MOTION IN ONE DIMENSION

Pre-class Assignment

Instruction: Complete each statement by filling in the blanks from the given *list of words/phrases.

1. ________ refers to the length of the path travelled by an object. *Distance*
2. ________ is denoted by *g*, is directed downwards, and has a value of 9.8 m/s^2 near the surface of the earth. *Gravitational acceleration*
3. ________ is defined as the rate of change of position with respect to time. *Velocity*

4. An object has acceleration if it changes speed and/or ________. *direction*
5. A ________ is a representation of a moving object at successive time intervals (assumed equal). *motion diagram*

* free-fall, magnitude, instantaneous acceleration, position, distance, displacement, speed, motion diagram, gravitational acceleration, acceleration, direction, velocity, gravity, graph, particle model

Do heavy objects really fall at a faster rate than light objects?

Video of bowling ball and feather:

https://www.youtube.com/watch?v=E43-CfukEgs

A. Displacement, Velocity, and Acceleration

1. Displacement (SI unit: m)

   a. Displacement is defined as change in position of an object.

      i. Magnitude: shortest (straight-line) distance between final and initial position

      ii. Direction: points from an object’s initial position to its final position

b. Distance and displacement are not the same physical quantities.

Distance is a scalar that refers to the length of the path travelled by an object.

2. Velocity (SI unit: m/s)

a. Velocity is defined as the rate of change of position with respect to time.

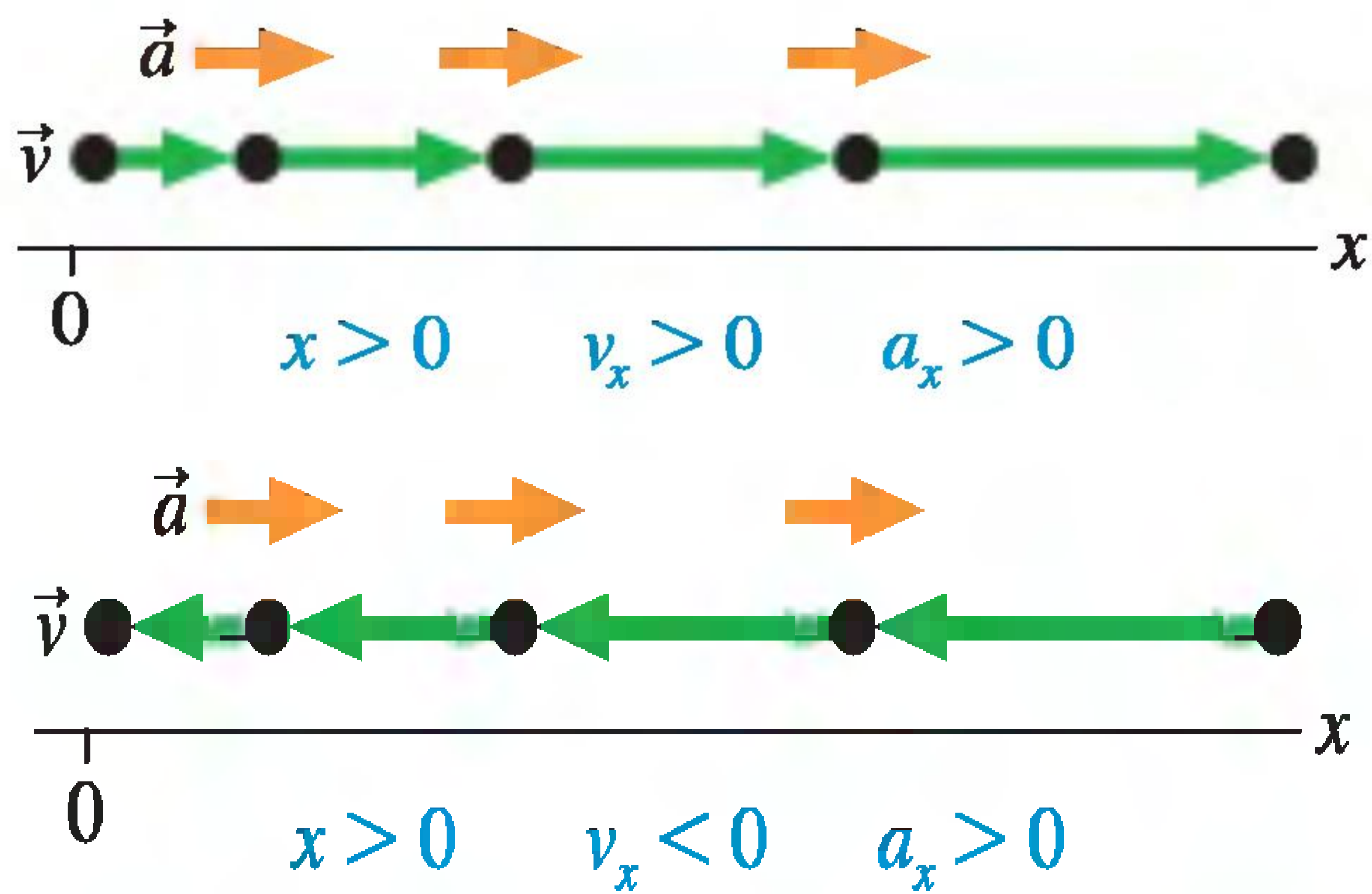
i. Magnitude: measure of how fast the object is moving

ii. Direction: points in the direction of motion or the same direction as the displacement vector

b. Average and Instantaneous Velocity
   i. Average velocity is the change in position (displacement) divided by a time interval.
   ii. Instantaneous velocity is the object’s velocity at a particular instant of time.

c. Speed is distance travelled divided by time. Instantaneous speed is the magnitude of instantaneous velocity. However, average speed is not the magnitude of average velocity. Both average speed and instantaneous speed are scalars, not vectors.

3. Acceleration (SI unit: m/s^2)
   a. Acceleration is defined as the rate of change of velocity with respect to time.
      i. Magnitude: measure of how fast the object's velocity is changing
      ii. Direction:
         - Speeding up: velocity and acceleration vectors point in the same direction or have the same sign
         - Slowing down: velocity and acceleration vectors point in opposite directions or have opposite signs



Note: The sign of acceleration indicates which way it points, not whether the object is speeding up or slowing down.

An object has acceleration if it:

i. changes speed and/or
ii. changes direction

b. Average and Instantaneous Acceleration
   i. Average acceleration is the change in velocity divided by a time interval.
   ii. Instantaneous acceleration is the object's acceleration at a particular instant of time.

Note: In physics, an instant refers to a single value of time.

Checkpoint Questions:

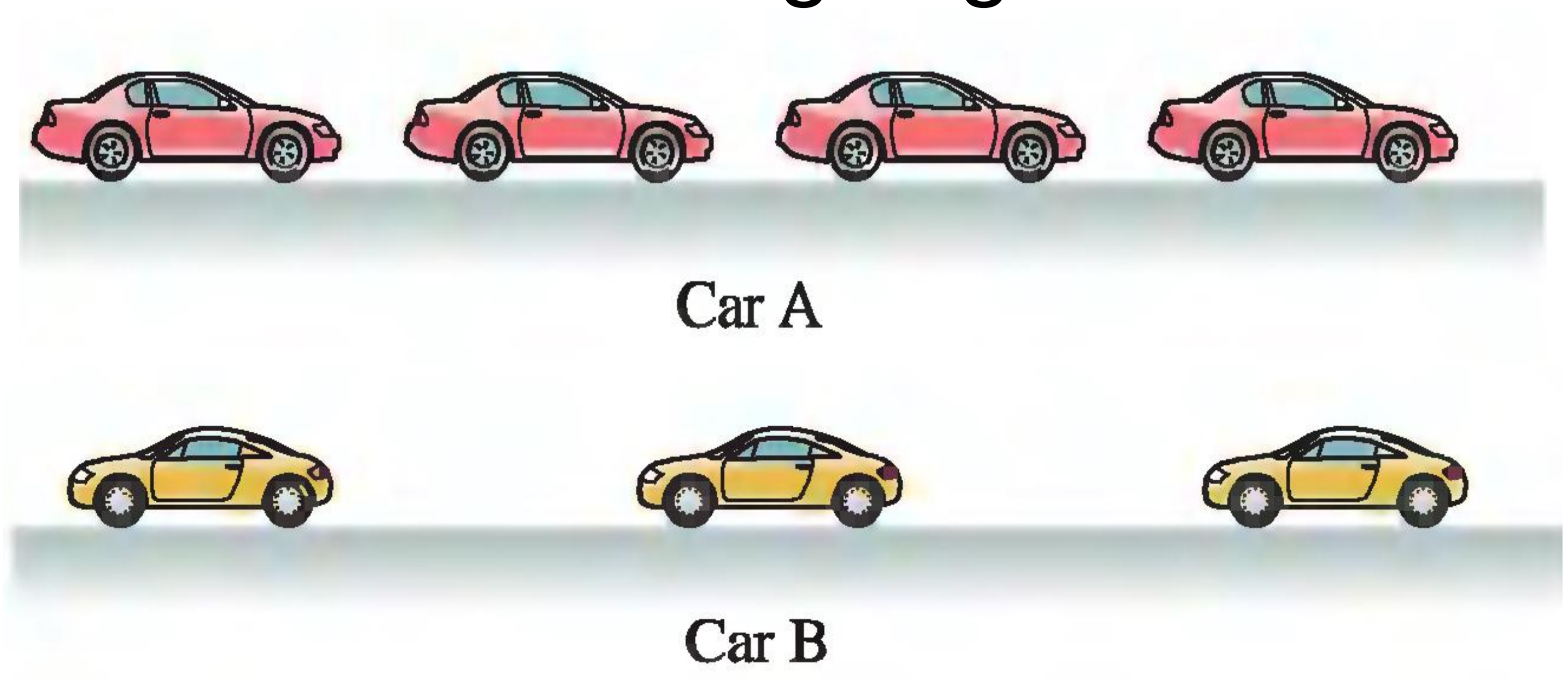
1. Enumerate the SI units of displacement, velocity, and acceleration.
2. Jose leaves school and travels a total distance of 2 km before returning to school. What is the magnitude of the total displacement of Jose?
3. Two buses depart from Cebu City, one going north and one going south. Each bus travels at a speed of 30 m/s. Do they have equal velocities?
4. Identify what is incorrect in the following statement: The car travelled around the circular track at a constant velocity.

5. A negative acceleration means the object is decelerating or slowing down. True or false?

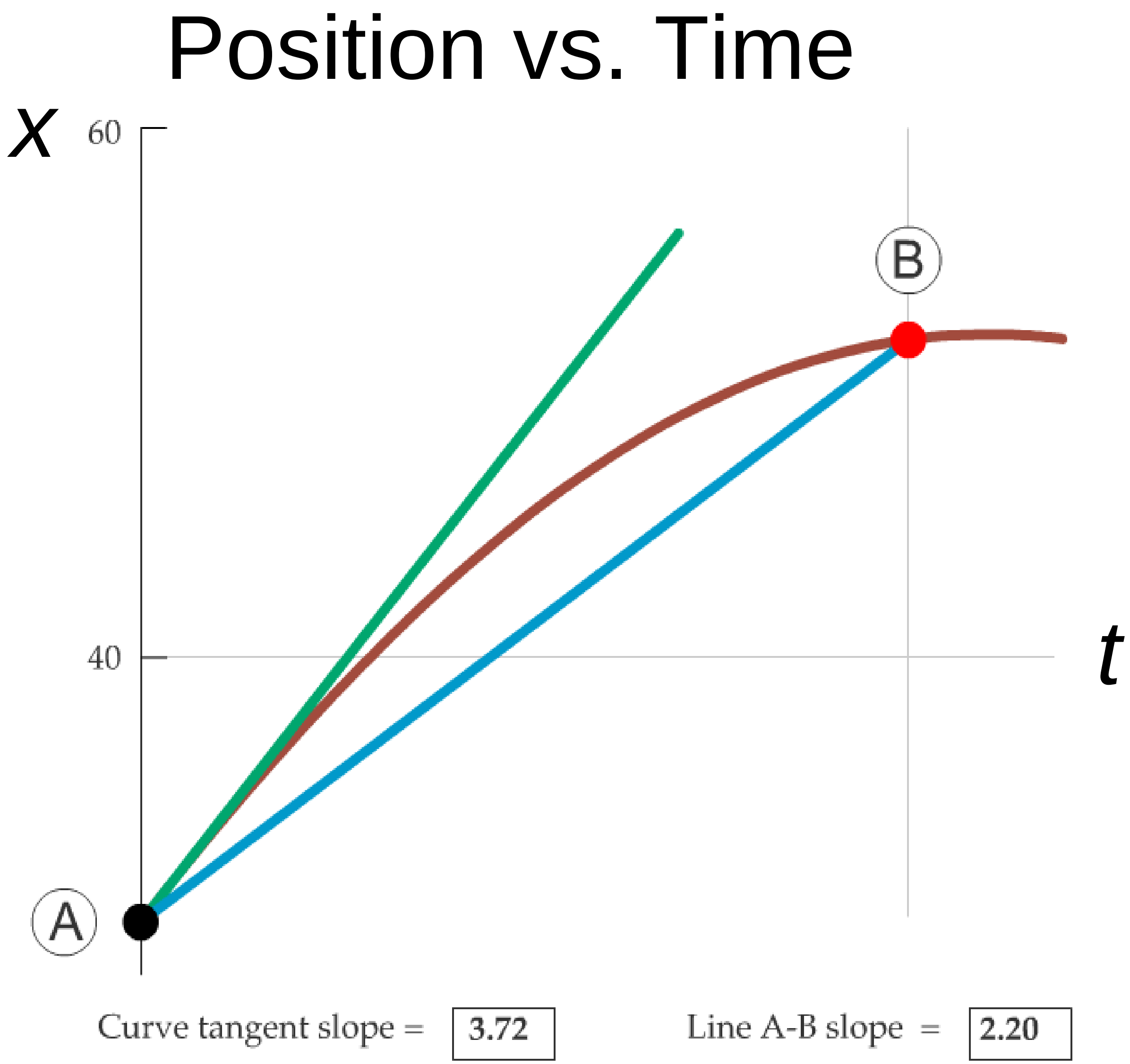
B. Motion Diagram and Graphs

1. A motion diagram is a representation of a moving object at successive time intervals (assumed equal).

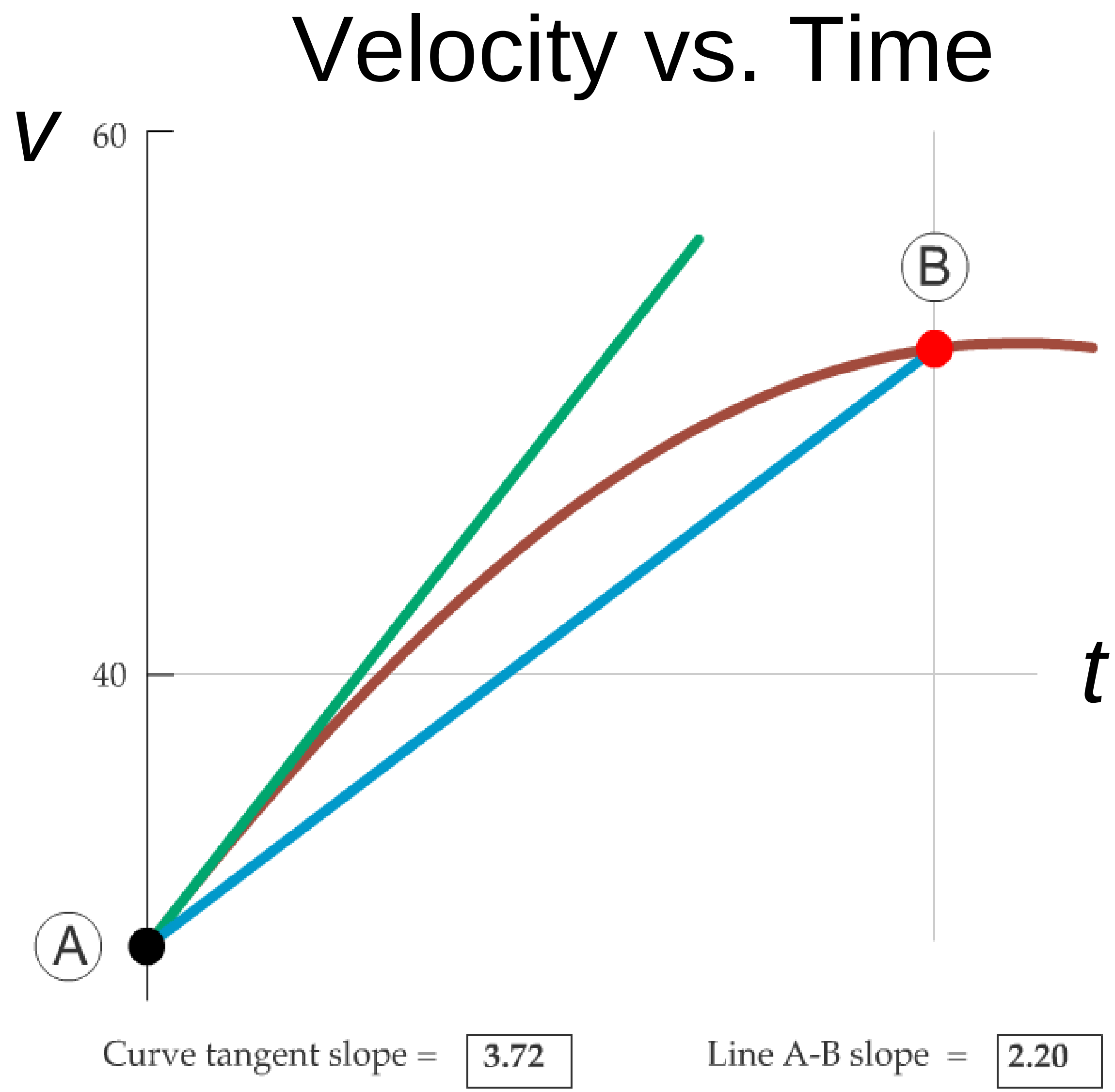
Which car is going faster?



2. Graphical Analysis of Velocity and Acceleration
    a. The slope of the secant line in a position vs. time graph is defined to be the average velocity of the given time interval.
    b. The slope of the tangent line in a position vs. time graph is defined to be the instantaneous velocity at that time.
    c. The slope of the secant line in a velocity vs. time graph is defined to be the average acceleration of the given time interval.
    d. The slope of the tangent line in a velocity vs. time graph is defined to be the instantaneous acceleration at that time.



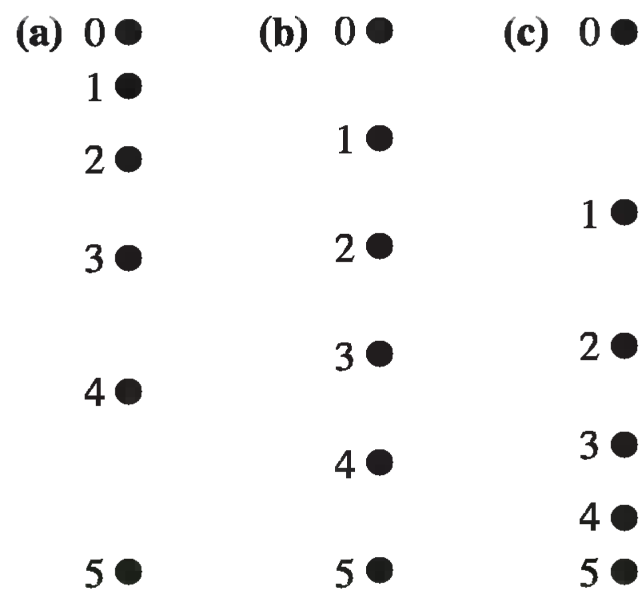
Position vs. Time
x
60
40
t
A
B
Curve tangent slope =
3.72
Line A-B slope =
2.20



Velocity vs. Time
v
60
40
t
A
B
Curve tangent slope =
3.72
Line A-B slope =
2.20

Checkpoint Questions:

1. Identify the motion diagram for the following situations:
   - A dust particle settling to the floor at constant speed.
   - A ball dropped from the roof of a building.



2. The slope of the secant line in a velocity vs. time graph is defined to be the ________ of the given time interval.

3. A freely falling object is thrown straight up into the air. When will the object's acceleration have a value other than g?
4. If you drop an object in the absence of air resistance, it accelerates downward at 9.8 m/s^2. If instead you throw it downward (not just drop it), its downward acceleration after release is _______.

C. One-Dimensional Motion with Constant Acceleration and Free-Fall Motion

1. One-Dimensional Kinematic Equations with Constant Acceleration

$$v = v_o + at$$

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

$$v^2 = v_o^2 + 2a(x - x_o)$$

$$x_o = initial\ position;\ x = final\ position$$

$$v_o = initial\ velocity;\ v = final\ velocity$$

$$a = constant\ acceleration;\ t = time$$

2. Example of One-Dimensional Motion: Free-fall

The motion of an object moving under the influence of gravity only, and no other forces, is called free-fall.

Important points about free-fall:

a. Any two objects in free-fall, regardless of their mass have the same acceleration.
b. Gravitational acceleration, by definition $g = 9.8\,m/s^2$ near the Earth's surface, is not called "gravity."

c. g is the magnitude of free-fall acceleration. By convention, the negative y-axis points downward. Hence, $a_y = -g = -9.8\ m/s^2$.
d. At the highest point of free-fall motion, where the velocity is zero, the acceleration is equal to the gravitational acceleration (not zero).

** Each of the following car trips takes one hour. The positive x-direction is to the east. Determine the total distance, average speed, total displacement, and average velocity of each of the following cars:

i. Honda travels 60 km due east, then turns around and travels 10 km due west.
ii. Porsche travels 50 km due west, then turns around and travels 5 km due east.
iii. Ford travels 20 km due west, then turns around and travels 20 km due east.

** Starting from a pillar, you run 200 m east (+x-direction) at an average speed of 5.0 m/s, and then run 280 m west at an average speed of 4.0 m/s to a post. Calculate a) the total time from pillar to post; b) your average speed from pillar to post; c) your average velocity from pillar to post.

** A certain car is capable of accelerating at a rate of $0.60\ m/s^2$. How long does it take for this car to go from a speed of 55 mi/h to a speed of 60 mi/h? (1 mi = 1 609 m)

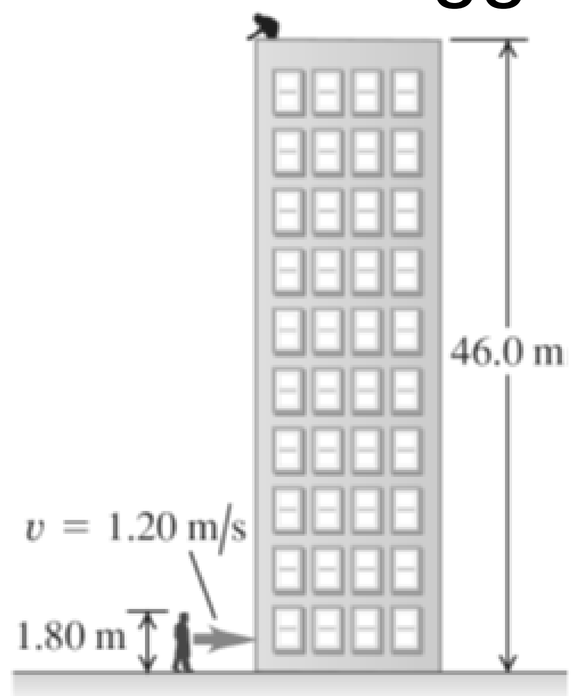
* A jet plane lands with a speed of 100 m/s and can accelerate at a maximum rate of $-5 m/s^2$ as it comes to rest. a) From the instant the plane touches the runway, what is the minimum time needed before it can come to rest? b) Can this plane land on a small tropical island airport where the runway is 0.800 km long?

** A Cessna aircraft has a liftoff speed of 120 km/h. a) What minimum constant acceleration does the aircraft require if it is to be airborne after a takeoff run of 240 m? b) How long does it take the aircraft to become airborne?

** A ball is thrown vertically upward with a speed of 25 m/s. a) How high does it rise? b) How long does it take to reach its highest point? c) How long does the ball take to hit the ground after it reaches its highest point? d) What is its velocity when it returns to the level from which it started?

** a) If a flea can jump straight up to a height of 0.440 m, what is its initial speed as it leaves the ground? b) How long is it in the air?

* You are on the roof of the physics building, 46.0 m above the ground in the figure below. Your physics instructor, who is 1.80 m tall, is walking alongside the building at a constant speed of 1.20 m/s. If you wish to drop an egg on your instructor's head, where should the instructor be when you release the egg? Assume that the egg is in free-fall.



** A stuntman sitting on a tree branch wishes to drop vertically onto a horse galloping under the tree. The constant speed of the horse is 10 m/s, and the man is initially 3 m above the level of the saddle. What must be the horizontal distance between the saddle and the branch when the man makes his move?

** i. Honda:

$d = 60\,Km + 10\,Km = \boxed{70\,Km}$

$s_{av} = \frac{d}{\Delta t} = \frac{70\,Km}{1\,hr} = \boxed{70\,Km/hr}$

$\Delta x = 60\,Km + (-10\,Km) = +50\,Km$

or $\boxed{50\,Km \text{ due east}}$

$V_{av} = \frac{\Delta x}{\Delta t} = \frac{50\,Km}{1\,hr} = \boxed{50\,Km/hr \text{ due east}}$

ii. Porsche:

$d = 50\,Km + 5\,Km = \boxed{55\,Km}$

$s_{av} = \frac{55\,Km}{1\,hr} = \boxed{55\,Km/hr}$

$\Delta x = (-50\,Km) + 5\,Km = -45\,Km$

or $\boxed{45\,Km \text{ due west}}$

$V_{av} = \frac{45\,Km}{1\,hr} = \boxed{45\,Km/hr \text{ due west}}$

iii. Ford:

$d = 20\,Km + 20\,Km = \boxed{40\,Km}$

$s_{av} = \boxed{40\,Km/hr}$

$\Delta x = (-20\,Km) + 20\,Km = \boxed{0}$

$V_{av} = \boxed{0}$

Note: East is positive direction
West is negative direction

**

a) $s_{av} = \frac{d}{\Delta t}$

$\Delta t_1 = \frac{d}{s_{av}} = \frac{200\,m}{5.0\,m/s} = 40\,s$

$\Delta t_2 = \frac{280\,m}{4.0\,m/s} \simeq 70\,s$

$\Delta t_{total} = \Delta t_1 + \Delta t_2 \simeq \boxed{110\,s}$

b) $s_{av} = \frac{200\,m + 280\,m}{110\,s} \simeq \boxed{4.36\,m/s}$

c) $V_{av} = \frac{\Delta x}{\Delta t_{total}} = \frac{200\,m + (-280\,m)}{110\,s}$

$\simeq -0.73\,m/s$

or $\boxed{0.73\,m/s \text{ west}}$

** $v = v_0 + at$

$$t = \frac{v - v_0}{a} = \frac{\left(60\frac{mi}{hr} - 55\frac{mi}{hr}\right)\left(\frac{1609\,m}{1\,mi}\right)\left(\frac{1\,hr}{3600\,s}\right)}{0.60\,m/s^2}$$

$t \simeq \boxed{3.7\,s}$

* a) $v = v_0 + at$

$$t = \frac{v - v_0}{a} = \frac{0 - 100\,m/s}{-5\,m/s^2}$$

$t \simeq \boxed{20\,s}$

b) $v^2 = v_0^2 + 2a\Delta x$ where $\Delta x = x - x_0$

$$\Delta x = \frac{v^2 - v_0^2}{2a} = \frac{0^2 - (100\,m/s)^2}{2(-5\,m/s^2)}$$

$\Delta x \simeq 1000\,m$ or $1\,Km$

$\boxed{\text{No, because } 0.800\,Km < 1\,Km.}$

** a) $v^2 = v_0^2 + 2a\Delta x$ $\quad 120\,Km/hr \simeq 33.33\frac{m}{s}$

$$a = \frac{v^2 - \cancel{v_0^2}^{\,0}}{2\Delta x} = \frac{(33.33\,m/s)^2}{2\,(240\,m)}$$

$a \simeq \boxed{2.3\,m/s^2}$

b) $t = \frac{v - \cancel{v_0}^{\,0}}{a} = \frac{33.33\,m/s}{2.3\,m/s^2} \simeq \boxed{14.5\,s}$

** $a = -g$

a) $\cancel{v^2}^{\,0} = v_0^2 - 2g\Delta y$

$$0 = (25\,m/s)^2 - 2(9.8\,m/s^2)\Delta y$$

$\Delta y \simeq \boxed{31.89\,m}$

b) $v = v_0 - gt$

$$t_{up} = \frac{\cancel{v}^{\,0} - v_0}{-g} = \frac{-25\,m/s}{-9.8\,m/s^2} \simeq \boxed{2.55\,s}$$

c) $\Delta y = v_0 t + \frac{1}{2}at^2$ where $a = -g$

and Δy is negative because direction of motion is downward

$\Delta y = \cancel{v_0 t}^{\,0} - \frac{1}{2}gt^2$ $\quad v_0 = 0$ at highest point

$$t_{down} = \sqrt{\frac{2\Delta y}{g}} = \sqrt{\frac{2(-31.89\,m)}{-9.8\,m/s^2}}$$

$t_{down} \simeq \boxed{2.55\,s}$

Note: $t_{up} = t_{down}$ because free-fall motion is symmetrical

d) $v = \cancel{v_0}^{\,0} - gt = -(9.8\,m/s^2)(2.55\,s)$

$v \simeq -25\,m/s$ or $\boxed{25\,m/s \text{ downward}}$

** a) $\cancel{v}^{2\,0} = v_0^2 - 2g\Delta y$

$0 = v_0^2 - 2g\Delta y$

$v_0 = \sqrt{2g\Delta y} = \sqrt{2(9.8\,m/s^2)(0.440\,m)}$

$v_0 \approx \boxed{8.62\ m/s}$

b) $v = v_0 - gt$

$t_{up} = \frac{\cancel{v}^{0} - v_0}{-g} = \frac{-8.62\ m/s}{-9.8\ m/s^2} \approx 0.88\,s$

$t_{up} = t_{down}$

$t_{total} = t_{up} + t_{down} = \boxed{1.76\,s}$

* Instructor:

$v = \frac{\Delta x}{\Delta t} = \frac{x - x_0}{\Delta t}$

$\Delta t = \frac{x - \cancel{x_0}^{0}}{v}$

Egg:

$\Delta t = t$ time when the egg reaches the instructor's head

$\Delta y = \cancel{v_0}^{0} t - \frac{1}{2} g t^2$

$y - y_0 = -\frac{1}{2} g t^2$

$1.8 - 46 = -\frac{1}{2}(9.8)\left(\frac{x - 0}{1.20}\right)^2$

$-44.2 = -\frac{1}{2}(9.8)\frac{x^2}{(1.20)^2}$

$x \approx \boxed{3.60\,m}$

** Horse: $v = \frac{\Delta x}{\Delta t} = \frac{x - x_0}{\Delta t}$

$\Delta t = \frac{x - \cancel{x_0}^{0}}{v}$

Stuntman:

$\Delta t = t$ time when stuntman is on the saddle of the horse

$\Delta y = \cancel{v_0}^{0} t - \frac{1}{2} g t^2$

$\cancel{y}^{0} - y_0 = -\frac{1}{2} g t^2$

$-3 = -\frac{1}{2}(9.8)\frac{x^2}{v^2} = -\frac{1}{2}(9.8)\frac{x^2}{10^2}$

$x \approx \boxed{7.82\,m}$