Chapter 2

Motion in One Dimension

Dynamics and Kinematics

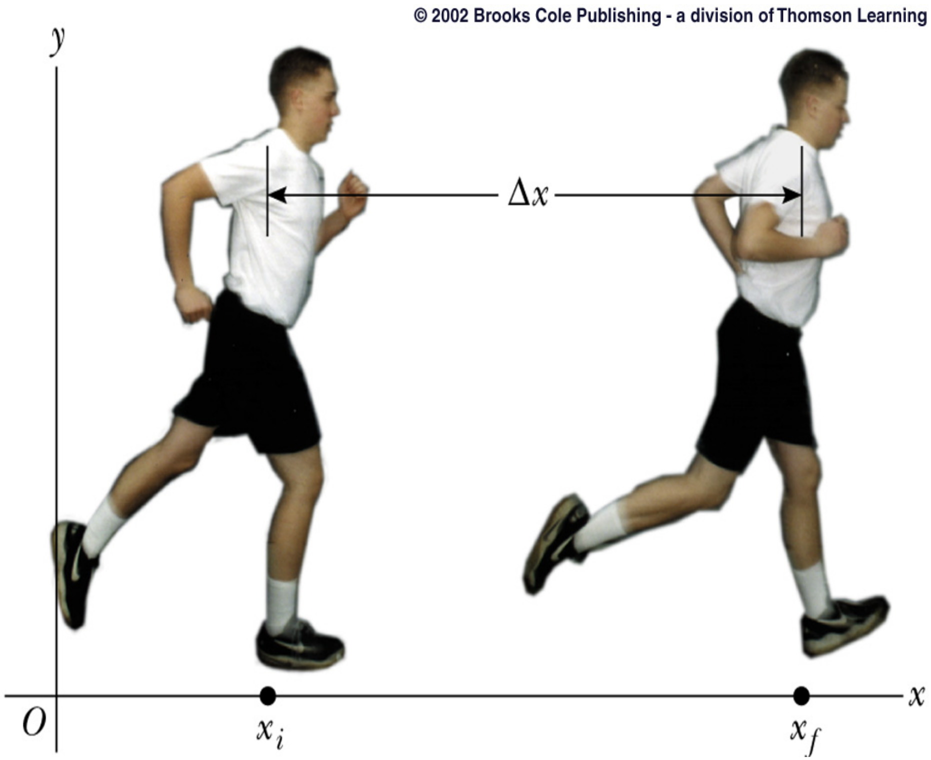
- Dynamics is a branch of physics involving the motion of an object
- ***Kinematics*** is a part of dynamics
  - In kinematics, you are interested in the *description* of motion
  - *Not* concerned with the cause of the motion

Quantities in Motion

- Any motion of an object involves four concepts
  - Position of the object
  - Displacement of the object
  - Velocity of the object
  - Acceleration of the oblect
- All these quantities generally may change with time

Position change=motion

- Position is defined as a coordinate in a reference frame
- Motion is change of position with time
- In this chapter we discuss motion in one dimension, along a straight line
  - usually select along 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
    - usually use Δy if vertical
    - In principle, may select X-axis as vertical if want, the name does not matter
  - Units are meters (m) in SI

Vector and Scalar Quantities

- Vector quantities have both magnitude (size) and direction
  - For notation of vectors usually use bold and an arrow over the letter: $\vec{\mathbf{A}}$
  - Displacement is a vector, pointing from initial position to final
  - + or – sign is sufficient to show the direction of vectors for one dimensional motion, considered in this chapter: since we consider only one dimensional

    + means vector pointing in the same direction as a selected axis, - means pointing opposite to axis

- Scalar quantities are described by magnitude only (no direction)

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

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

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

- Speed is a scalar quantity, has no direction
- SI units are m/s

Velocity

- The **average velocity** is rate at which the displacement occurs

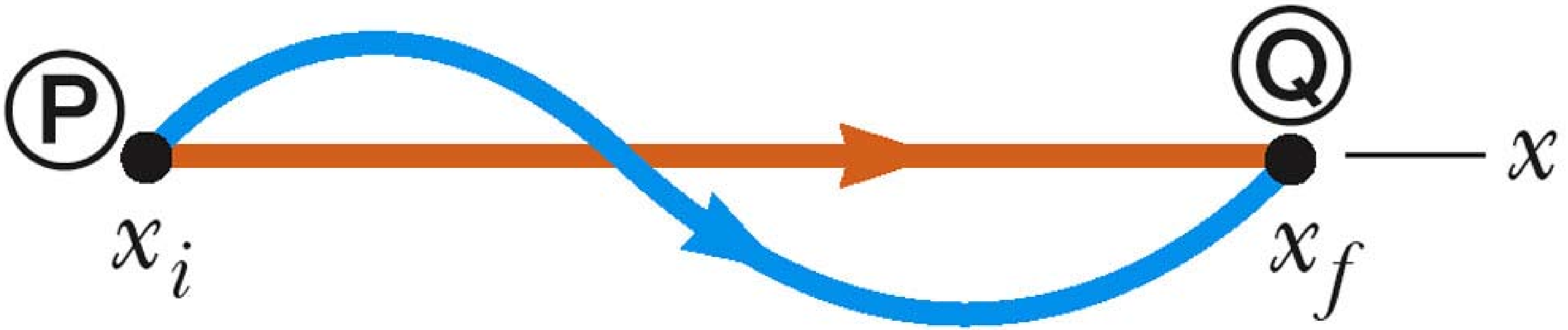
$$v_{average} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$

  - Usually select $t_i = 0$
- Velocity is a vector (has a direction, same as displacement)

Velocity continued

- Direction of average velocity will be the same as the direction of the displacement (time interval is always positive)
  - + or - is sufficient to show the direction
- Units of velocity are m/s (SI)
  - Other units (e.g. ft/s) may be given in a problem, but generally will need to be converted to these

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 distance it traveled is larger

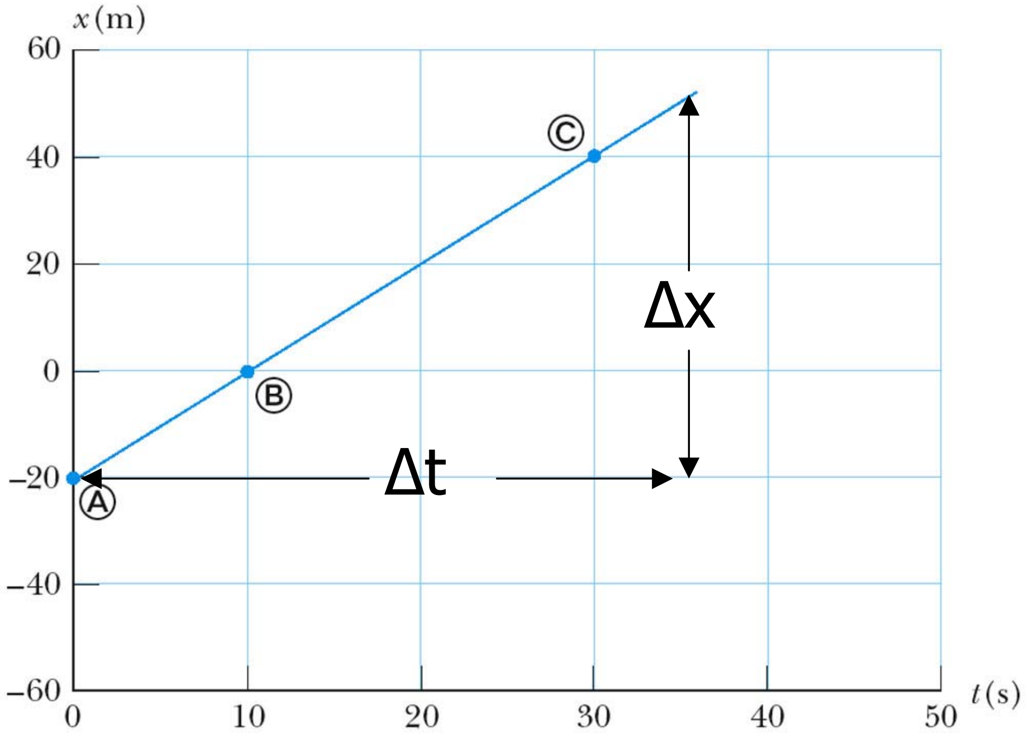
Graphical Interpretation of Velocity

- Velocity can be determined from a position-time graph
- Average velocity equals the slope of the line joining the initial and final positions
- 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, use

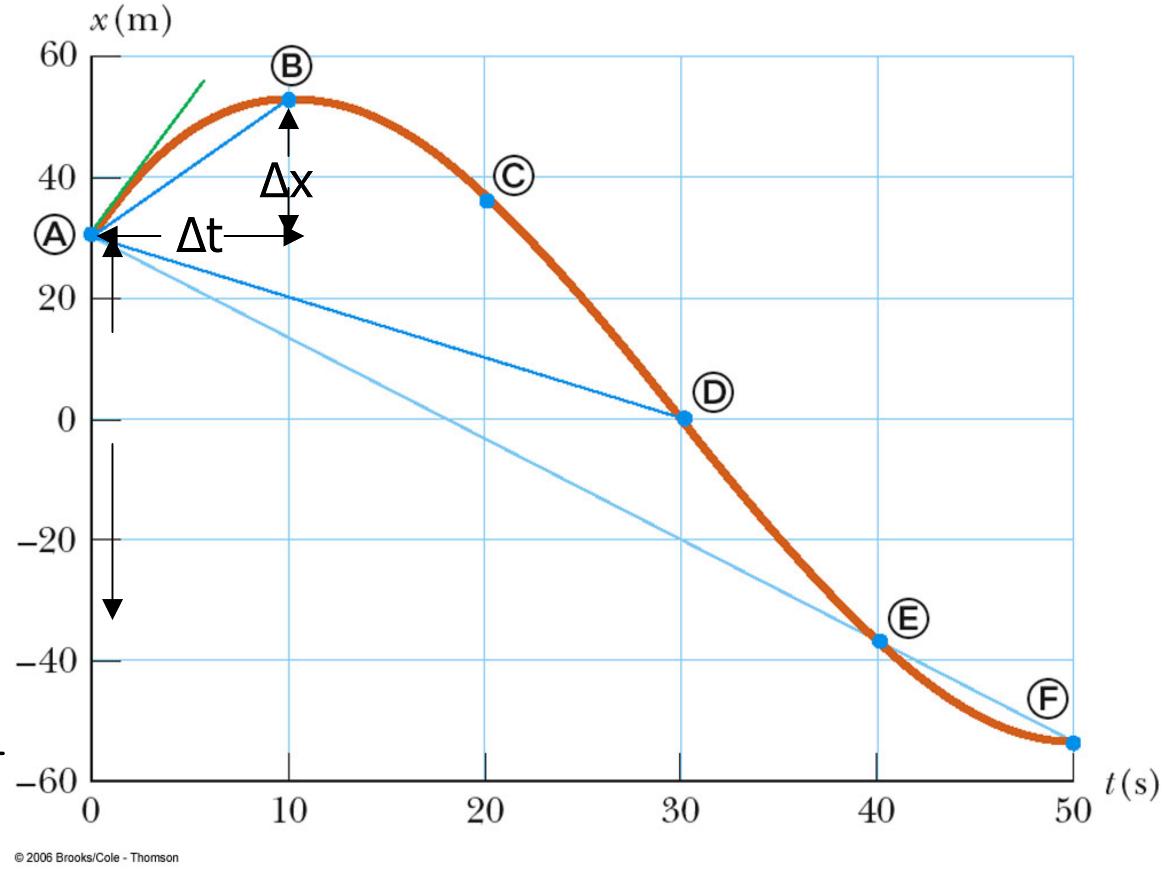
$$v_{average} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{t_f - t_i}$$



Average Velocity, Non Constant

- The average velocity is the slope of the blue line joining two points, use

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



Instantaneous Velocity

- The limit of the average velocity as the time interval becomes very short, approaching zero

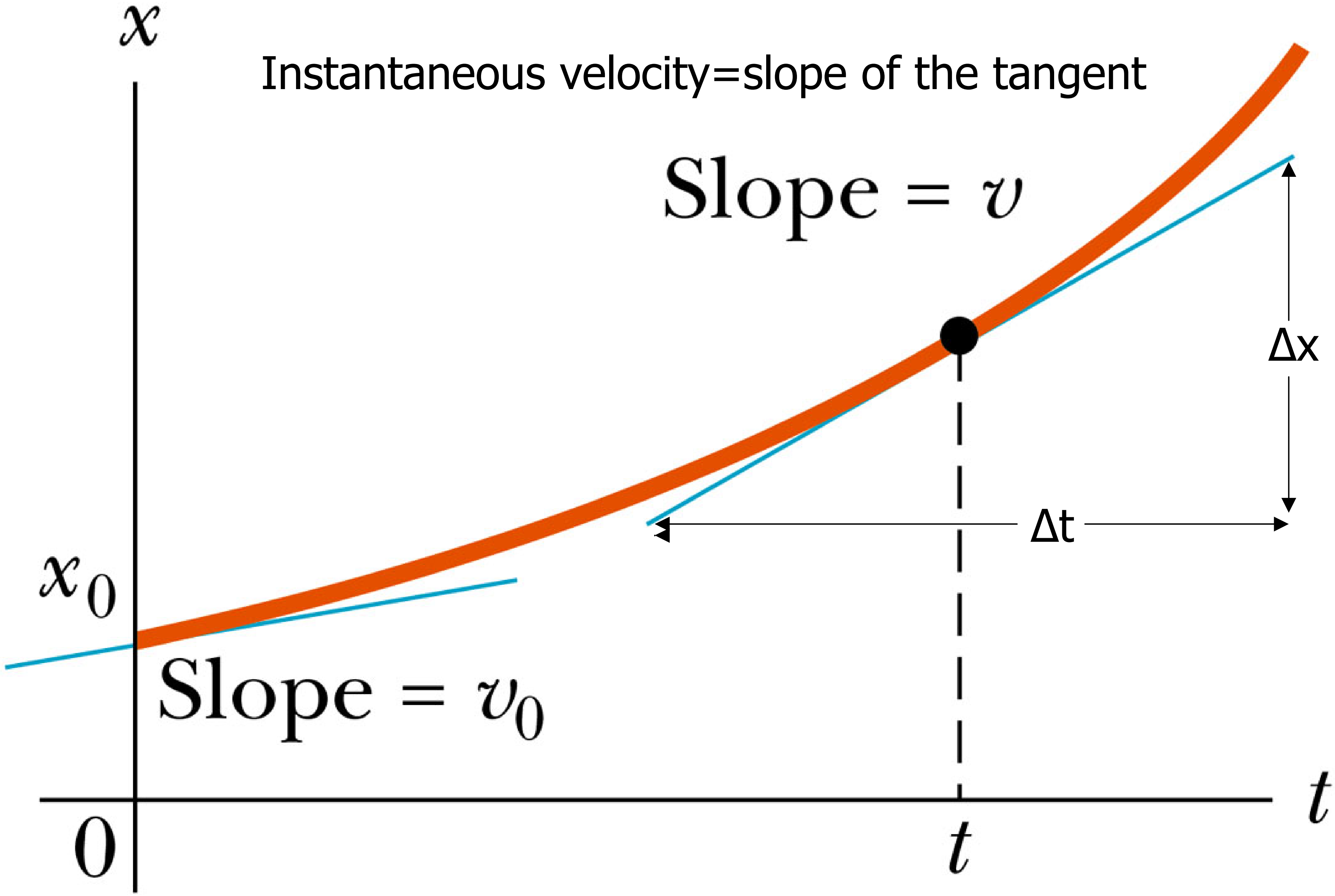
$$v \equiv \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$$

- The instantaneous velocity indicates the velocity at every point of time

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

Instantaneous velocity=slope of the tangent



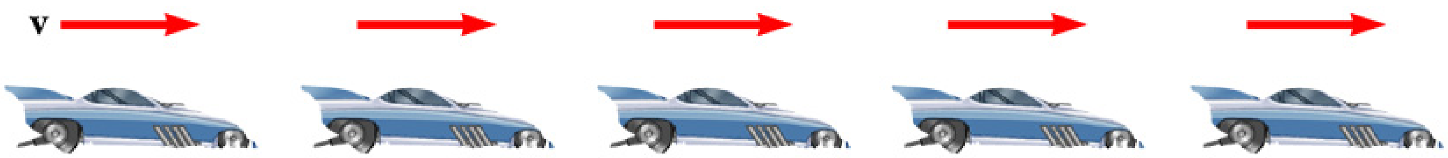
Acceleration

- When velocity changes with time (e.g. increasing or decreasing), an **acceleration** is present (is non-zero)
- Acceleration is the rate of change of the velocity:

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

- Units are m/s^2 (SI)
- Instantaneous acceleration is the limit of the average acceleration as the time interval goes to zero.
- Uniform acceleration means that acceleration a=const (not changing with time)
- Acceleration is a vector quantity (has direction, may be positive or negative for motion along a straight line)

Acceleration in case of uniform (constant) Velocity



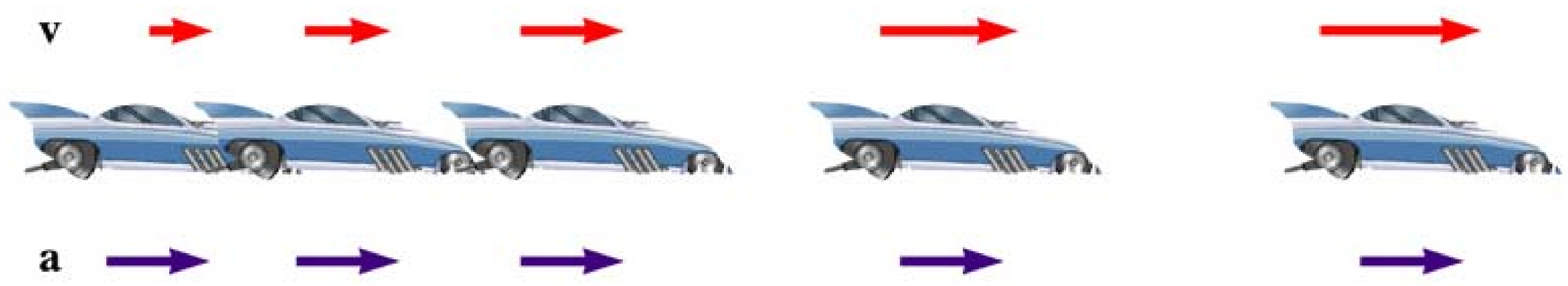
- Uniform velocity (shown by red arrows maintaining the same size)
- Acceleration equals zero, since $\Delta v = 0$

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

Velocity and Acceleration are vectors! Both have directions, may be positive or negative!

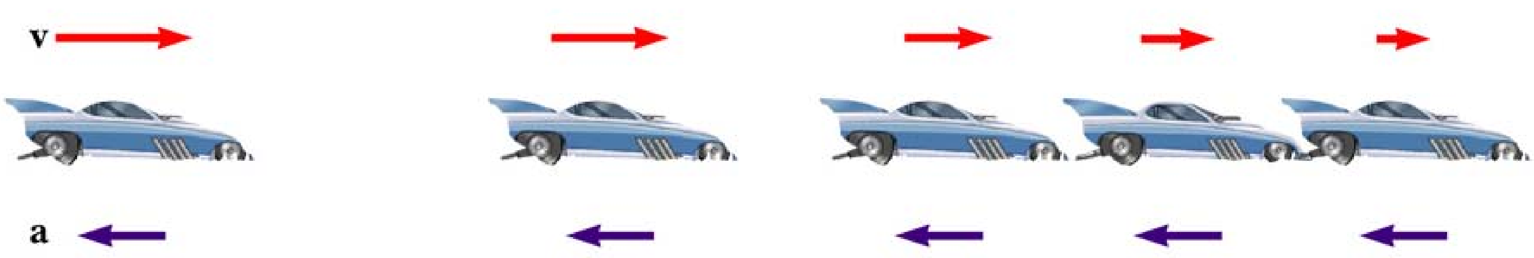
- When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
- When the sign of the velocity and the acceleration are in the opposite directions, the speed is decreasing

Velocity and Acceleration: constant acceleration in the same direction as velocity



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

Velocity and Acceleration: case of opposite directions

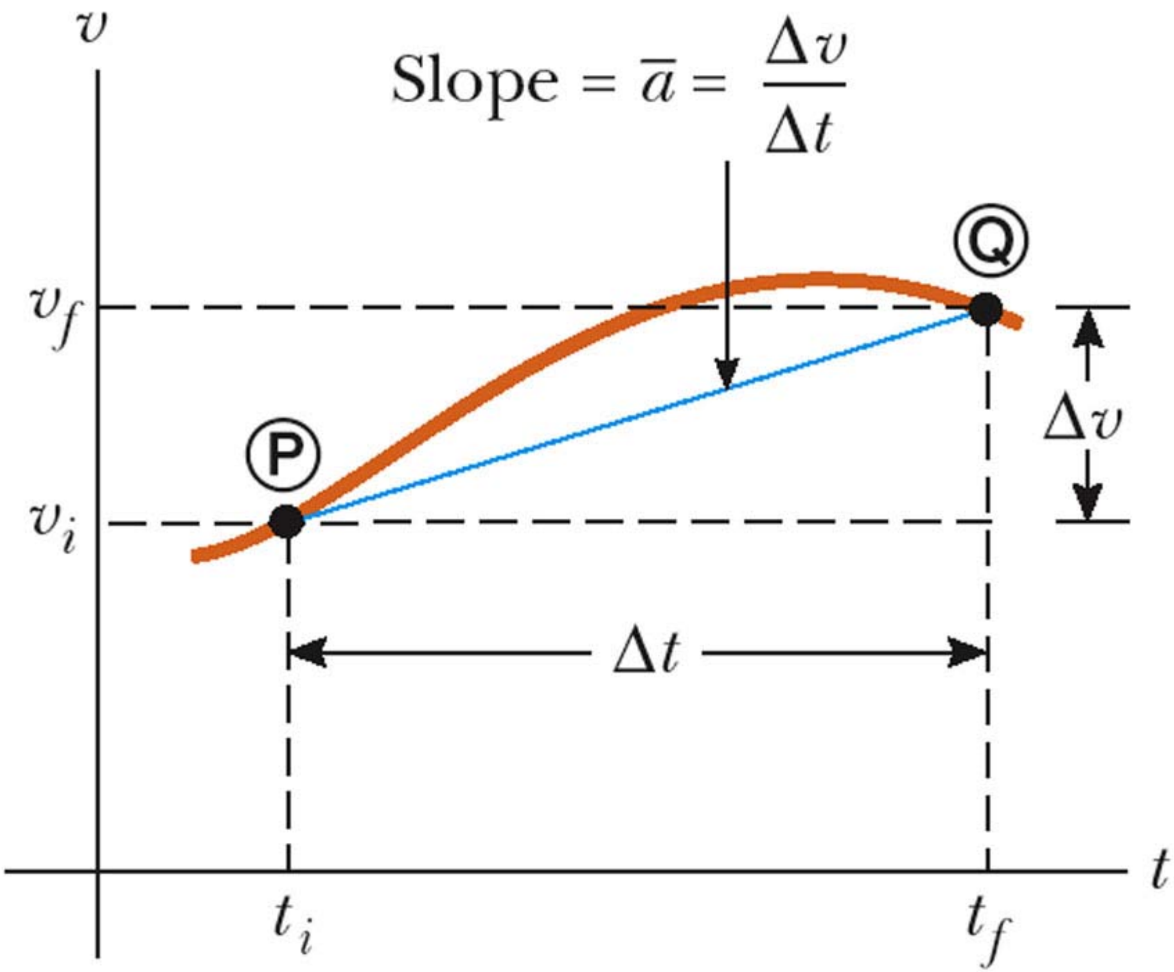


- Acceleration and velocity are in opposite directions
- Velocity is positive and acceleration is negative (axis goes from left to right)
- Acceleration is uniform (blue arrows maintain the same length)
- Velocity is decreasing (red arrows are getting shorter)

Graphical Interpretation of Acceleration

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

Average Acceleration



Most important equations for Chapter 2 as summarized in your book

TABLE 2.4

Equations for Motion in a Straight Line Under Constant Acceleration

Equation	Information Given by Equation
$v = v_0 + at$	Velocity as a function of time
$\Delta x = v_0 t + \frac{1}{2}at^2$	Displacement as a function of time
$v^2 = v_0^2 + 2a\Delta x$	Velocity as a function of displacement

Note: Motion is along the x-axis. At $t = 0$, the velocity of the particle is v_0.

Kinematic Equations (discussion)

- Used in situations with uniform acceleration for motion along straight line

$$v = v_o + at$$

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

$$\Delta x = v_o t + \frac{1}{2} a t^2$$ (alternative formula for Δx)

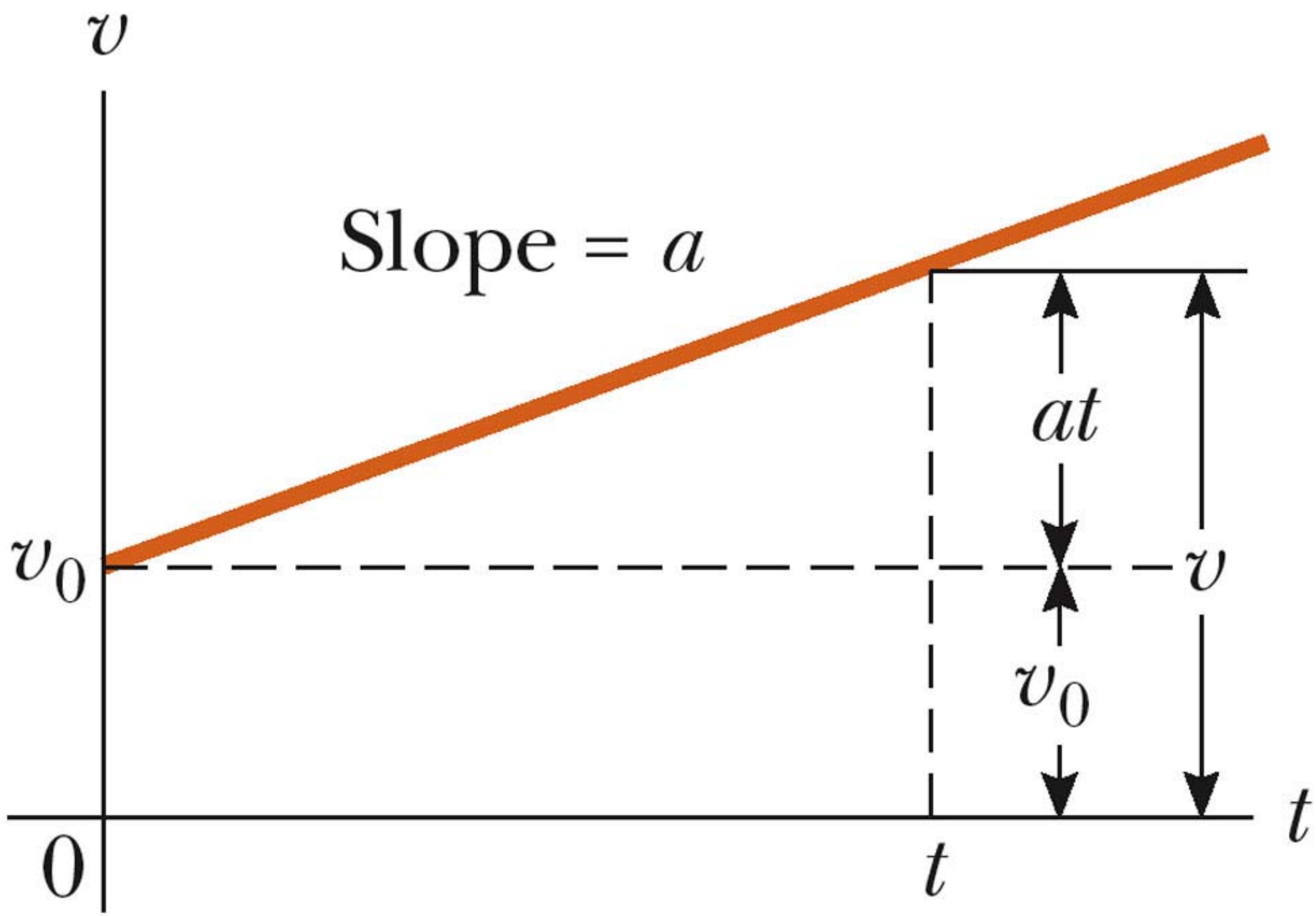
$$v^2 = v_o^2 + 2a\Delta x$$

Notes on the equations (1)

$$v = v_o + at$$

- 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 $v = v_o + at$



Notes on the equasions (2)

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

- 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 (3)

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

- 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

Notes on the equations (4)

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

- 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 (or N equations for N unknowns)

Problem-Solving Hints, cont

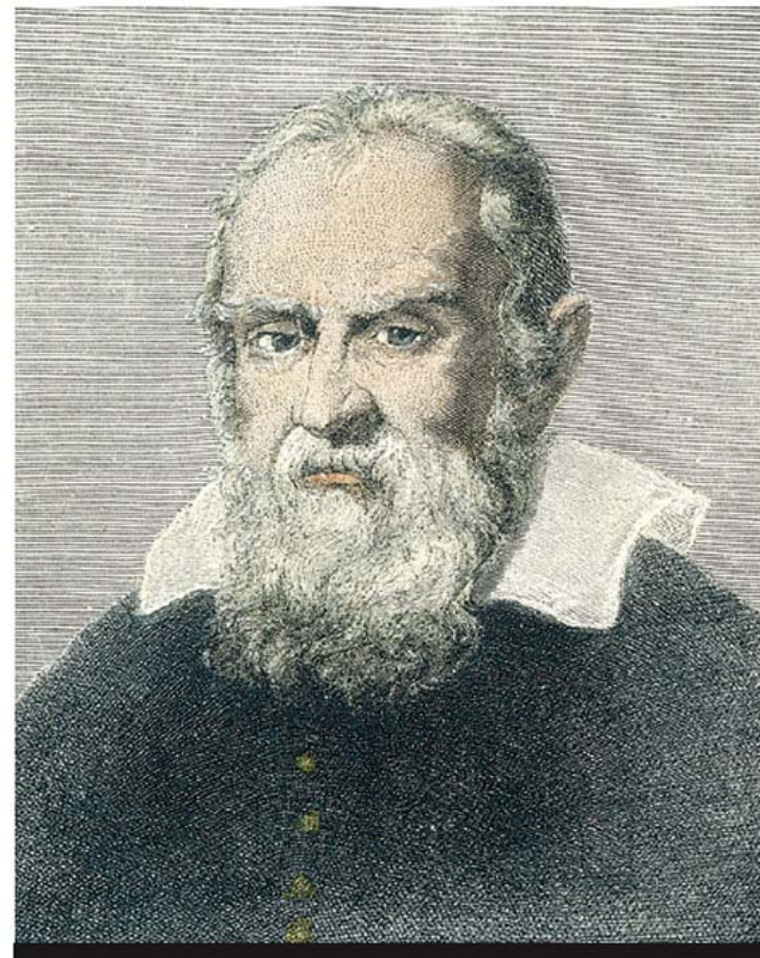
- Solve for the unknowns
  - You may have to solve two equations for two unknowns etc.
- Check your results
  - Estimate and compare
  - Check units
- Use common sense! If the result does not make sense it is likely incorrect

Free Fall

- All objects moving under the influence of gravity only are said to be in free fall
- All objects falling near the earth's surface fall with a constant acceleration

Galileo Galilei

- 1564 - 1642
- Galileo formulated the laws that govern the motion of objects in free fall
- Verified the laws by experiments: dropping objects from the leaning tower in Pisa, Italy
- “Father” of experimental science, understood that it is not enough just to think…

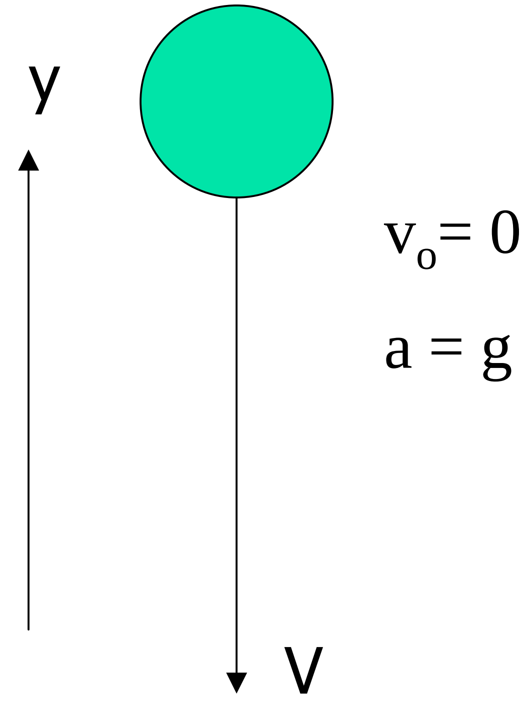


Acceleration due to Gravity

- Acceleration due to gravity is usually noted as g
- Magnitude of $g = 9.80\ m/s^2$
  - 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 gravity doesn't vary with altitude over short vertical distances, acceleration in free fall is equal to $g = 9.80\ m/s^2$ and does not change

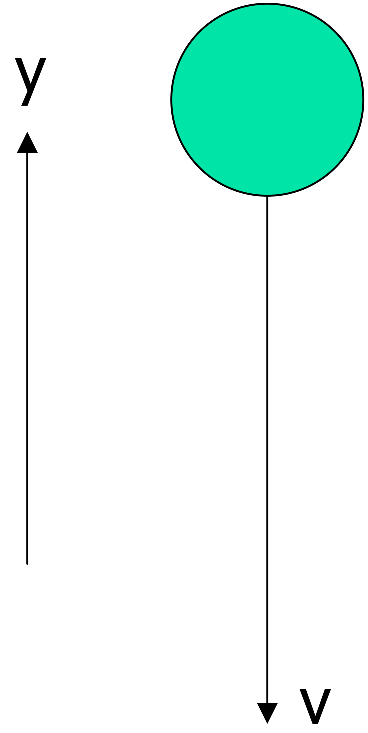
Free Fall – an object dropped with zero initial velocity

- Initial velocity is zero
- Use the kinematic equations
  - Usually use y instead of x since vertical
  - Let up be positive direction of y
- Acceleration is negative (since opposite to the direction of y-axis) $g = -9.80\ m/s^2$



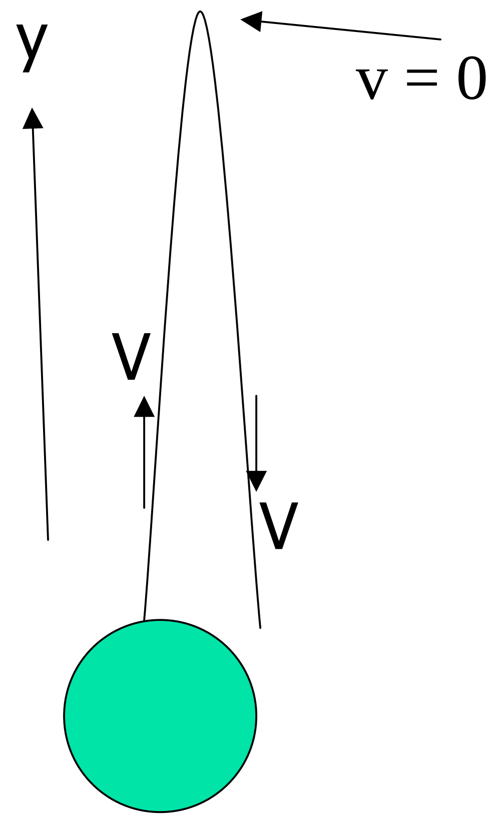
Free Fall – an object thrown downward

- $a = g = -9.80\ m/s^2$
- 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

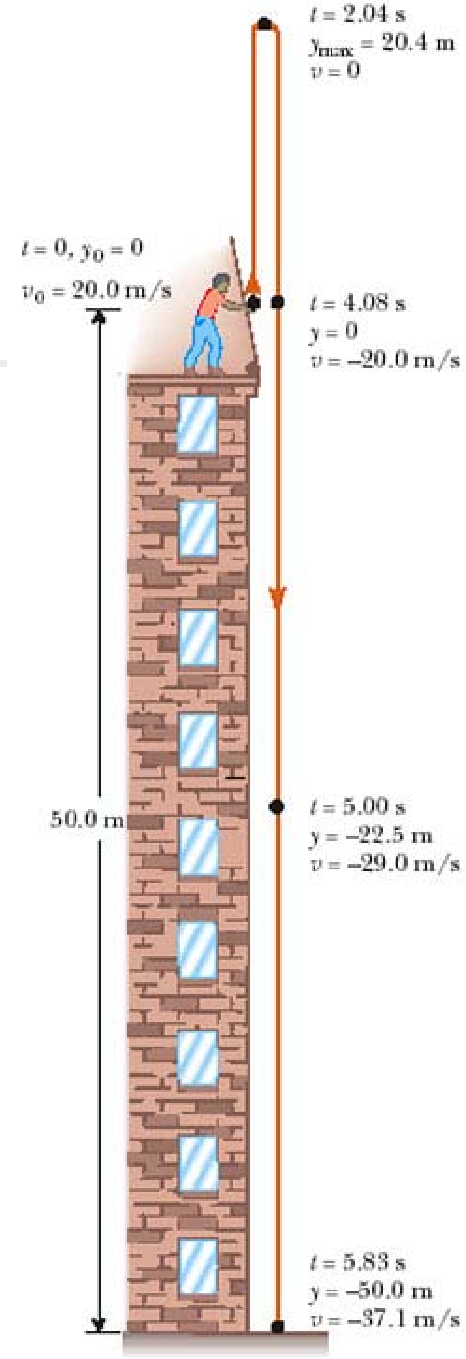


Thrown upward, useful hints

- In case distance up and down the same:
  - Then $t_{up} = t_{down}$
  - And the final velocity $v = -v_o$
- This is "obvious" from the symmetry of going up and down
- Also may be directly calculated from kinematic equations

Non-symmetrical Free Fall

- For understanding helps 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 Motion (an example)

- first stage: rocket acceleration +gravity
- gravity only afterwards