Physics 101: Mechanics
Lecture 3

Motion along a straight line

- Motion
- Position and displacement
- Average velocity and average speed
- Instantaneous velocity and speed
- Acceleration
- Free fall acceleration

Motion

- Everything moves!
- Simplification: Moving object is a particle or moves like a particle: “point object”
- Simplest case: Motion along straight line, 1 dimension

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One Dimensional Position x

- What is motion? Change of position over time.
- How can we represent position along a straight line?
- Position definition:
  - a starting point: origin (x = 0), x relative to origin
  - Direction: positive (right or up), negative (left or down)
  - It depends on time: t = 0 (start clock), x(t=0) does not have to be zero.
- Position has units of [Length]: meters.

Vector and Scalar

- A vector quantity is characterized by having both a magnitude and a direction.
  - Displacement, Velocity, Acceleration, Force …
  - Denoted in boldface type with an arrow over the top. $\vec{v}$, $\vec{\mathrm{a}}$, $\vec{\mathrm{F}}$......
- Scales have a quantity size, but no direction.
  - Distance, Mass, Temperature, Time …
- For the motion along a straight line, the direction is represented simply by + and – signs.
  - + sign: Right or Up.
  - - sign: Left or Down.
- 2-D and 3-D motions.

Quantities in Motion

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

Displacement

- Displacement is a change of position in time.
- Displacement: $\Delta x = x_f(t_f) - x_i(t_i)$
  - *f* stands for final and *i* stands for initial.
- It is a vector quantity.
- It has both magnitude and direction: + or - sign
- It has units of [length]: meters.

$x_1(t_1) = +3.5$ m
$x_2(t_2) = -3.0$ m
$\Delta x = -3.0$ m $- 3.5$ m $= -6.5$ m

$x_1(t_1) = -2.0$ m
$x_2(t_2) = +2.0$ m
$\Delta x = +2.0$ m $+ 2.0$ m $= +4.0$ m

Distance and Position-time graph

Figure 1, Table 1
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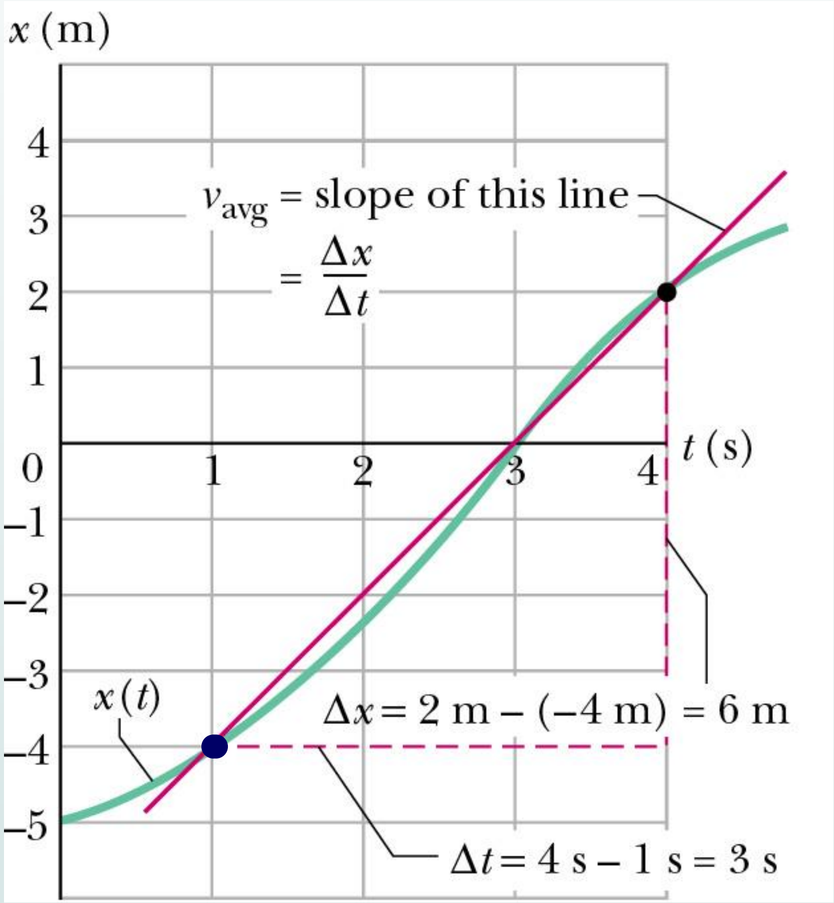
- Displacement in space
  - From A to B: $\Delta x = x_B - x_A = 52\text{ m} - 30\text{ m} = 22\text{ m}$
  - From A to C: $\Delta x = x_c - x_A = 38\text{ m} - 30\text{ m} = 8\text{ m}$
- Distance is the length of a path followed by a particle
  - from A to B: $d = |x_B - x_A| = |52\text{ m} - 30\text{ m}| = 22\text{ m}$
  - from A to C: $d = |x_B - x_A| + |x_C - x_B| = 22\text{ m} + |38\text{ m} - 52\text{ m}| = 36\text{ m}$
- Displacement is not Distance.

Velocity

- Velocity is the rate of change of position.
- Velocity is a vector quantity.
- Velocity has both magnitude and direction.
- Velocity has a unit of [length/time]: meter/second.
- Definition:
  - Average velocity $$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$$
  - Average speed $$s_{\text{avg}} = \frac{\text{total distance}}{\Delta t}$$
  - Instantaneous velocity $$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Average Velocity

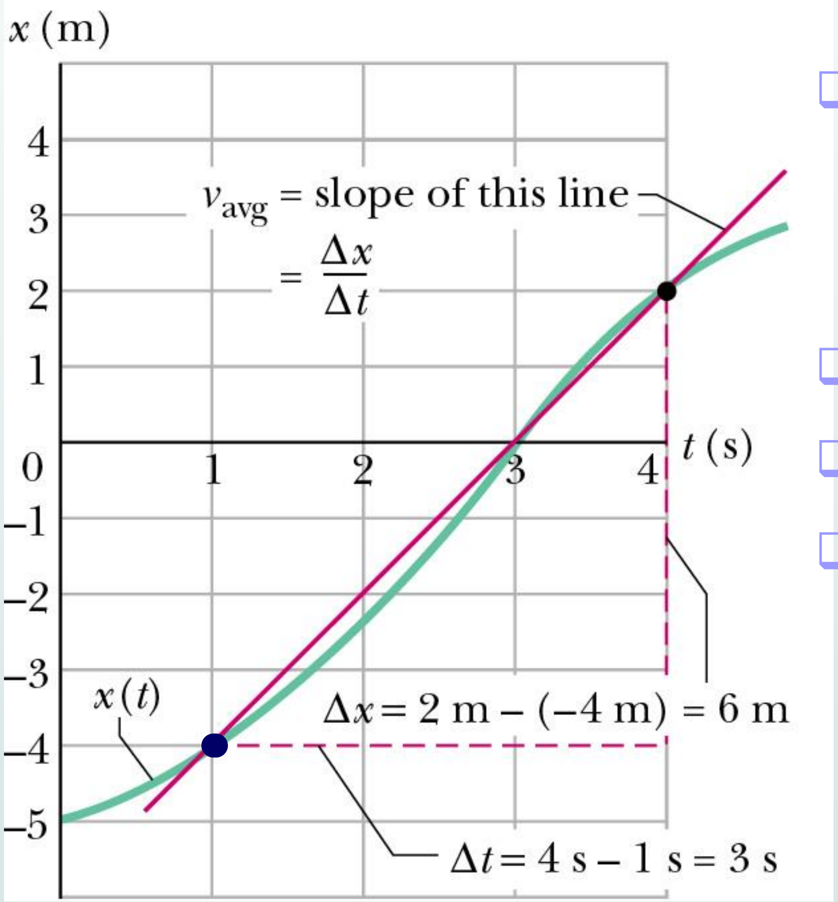


- Average velocity

$$v_{avg} = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$$

- It is slope of line segment.
- Dimension: [length/time].
- SI unit: m/s.
- It is a vector.
- Displacement sets its sign.
-

Average Speed



- Average speed

$$s_{avg} = \frac{\text{total distance}}{\Delta t}$$

- Dimension: [length/time], m/s.
- Scalar: No direction involved.
- Not necessarily close to V_{avg}:
  - S_{avg} = (6m + 6m)/(3s+3s) = 2 m/s
  - V_{avg} = (0 m)/(3s+3s) = 0 m/s

Instantaneous Velocity

- The instant means "in some moment". Instantaneous velocity shows what is at every point.
- Limiting process:
  - Chords approach the tangent as Δt => 0
  - Slope measure rate of change of position
- Instantaneous velocity:

$$v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

- It is a vector quantity.
- Dimension: [Length/time], m/s.
- It is the slope of the tangent line to x(t).
- Instantaneous velocity v(t) is a function of time.

Figure 3
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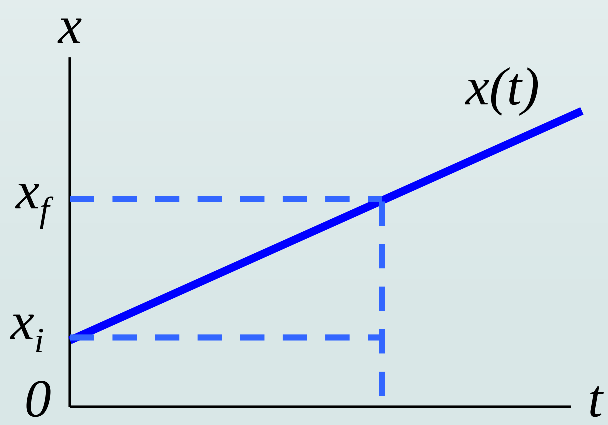
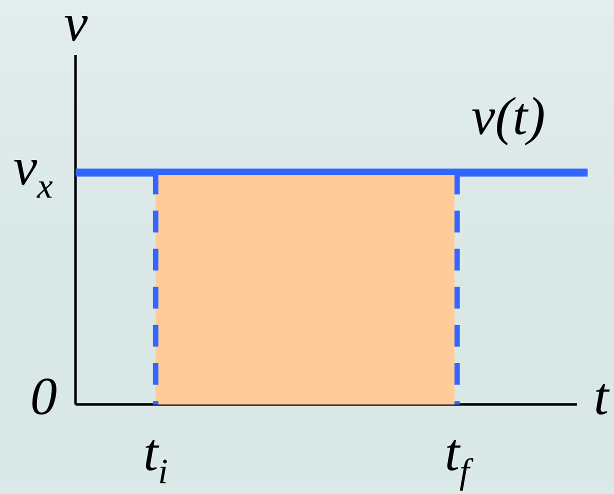
Uniform Velocity

- Uniform velocity is constant velocity
- The instantaneous velocities are always the same, all the instantaneous velocities will also equal the average velocity
- Begin with $v_x = \frac{\Delta x}{\Delta t} = \frac{x_f - x_i}{\Delta t}$ then $x_f = x_i + v_x \Delta t$





Average Acceleration

- Changing velocity (non-uniform) means an acceleration is present.
- Acceleration is the rate of change of velocity.
- Acceleration is a vector quantity.
- Acceleration has both magnitude and direction.
- Acceleration has a unit of [length/time^2]: m/s^2.
- Definition:
  - Average acceleration $$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$
  - Instantaneous acceleration $$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d}{dt}\frac{dx}{dt} = \frac{d^2 v}{dt^2}$$

Average Acceleration

- Average acceleration

$$a_{avg} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

- Velocity as a function of time

$$v_f(t) = v_i + a_{avg}\Delta t$$

Instantaneous and Uniform Acceleration

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

$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d}{dt}\frac{dx}{dt} = \frac{d^2x}{dt^2}$$

- When the instantaneous accelerations are always the same, the acceleration will be uniform. The instantaneous acceleration will be equal to the average acceleration
- Instantaneous acceleration is the slope of the tangent to the curve of the velocity-time graph

Motion with a Uniform Acceleration

Figure 10
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- Acceleration is a constant
- Kinematic Equations

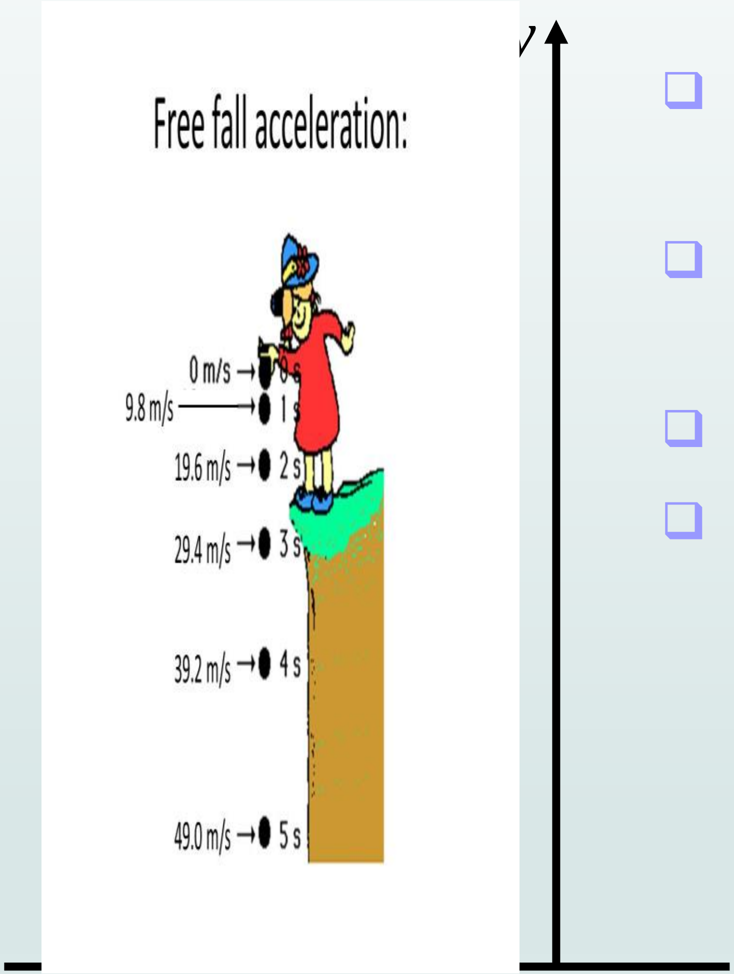
$$v = v_0 + at$$

$$\Delta x = \bar{v}t = \frac{1}{2}(v_0 + v)t$$

$$\Delta x = v_0 t + \tfrac{1}{2}at^2$$

$$v^2 = {v_0}^2 + 2a\Delta x$$

Free Fall Acceleration



- Earth gravity provides a constant acceleration.
- Free-fall acceleration is independent of mass.
- Magnitude: $|a| = g = 9.8\ m/s^2$
- Direction: always downward, so a_g is negative if define "up" as positive,

  $a = -g = -9.8\ m/s^2$

Free Fall Acceleration

- Two important equation:

$$v = v_0 - gt$$

$$x - x_0 = v_0 t - \frac{1}{2} g t^2$$

- If $t_0 = 0$, $v_0 = 0$, $x_0 = 0$
- So, $t^2 = 2|x|/g$ same for two balls!