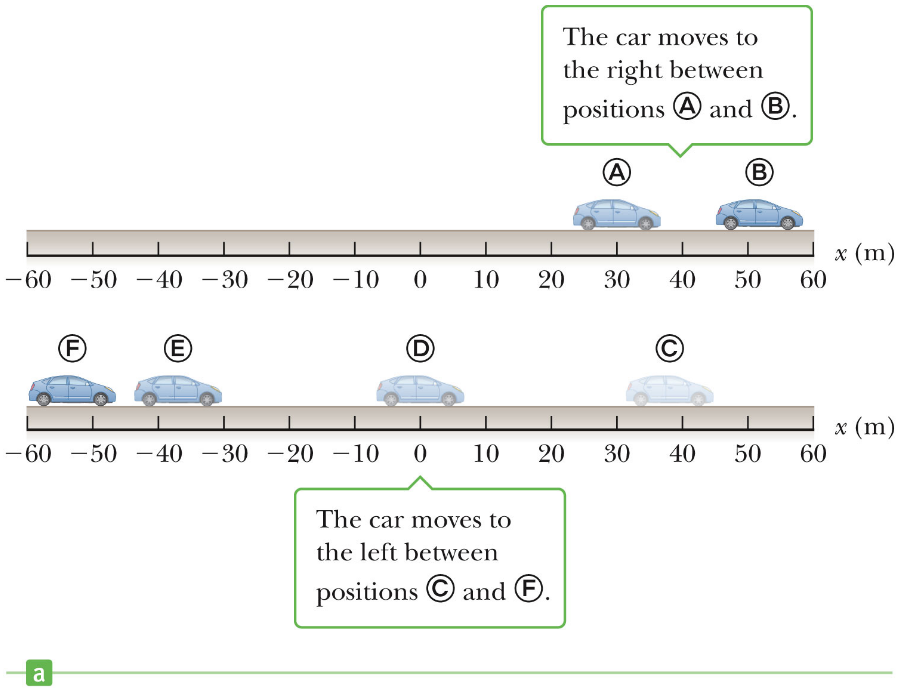
- Defined as the *change in position*
  - $\Delta x \equiv x_f - x_i$
    - f stands for final and i stands for initial
  - Units are meters (m) in SI

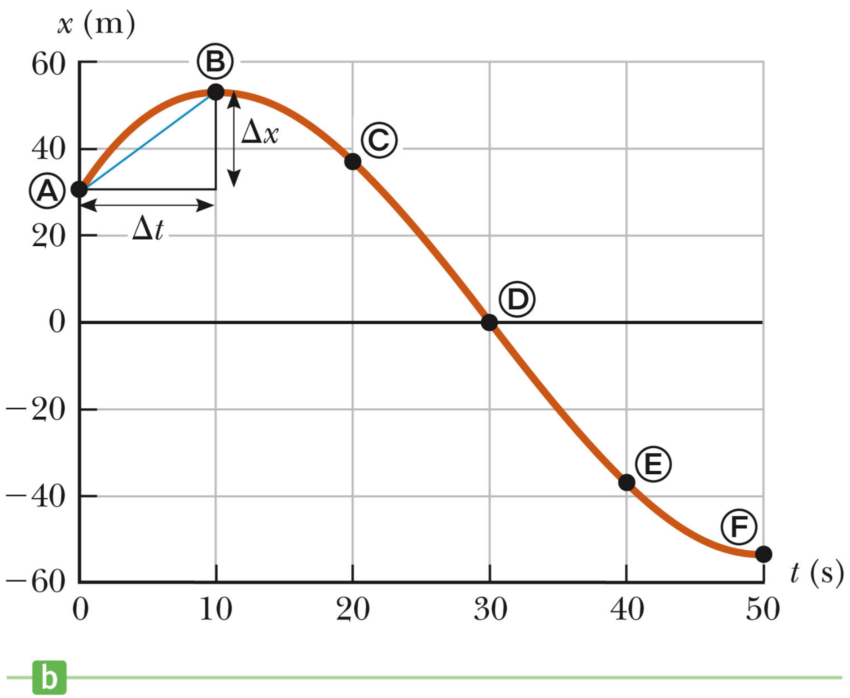
Displacement Examples

- From A to B
  - x_i = 30 m
  - x_f = 52 m
  - Δx = 22 m
  - The displacement is positive, indicating the motion was in the positive x direction
- From C to F
  - x_i = 38 m
  - x_f = -53 m
  - Δx = -91 m
  - The displacement is negative, indicating the motion was in the negative x direction



Displacement, Graphical





Vector and Scalar Quantities

- Vector quantities need both magnitude (size) and direction to completely describe them
  – Generally denoted by boldfaced type and an arrow over the letter
  – + or – sign is sufficient for this chapter
- Scalar quantities are completely described by magnitude only

Displacement Isn’t Distance

- The displacement of an object is not the same as the distance it travels
  - Example: Throw a ball straight up and then catch it at the same point you released it
    - The distance is twice the height
    - The displacement is zero

Speed

- The **average speed** of an object is defined as the total distance traveled divided by the total time elapsed

$$\text{Average speed} = \frac{\text{path length}}{\text{elapsed time}}$$

$$v = \frac{d}{t}$$

  – Speed is a scalar quantity

Speed, cont

- Average speed totally ignores any variations in the object's actual motion during the trip
- The path length and the total time are all that is important
  - Both will be positive, so speed will be positive
- SI units are m/s

Path Length vs. Distance

- Distance depends only on the endpoints

$$\Delta s = \sqrt{\left(x_f - x_i\right)^2 + \left(y_f - y_i\right)^2}$$

  - The distance does not depend on what happens between the endpoints
  - Is the magnitude of the displacement
- Path length will depend on the actual route taken

Velocity

- It takes time for an object to undergo a displacement
- The **average velocity** is rate at which the displacement occurs

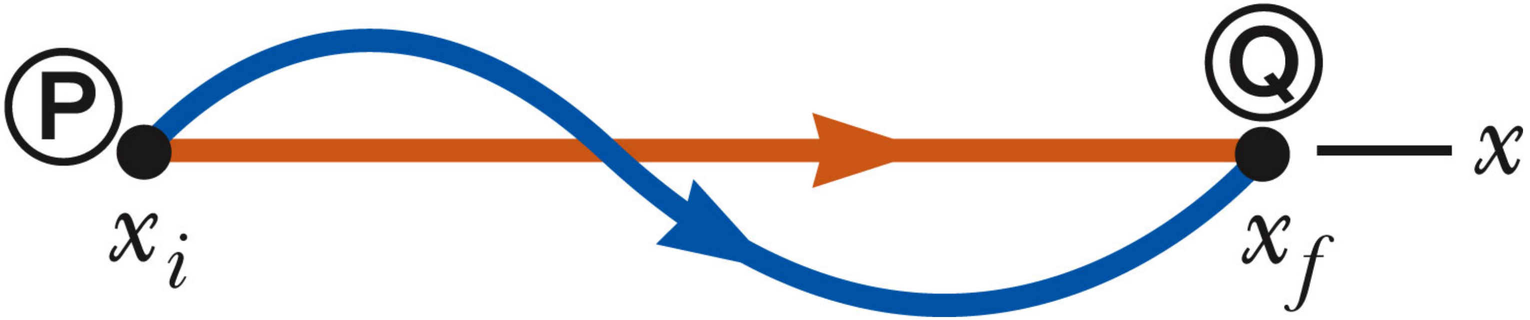
$$v_{average} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

- Velocity can be positive or negative
  - Δt is always positive
- Average speed is not the same as the average velocity

Velocity continued

- Direction will be the same as the direction of the displacement, + or - is sufficient in one-dimensional motion
- Units of velocity are m/s (SI)
  - Other units may be given in a problem, but generally will need to be converted to these
  - In other systems:
    - US Customary: ft/s
    - cgs: cm/s

Speed vs. Velocity



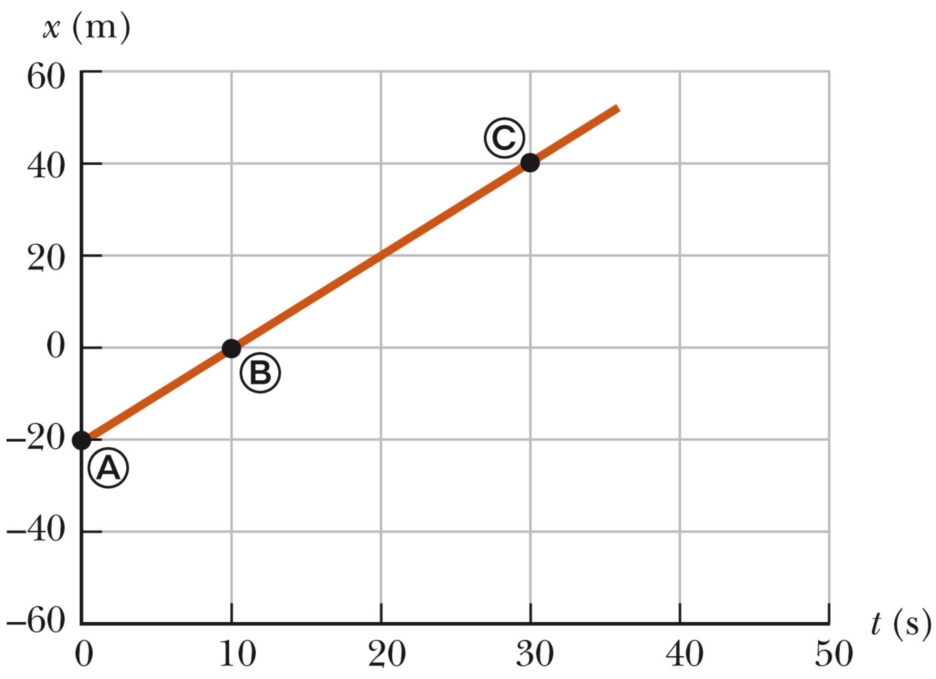
- Cars on both paths have the same average velocity since they had the same displacement in the same time interval
- The car on the blue path will have a greater average speed since the path length it traveled is larger

Graphical Interpretation of Velocity

- Velocity can be determined from a position-time graph
- Average velocity equals the slope of the line joining the initial and final points on the graph
- An object moving with a constant velocity will have a graph that is a straight line

Average Velocity, Constant

- The straight line indicates constant velocity
- The slope of the line is the value of the average velocity



Notes on Slopes

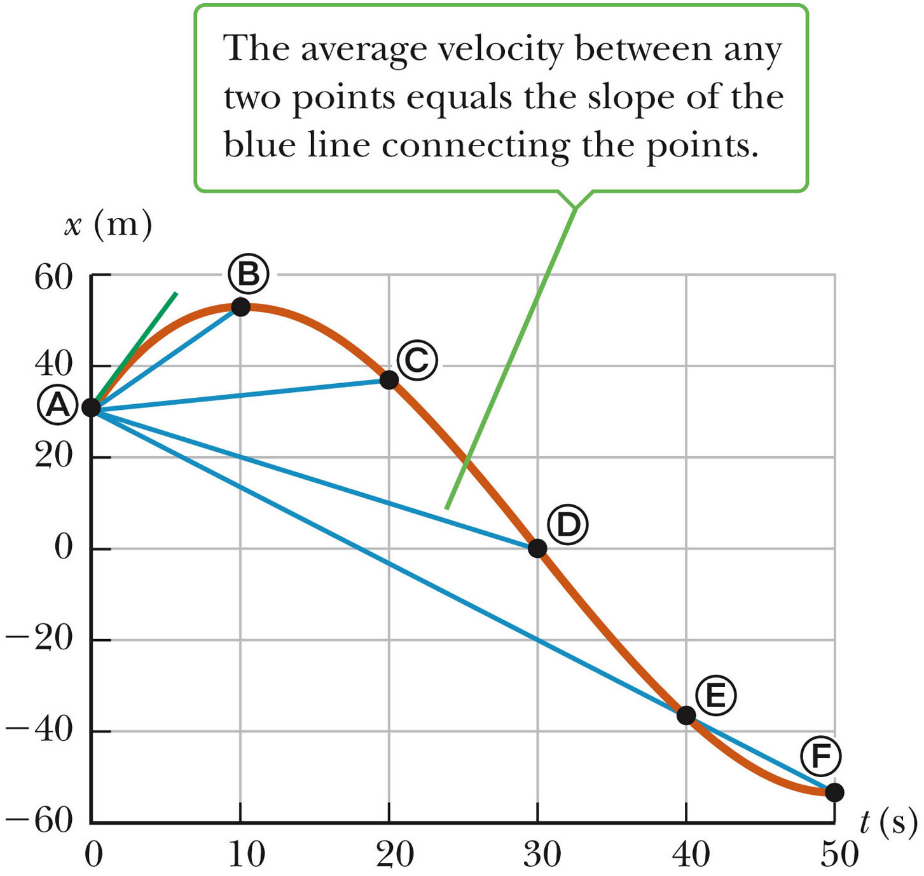
- The general equation for the slope of any line is

$$slope = \frac{change\ in\ vertical\ axis}{change\ in\ horizontal\ axis}$$

  – The meaning of a specific slope will depend on the physical data being graphed
- Slope carries units

Average Velocity, Non Constant

- The motion is non-constant velocity
- The average velocity is the slope of the straight line joining the initial and final points



Instantaneous Velocity

- The limit of the average velocity as the time interval becomes infinitesimally short, or as the time interval approaches zero

$$v \equiv \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

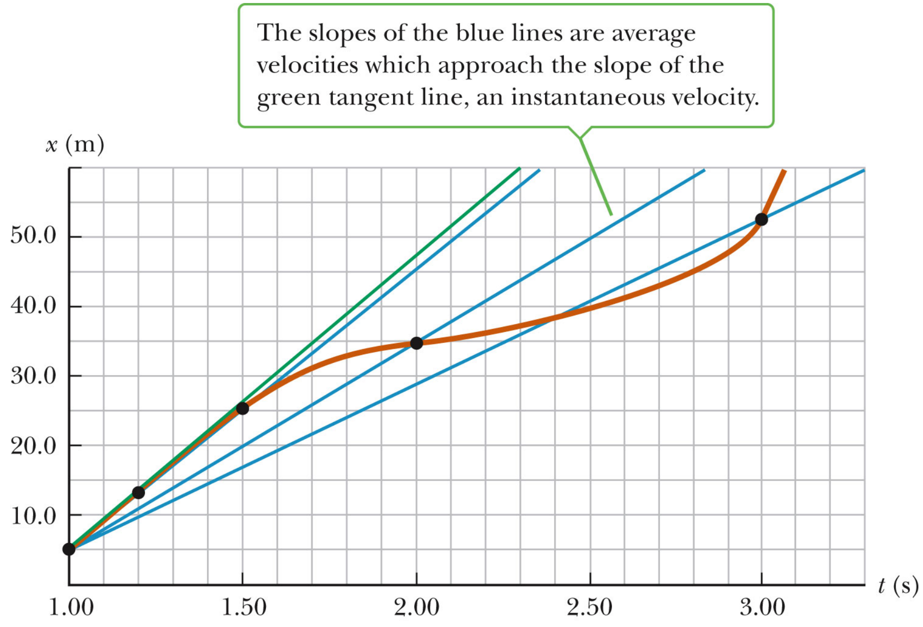
- The instantaneous velocity indicates what is happening at every point of time
  - The magnitude of the instantaneous velocity is what you read on a car's speedometer

Instantaneous Velocity on a Graph

- The slope of the line tangent to the position vs. time graph is defined to be the instantaneous velocity at that time
  - The instantaneous speed is defined as the magnitude of the instantaneous velocity

Graphical Instantaneous Velocity

- Average velocities are the blue lines
- The green line (tangent) is the instantaneous velocity



Acceleration

- Changing velocity means an acceleration is present
- Acceleration is the rate of change of the velocity

$$\bar{a} \equiv \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

- Units are m/s² (SI), cm/s² (cgs), and ft/s² (US Cust)

Average Acceleration

- Vector quantity
- When the object's velocity and acceleration are in the same direction (either positive or negative), then the speed of the object increases with time
- When the object's velocity and acceleration are in the opposite directions, the speed of the object decreases with time

Negative Acceleration

- A negative acceleration does not necessarily mean the object is slowing down
- If the acceleration and velocity are both negative, the object is speeding up
- “Deceleration” means a decrease in speed, not a negative acceleration

Instantaneous and Uniform Acceleration

- The limit of the average acceleration as the time interval goes to zero

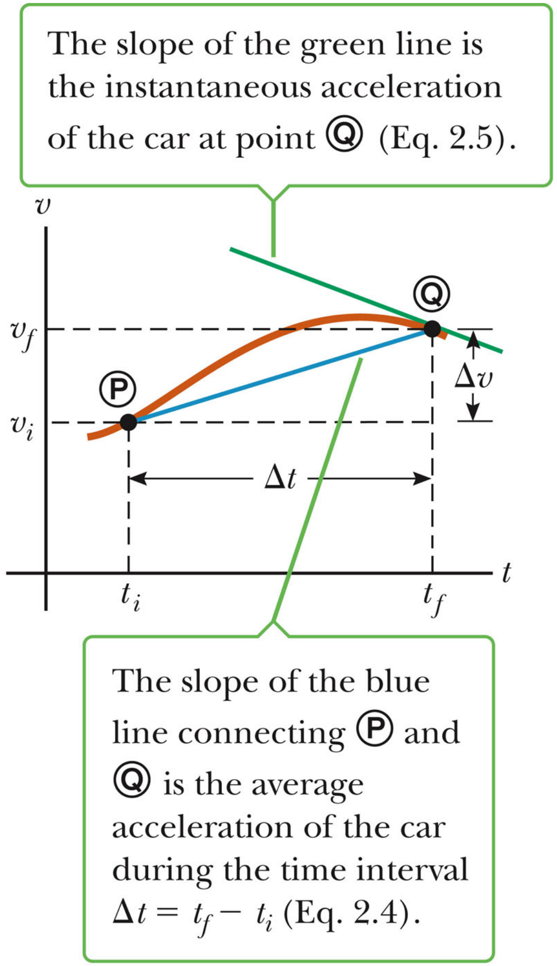
$$a \equiv \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t}$$

- When the instantaneous accelerations are always the same, the acceleration will be uniform
  - The instantaneous accelerations will all be equal to the average acceleration

Graphical Interpretation of Acceleration

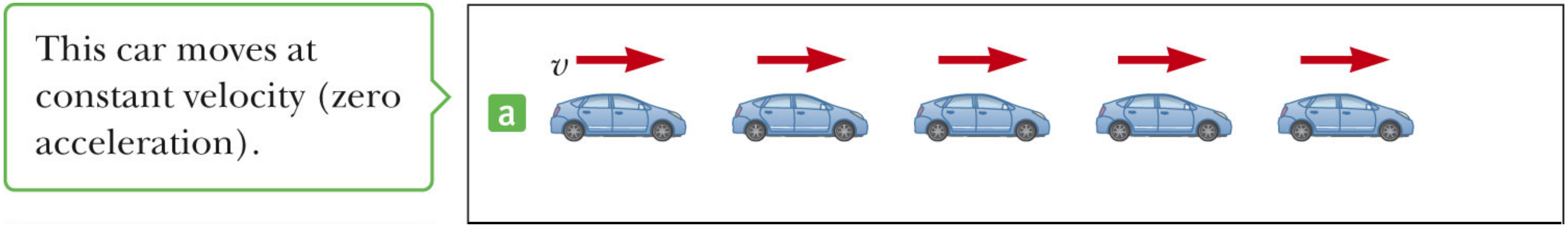
- Average acceleration is the slope of the line connecting the initial and final velocities on a velocity vs. time graph
- Instantaneous acceleration is the slope of the tangent to the curve of the velocity-time graph

Average Acceleration – Graphical Example



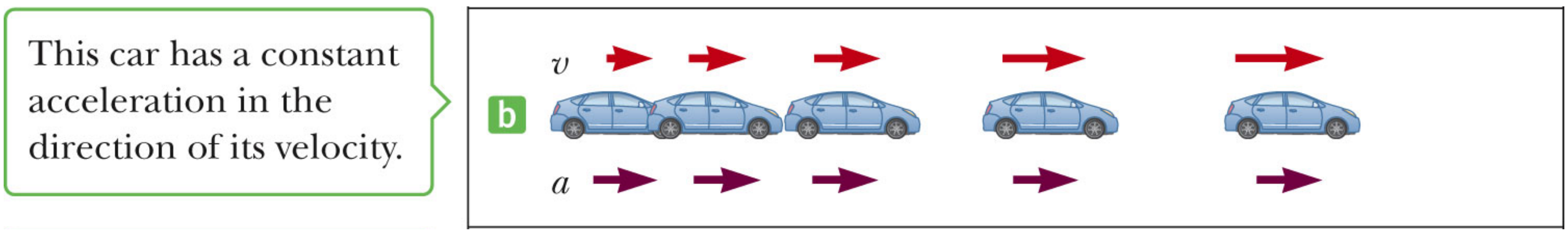
Section 2.3

Relationship Between Acceleration and Velocity



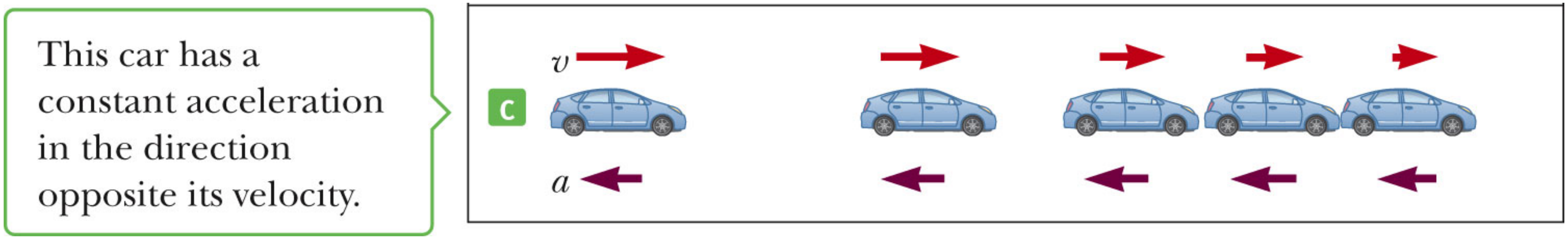
- Uniform velocity (shown by red arrows maintaining the same size)
- Acceleration equals zero

Relationship Between Velocity and Acceleration



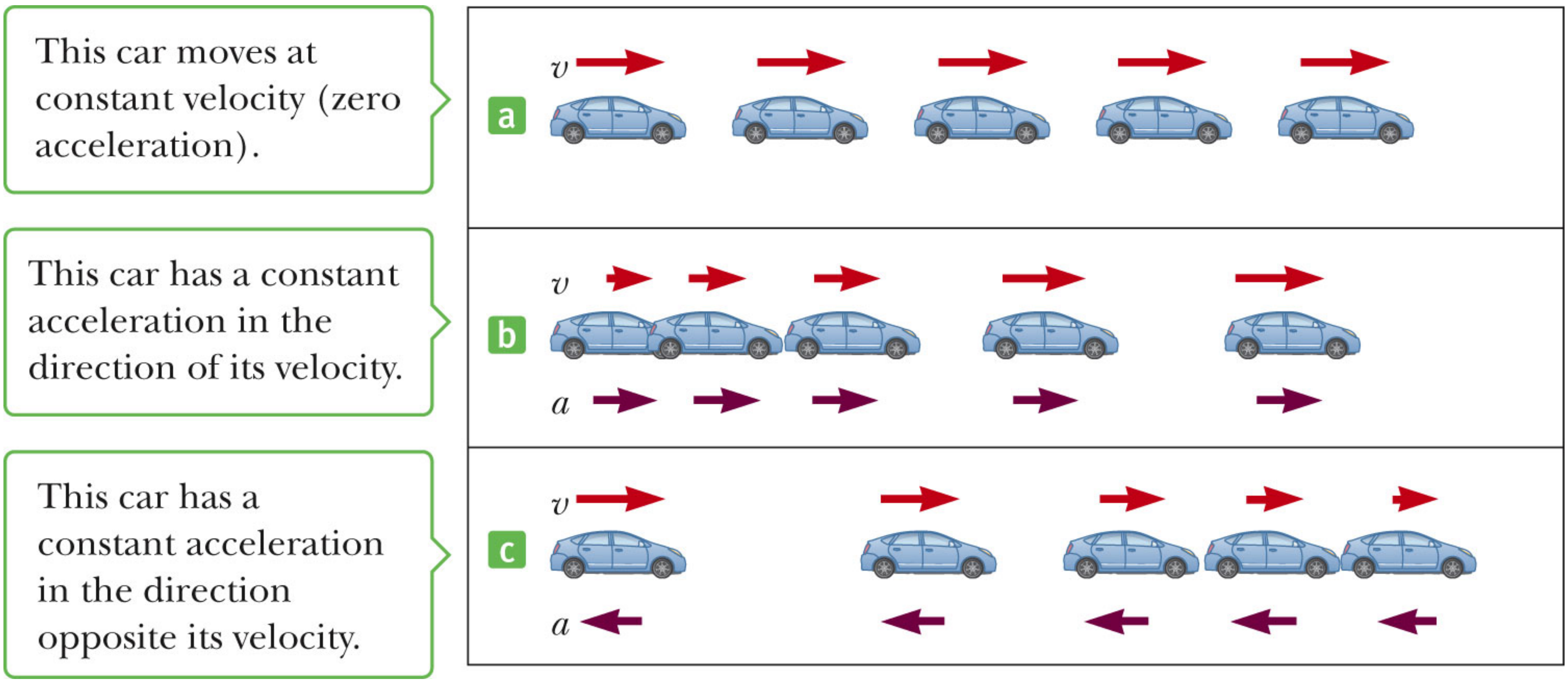
- Velocity and acceleration are in the same direction
- Acceleration is uniform (violet arrows maintain the same length)
- Velocity is increasing (red arrows are getting longer)
- Positive velocity and positive acceleration

Relationship Between Velocity and Acceleration



- Acceleration and velocity are in opposite directions
- Acceleration is uniform (violet arrows maintain the same length)
- Velocity is decreasing (red arrows are getting shorter)
- Velocity is positive and acceleration is negative

Motion Diagram Summary



Equations for Constant Acceleration

- These equations are used in situations with uniform acceleration

$$v = v_o + at$$

$$\Delta x = \bar{v}t = \frac{1}{2}\left(v_o + v\right) t$$

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

$$v^2 = v_o^2 + 2a\Delta x$$

Notes on the equations

$$\Delta x = v_{average}\, t = \left(\frac{v_o + v}{2}\right) t$$

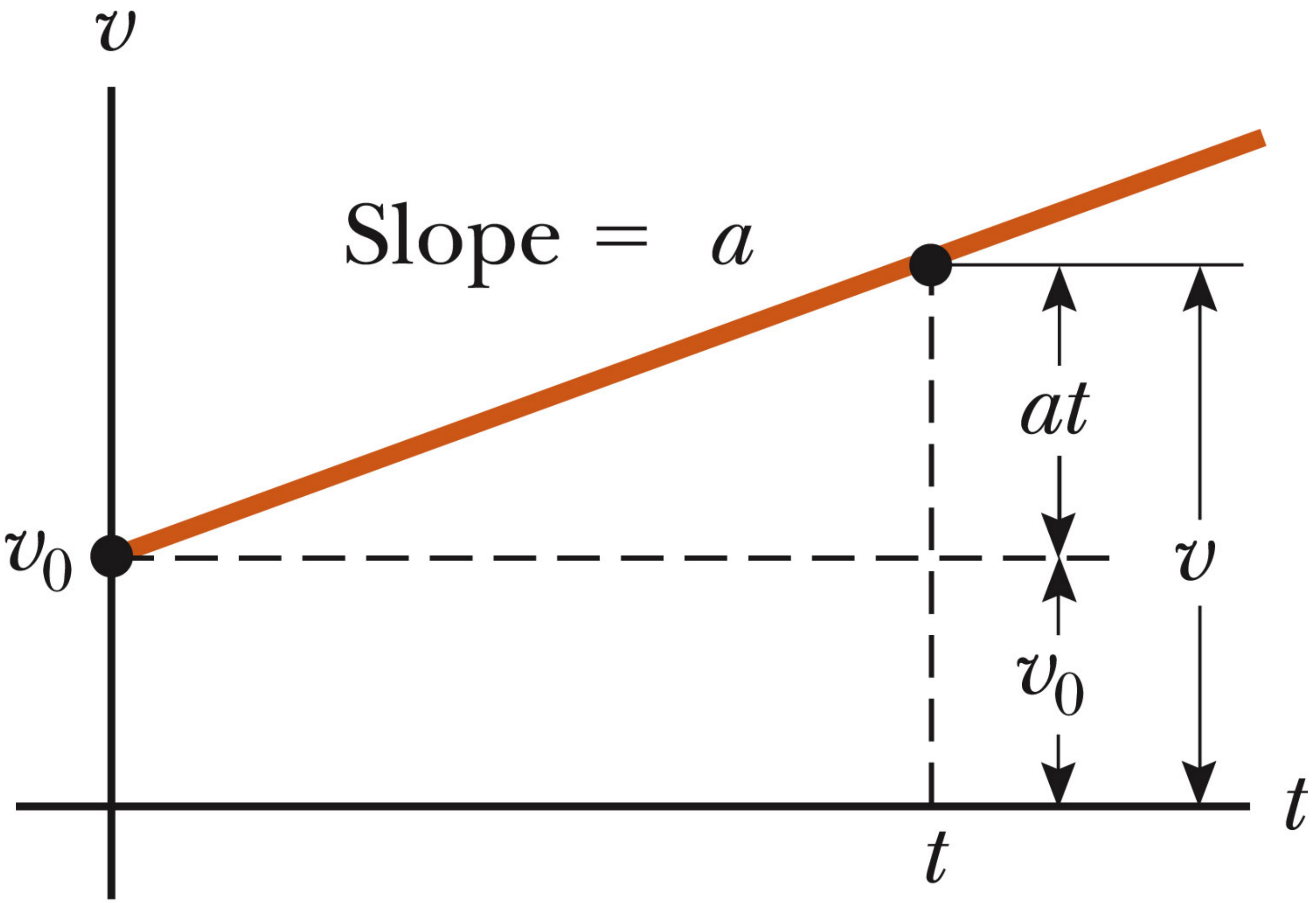
- Gives displacement as a function of velocity and time
- Use when you don't know and aren't asked for the acceleration

Notes on the equations

$$v = v_o + at$$

- Shows velocity as a function of acceleration and time
- Use when you don’t know and aren’t asked to find the displacement

Graphical Interpretation of the Equation



Notes on the equations

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

- Gives displacement as a function of time, velocity and acceleration
- Use when you don't know and aren't asked to find the final velocity
- The area under the graph of v vs. t for any object is equal to the displacement of the object

Notes on the equations

$$v^2 = v_o^2 + 2a\Delta x$$

- Gives velocity as a function of acceleration and displacement
- Use when you don't know and aren't asked for the time

Problem-Solving Hints

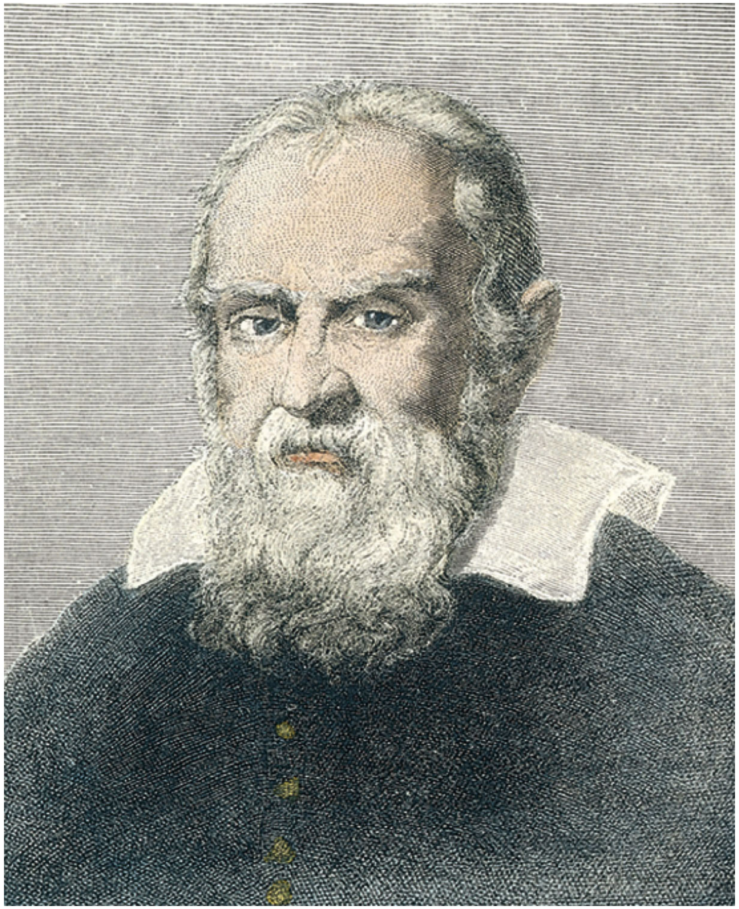
- Read the problem
- Draw a diagram
  - Choose a coordinate system
  - Label initial and final points
  - Indicate a positive direction for velocities and accelerations
- Label all quantities, be sure all the units are consistent
  - Convert if necessary
- Choose the appropriate kinematic equation

Problem-Solving Hints, cont

- Solve for the unknowns
  - You may have to solve two equations for two unknowns
- Check your results
  - Estimate and compare
  - Check units

Galileo Galilei

- 1564 - 1642
- Galileo formulated the laws that govern the motion of objects in free fall
- Also looked at:
  - Inclined planes
  - Relative motion
  - Thermometers
  - Pendulum



Free Fall

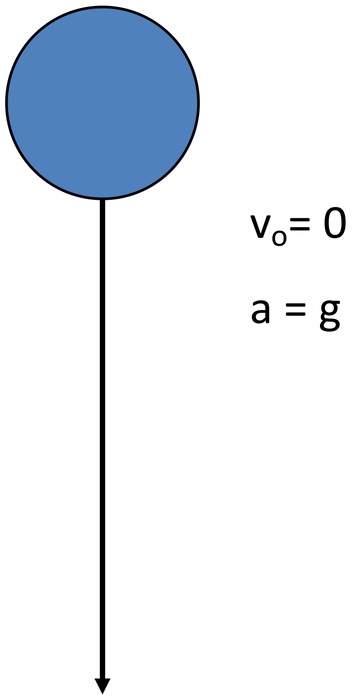
- A freely falling object is any object moving freely under the influence of gravity alone
  - Free fall does not depend on the object's original motion
- All objects falling near the earth's surface fall with a constant acceleration
- The acceleration is called the acceleration due to gravity, and indicated by g

Acceleration due to Gravity

- Symbolized by *g*
- g = 9.80 m/s^2
  - When estimating, use $g \approx 10$ m/s^2
- *g* is always directed downward
  - Toward the center of the earth
- Ignoring air resistance and assuming *g* doesn't vary with altitude over short vertical distances, free fall is constantly accelerated motion

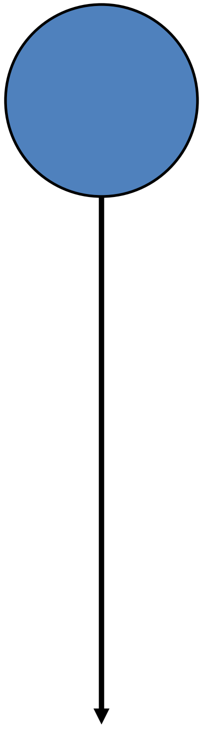
Free Fall – an object dropped

- Initial velocity is zero
- Let up be positive
  - Conventional
- Use the kinematic equations
  - Generally use y instead of x since vertical
- Acceleration is g = -9.80 m/s^2



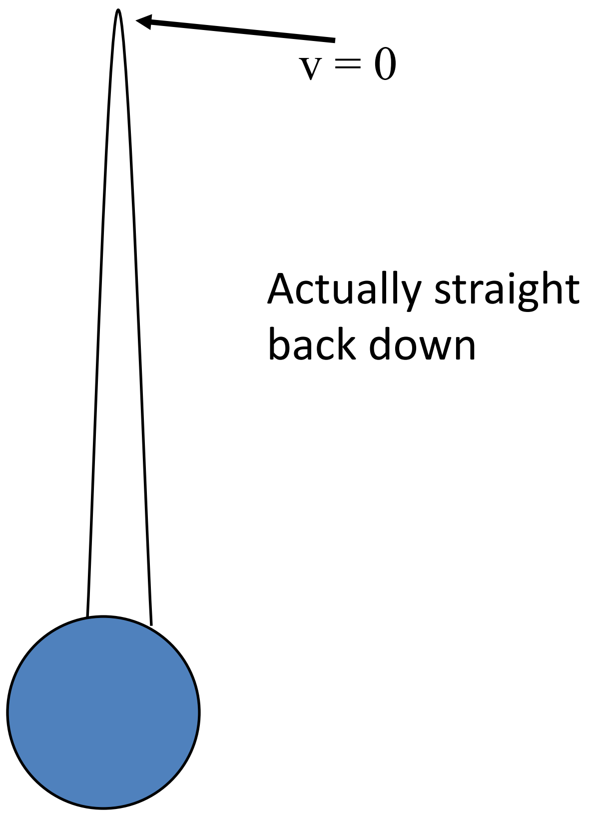
Free Fall – an object thrown downward

- $a = g = -9.80 \text{ m/s}^2$
- Initial velocity $\neq 0$
  - With upward being positive, initial velocity will be negative



Free Fall – object thrown upward

- Initial velocity is upward, so positive
- The instantaneous velocity at the maximum height is zero
- a = g = -9.80 m/s^2 everywhere in the motion

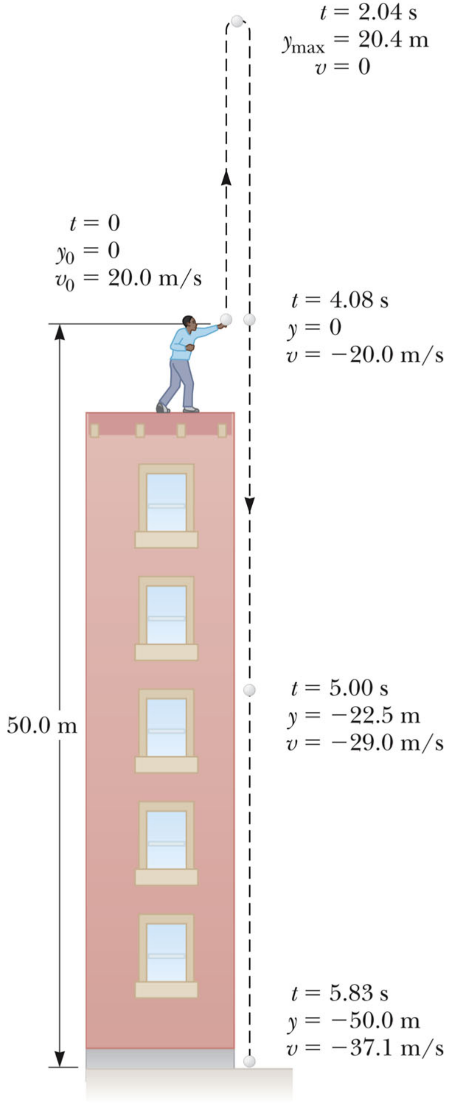


Thrown upward, cont.

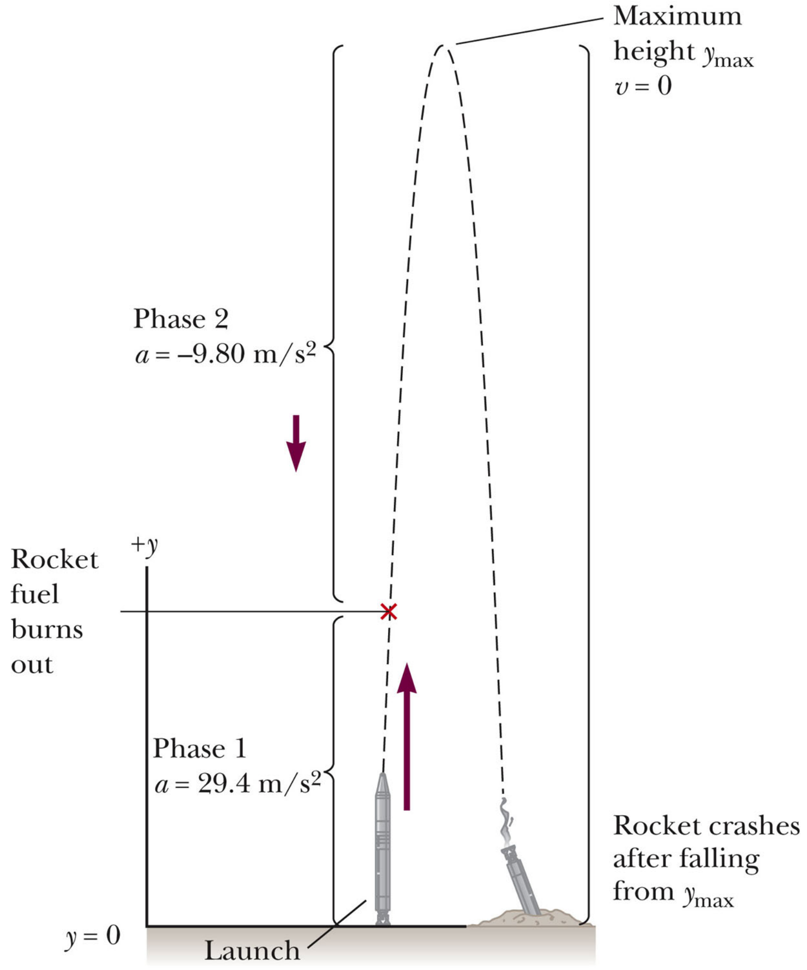
- The motion may be symmetrical
  - Then $t_{up} = t_{down}$
  - Then $v = -v_o$
- The motion may not be symmetrical
  - Break the motion into various parts
    - Generally up and down

Non-symmetrical Free Fall Example

- Need to divide the motion into segments
- Possibilities include
  - Upward and downward portions
  - The symmetrical portion back to the release point and then the non-symmetrical portion



Combination Motions



Section 2.6