Physics 131

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Office hours: 1:30-2:30pm on Tues and Thurs

- Today handouts:
  - ■ General Information for Physics 131-3
  - ■ Assignment Sheet
    - ◆ specific info on 131
    - ◆ schedule for course, homework, midterms, final
  - ■ Equation Sheet
  - ■ Lecture notes (Chapters 1 and 2)
    - ◆ distributed as a courtesy for those who attended the lectures

■ Goal:
- ☆ learn basic mechanics with everyday applications for scientists and engineers

☆ good understanding of basic mechanics give you competitive advantage over your colleagues in the work place

1. Measurement

Units:

- all measurements must have a unit
- units give physical meanings to numbers

e.g. I drove to take the P131 final at 70
-- unclear what you mean by “70”
I drove to take the P131 final at 70 miles per hour
-- miles per hour (mph) is the unit

System of Units:

We will use the SI units:

Base	SI	English
Time	second (s)	second (s)
Length	meter (m)	feet (ft)
Mass	kilogram (kg)	slug

- use these 3 base units to define other useful units:

  e.g. speed $+$ length / time

  : meter / second (m / s)

- for convenience, use units in powers of 10 of base units:

  e.g. 1000 meter (m) = 1 kilometer (km)

  (kilo = 1000)

  1 kilogram (kg) = 1000 grams (g)

  1 centimeter (cm) = $\frac{1}{100}$ meter (centi = $\frac{1}{100}$)

Unit Conversion:

Sometimes we need to convert from one unit to other:

e.g. converse 60 miles into SI unit:

$$60 \text{ miles} \times \frac{1.61 \text{ km}}{1 \text{ mile}} \times \frac{1000 \text{ m}}{1 \text{ km}} = 96,600 \text{ m}$$

Scientific Notation:

Use for very small or large numbers:

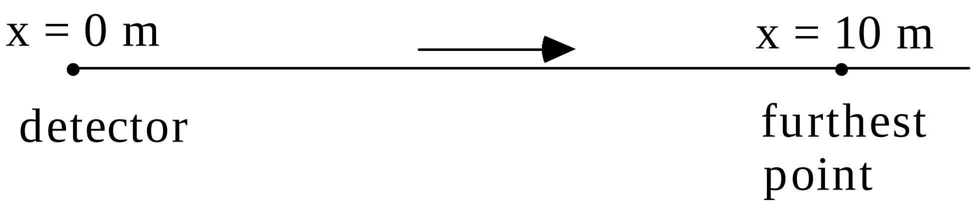
$$\text{e.g. } 0.000000615 \rightarrow 6.15 \times 10^{-7}$$
$$134,000,000,000 \rightarrow 1.34 \times 10^{11}$$

2. Straight Line Motion

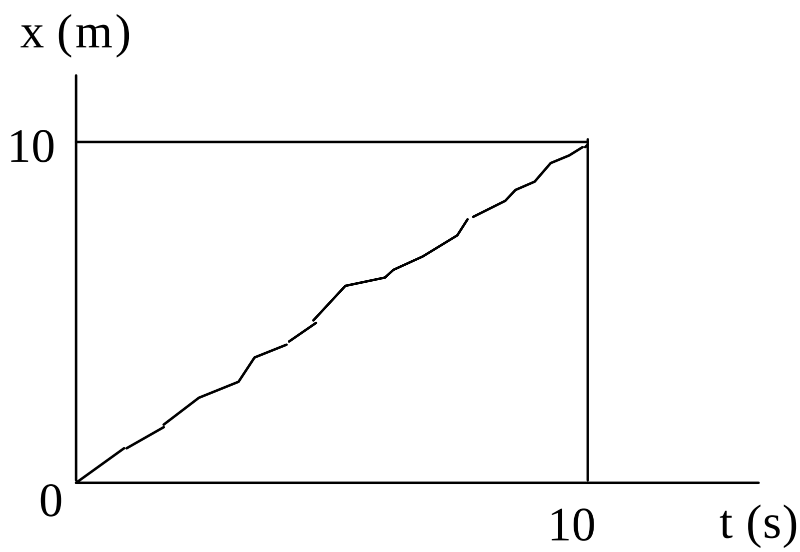
- study motion in a straight line
  i.e. one dimensional motion

- describe the motion using displacement, velocity, acceleration

Consider walking across the lecture hall:



The computer produces the following sketch of x vs t:



Displacement:

the change from one position to another:

$$\Delta x = x_2 - x_1$$

For the example on walking:

$$\Delta x = x_2 - x_1$$
$$= 10 - 0$$
$$= 10 \text{ m}$$

Question: If I return to the detector after pause for 60 s, what is the displacement between the beginning and end of the walk?

$$\Delta x = x_2 - x_1$$
$$= 0 - 0$$
$$= 0 \text{ m}$$

☆ displacement is not same as distance traveled. In the example, distance traveled is 20 m but displacement is zero.

- To describe how fast I walked, we define

☆ $$\text{average velocity} = \frac{\text{displacement}}{\text{time}}$$

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{x_2 - x_1}{t_2 - t_1}$$

☆ $$\text{average speed} = \frac{\text{distance traveled}}{\text{time}}$$

$$\bar{s} \geq 0$$

In the example on walking:

- for the 1st segment (detector □ furthest point)

$$\bar{v} = \frac{10 - 0}{10 - 0} = 1 \text{ m/s}$$

- for the round trip (detector □ furthest point □ detector)

$$\bar{v} = \frac{0}{10 + 60 + 15}$$

$$= 0 \text{ m/s}$$

-- time spent at furthest point is included in Δt

- for the round trip

$$\bar{s} = \frac{10 + 10}{10 + 60 + 15}$$

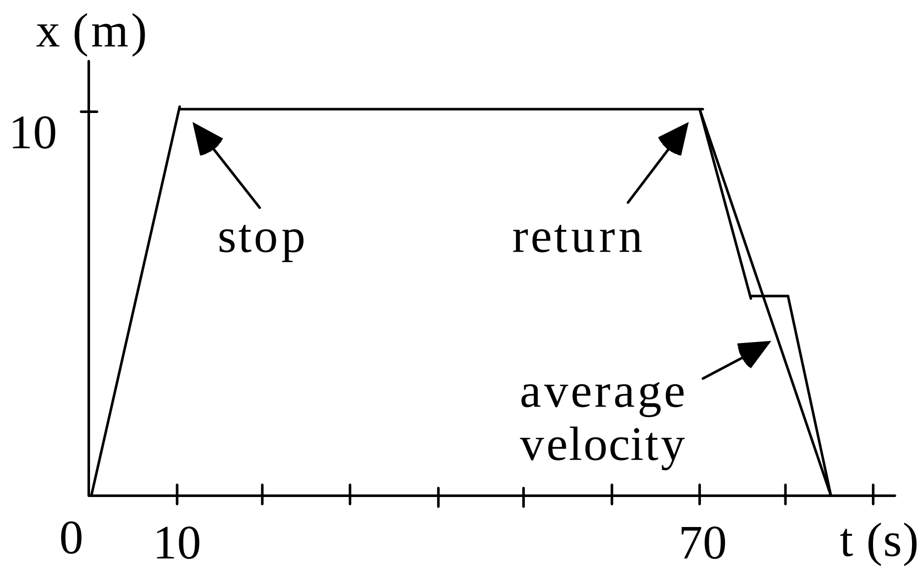
$$= 0.24 \text{ m/s}$$

✫ Zero average velocity does not necessary implies a zero average speed.

✫ We usually refer to the average speed in everyday conversation.

Instantaneous Velocity and Speed:

Consider the x vs t plot recorded by the computer for the walk:



• The average velocity is just the slope of the line connecting two positions

e.g. the line connecting x = 10 m and 0 m

$$\bar{v} = \frac{\Delta x}{\Delta t} = \frac{0-10}{85-70} = -\frac{10}{15} = -0.66 \text{ m/s}$$

-- this average velocity include the 5 s stoppage!

If we calculate the average velocity over a very small time interval

□ instantaneous velocity $v = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}$

$$= \frac{dx}{dt}$$

- a directional quantity

  i.e. $v > 0$ corresponds to moving in the $+x$ direction and vice verse
- When we talk about "velocity",

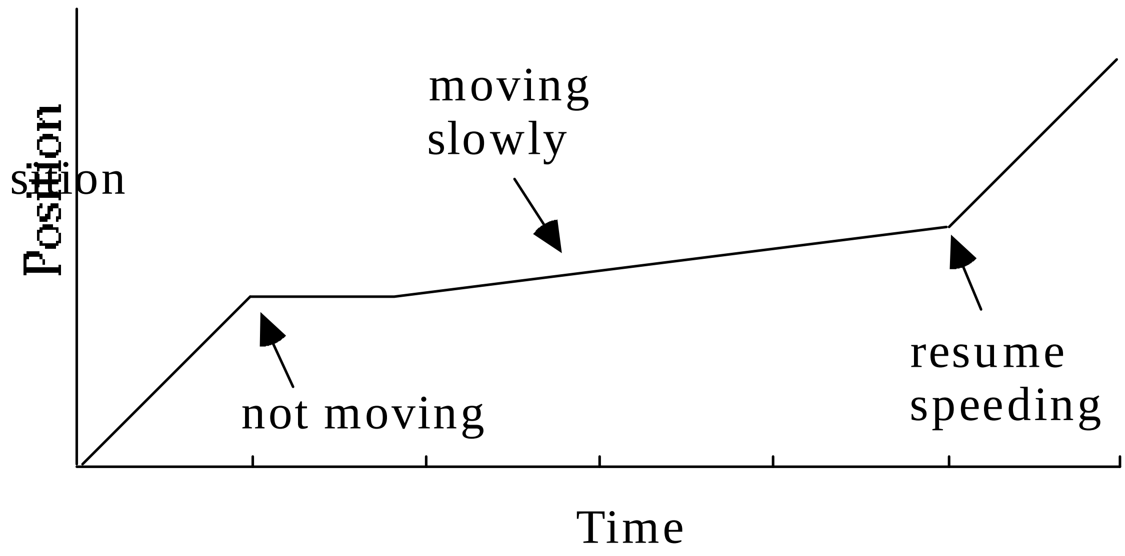
  we mean instantaneous velocity
- Instantaneous speed = magnitude of instantaneous velocity

  $$s = |v|$$

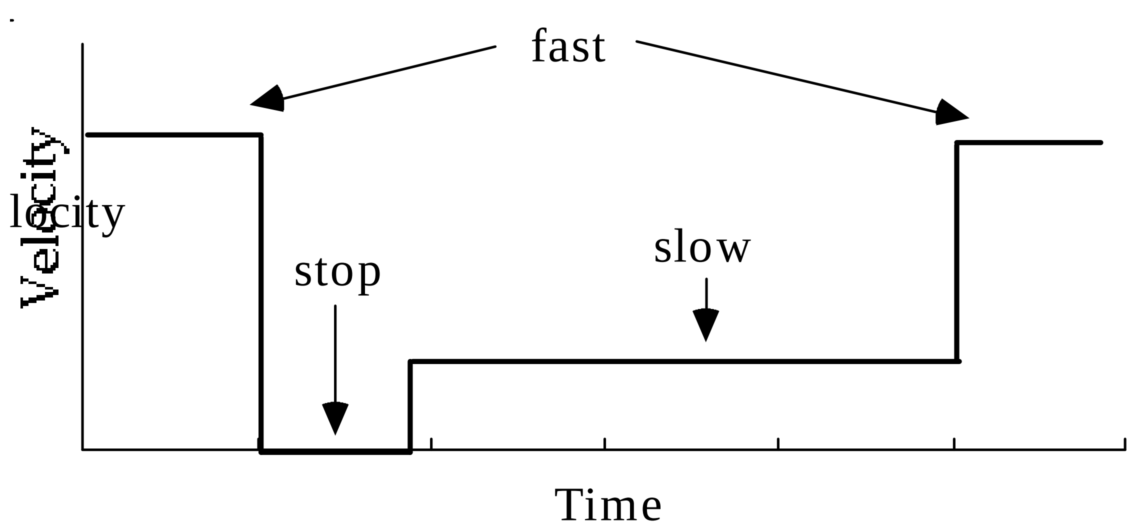
  □ no associated direction
- car speedometer measure the speed

Velocity vs Time Plot:

Consider a car traveling on a highway at 100 km / h. Because of construction, the car must come to a complete stop, then move with a velocity of 20 km / h before resuming the 100 km / h speed. The position vs time plot looks like:



Since the velocity at a given time is just the slope of the tangent to the curve, we can measure the slope and produce the following velocity vs time plot:



Two special features:

- the horizontal lines (zero slope) correspond to constant velocity

- the vertical lines (infinite slope) corresponds to instantaneous changes of velocity, e.g. from certain velocity to zero in no time

□ infinite "acceleration" and "deceleration"

Acceleration:

-- rate of change of velocity

Average acceleration:

$$\bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

Instantaneous acceleration:

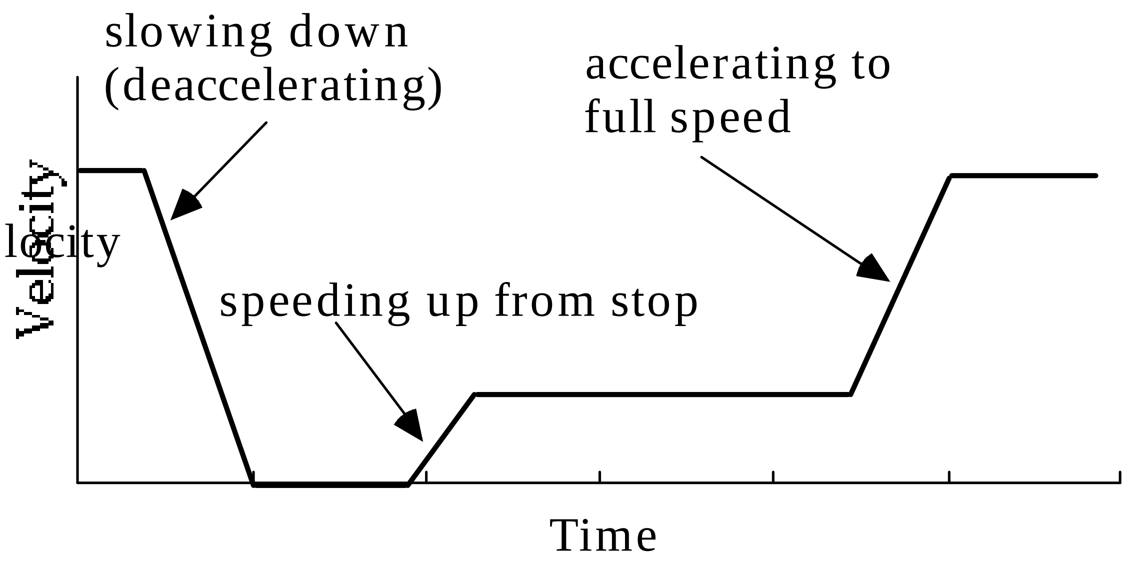
$$a = \lim_{\Delta t \to 0} \frac{\Delta v}{\Delta t} = \frac{dv}{dt} = \frac{d^2 x}{dt^2}$$

- a directional quantity
  i.e. $a > 0$ corresponds to accelerating in the $+x$ direction and vice verse.
- $a > 0$ can mean "acceleration" or

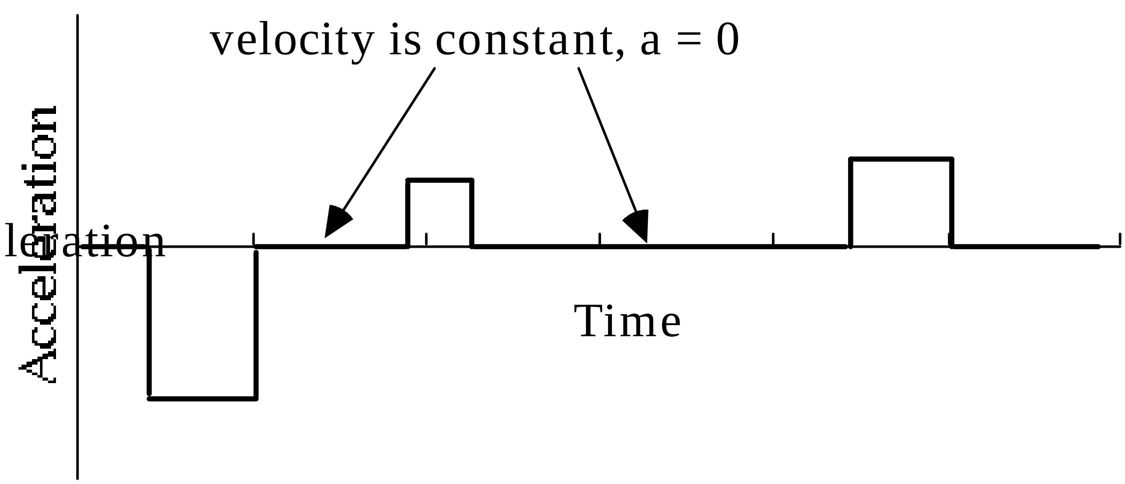
"deceleration", i.e. can't tell "acceleration" or "deceleration" from the sign of a.

- if v and a have same sign
  - □ v and a point in same direction
  - □ acceleration
- if v and a have opposite sign
  - □ v and a point in opposite direction
  - □ deceleration

A more realistic v vs t plot:



From the slope of the line □ *a* vs *t* plot:



Review:

	Definition	Units	Comment
displacement	$\Delta x = x_2 - x_1$	L	directional
distance trvl.	path length	L	> 0
avg. velocity	$\frac{\Delta x}{\Delta t}$	L / T	directional
inst. velocity	$\frac{dx}{dt}$	L / T	directional
avg. speed	$\frac{\text{path length}}{\Delta t}$	L / T	> 0
inst. speed	$\left\|\frac{dx}{dt}\right\|$	L / T	> 0
avg. accel.	$\frac{\Delta v}{\Delta t}$	L / T^2	directional
inst. accel.	$\frac{dv}{dt} = \frac{d^2 x}{dt^2}$	L / T^2	directional

Constant Acceleration:

- Plan: find the equation of motion for a particle under constant acceleration, $a(t) = a(0) = \text{constant}$ i.e. a horizontal line in a vs. t plot

First Equation of Motion:

Start with the definition:

$$a = \frac{v - v_0}{t - 0}$$

$$at = v - v_0$$

$$v = v_0 + at \qquad (1)$$

✓ for $a = 0, v = v_0 = \text{constant}$

Second Equation of Motion:

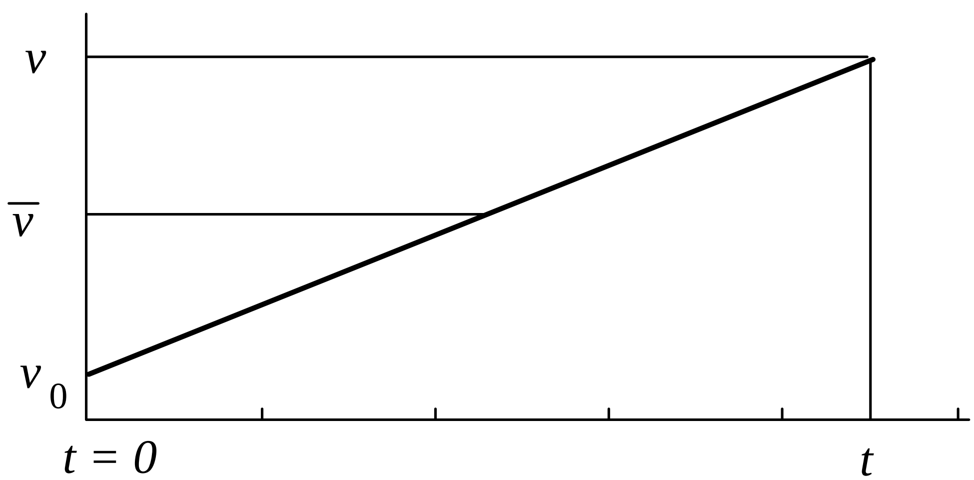
Start with the definition:

$$\bar{v} = \frac{x - x_0}{t - 0}$$

$$\bar{v}t = x - x_0$$

$$x = x_0 + \bar{v}t$$

For constant acceleration, we have a straight line in the *v* vs. *t* plot:



$\bar{v}$ is just halfway between v_0 and v:

$$\bar{v} = \frac{v + v_0}{2}$$

$$\Rightarrow x = x_0 + \frac{1}{2}(v + v_0)t \qquad (2)$$

Third Equation of Motion:

Substituting (1) into (2):

$$x = x_0 + \frac{1}{2}(v_0 + at + v_0)t$$

$$\Rightarrow x = x_0 + v_0 t + \frac{1}{2}at^2 \qquad (3)$$

Use this to calculate the position at time t if you know the acceleration (a), initial position (x_0), and initial velocity (v_0).

Fourth Equation of Motion:

From (1):

$$v = v_0 + at$$

$$\Rightarrow t = \frac{v - v_0}{a}$$

Substituting into (3):

$$x = x_0 + v_0 \frac{v - v_0}{a} + \frac{1}{2} a \frac{(v - v_0)^2}{a^2}$$

$$= x_0 + \frac{vv_0}{a} - \frac{{v_0}^2}{a} + \frac{v^2}{2a} + \frac{{v_0}^2}{2a} - \frac{vv_0}{a}$$

$$= x_0 - \frac{{v_0}^2}{2a} + \frac{v^2}{2a}$$

$$\Rightarrow v^2 = {v_0}^2 + 2a(x - x_0)$$

Use this to calculate the velocity at position x if you know the acceleration (a), initial position (x_0), and initial velocity (v_0).

Summary:

Equation	Missing Quantity
$v = v_0 + at$	x, x_0
$x = x_0 + v_0 t + \frac{1}{2} at^2$	v
$v^2 = v_0^2 + 2a(x - x_0)$	t
$x = x_0 + \frac{1}{2}(v_0 + v)t$	a
$x = x_0 + vt - \frac{1}{2} at^2$	v_0

Problem 44E (p. 31):

A P131 student is driving at 85 mi/h on a highway, and spots a state trooper. If his brakes are capable of decelerating at 17 ft/s^2, what is the minimum time to bring the car under the 55 mi/h limit?

Convert all quantities into the same unit:

$$a = -17\ \mathrm{ft/s^2} \times \frac{1\ \mathrm{mi}}{5280\ \mathrm{ft}} = -0.0032\ \mathrm{mi/s^2}$$

$$v_0 = 85\ \mathrm{mi/h} \times \frac{1\ \mathrm{h}}{3600\ \mathrm{s}} = 0.024\ \mathrm{mi/s}$$

$$v = 55\ \mathrm{mi/h} \times \frac{1\ \mathrm{h}}{3600\ \mathrm{s}} = 0.015\ \mathrm{mi/s}$$

$$t = \frac{v - v_0}{a}$$

$$= \frac{0.015\ \mathrm{mi/s} - 0.024\ \mathrm{mi/s}}{-0.0032\ \mathrm{mi/s^2}}$$

$$= 2.8\ \mathrm{s}$$

✓ The answer has the proper units.

✓ The answer is reasonable.

Problem 56P (p. 32):

When a traffic light turns green, a car starts with constant acceleration a = 2.2 m/s^2. At the same time, a truck traveling with a constant speed of 9.5 m/s overtakes the car. (a) Where will the car overtake the truck? (b) What is the speed then?

Draw a diagram and write down all known quantities:

truck	•⟶	v_{truck} = 9.5 m/s	•⟶	v_{truck} = 9.5 m/s
car	∘	v_0 = 0, a = 2.2 m/s^2	∘⟶	v = ?, a = 2.2 m/s^2
	t = 0		t = ?	
	x = 0		x = ?	

Truck: $$x = x_0 + v_{truck}t = v_{truck}t \qquad (1)$$

Car: $$x = x_0 + v_0 t + \tfrac{1}{2}at^2 = \tfrac{1}{2}at^2$$

$$v_{\text{truck}}t = \tfrac{1}{2}at^2$$

$$\frac{2v_{\text{truck}}}{a} = t$$

$$t = \frac{2 \times 9.5 \text{ m/s}}{2.2 \text{ m/s}^2}$$

$$= 8.6 \text{ s}$$

Subtituting in (1):

$$x = v_{truck} t = (9.5 \text{ m/s})(8.6 \text{ s}) = 82 \text{ m}$$

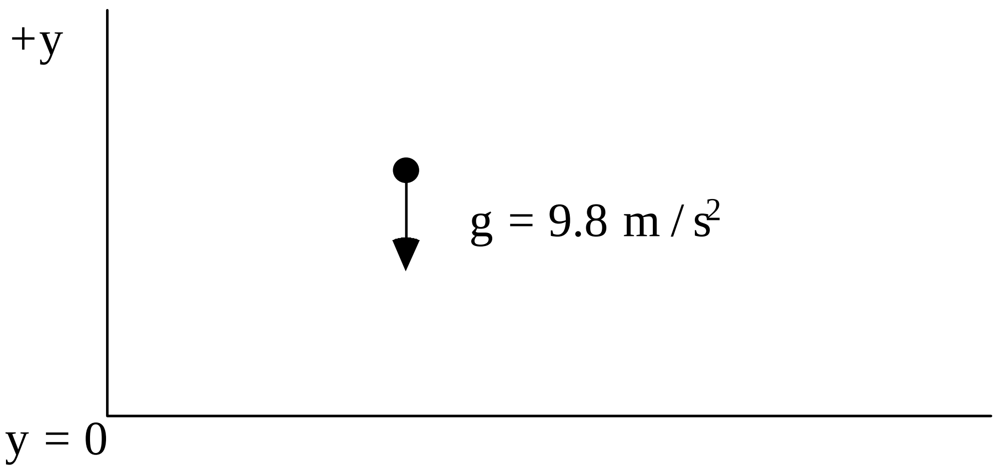
$$v = v_0 + at = 0 + (2.2 \text{ m/s}^2)(8.6 \text{ s}) = 19 \text{ m/s}$$

✓ The answer has the proper units.

✓ $v > v_{truck}$ when overtaken.

Free-Fall Acceleration:

We will study the motion of freely falling objects near the Earth's surface (several miles), neglecting air resistance.



The new equations of motion, with $a = -g$:

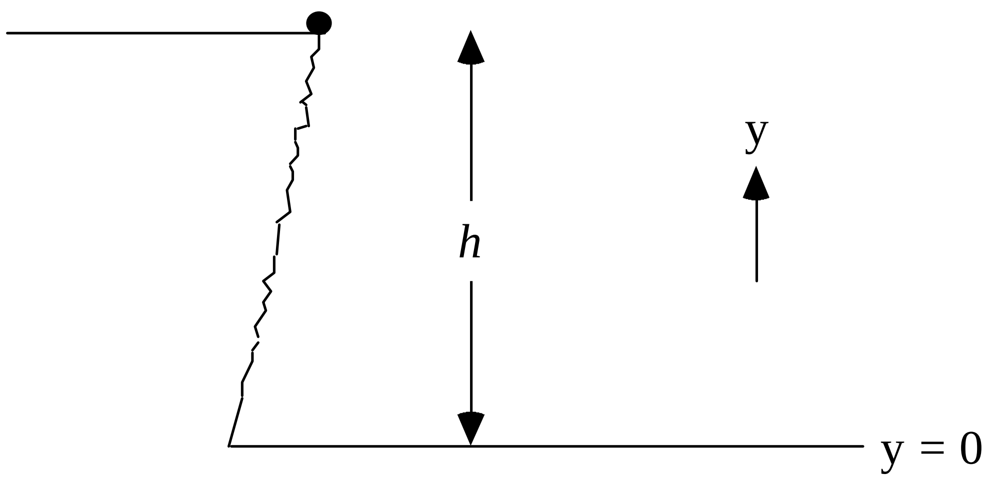
$$y = y_0 + v_0 t - \frac{1}{2} g t^2$$

$$v = v_0 - gt$$

$$v^2 = v_0^2 - 2g(y - y_0)$$

Example:

A rock falls off a cliff of height *h*. (a) How long does it take to hit the ground? (b) What is the velocity of the rock at that instant?



$$y_0 = h, \quad v_0 = 0$$

$$y = 0, \quad t = ?, \quad v = ?$$

$$y = y_0 + v_0 t - \frac{1}{2} g t^2$$

$$\Rightarrow 0 = h - \frac{1}{2} g t^2$$

$$\Rightarrow t = \sqrt{\frac{2h}{g}}$$

$$v = v_0 - gt$$

$$\Rightarrow v = -g\sqrt{\frac{2h}{g}}$$

$$\Rightarrow v = -\sqrt{2gh}$$

✓ Unit: $t = \sqrt{\dfrac{length}{length / time^2}} = time$

✓ Unit: $v = \sqrt{\dfrac{length}{time^2} \times length} = \dfrac{length}{time}$

✓ $time > 0$

✓ $v < 0$

✓ $t = 0$ and $v = 0$ for $h = 0$

- The problem is solved using algebra,
  i.e. without numbers.
  This is the preferred technique.
- The solution is for a general problem,
  i.e. valid for any falling object
  at rest from a height *h*.
- The solution is independent
  of the mass of the object!

Question:

- ❏ If I drop a ball and a piece of paper from the same height, which object will hit the ground first?
- ❏ If I repeat the experiment with the paper balled up, which object will hit the ground first?

Conceptual Question:

If you drop an object in the absence of air resistance, it accelerates dowward at $9.8\ \mathrm{m/s^2}$. If instead you throw it downward, its downward acceleration after the release is:

(1) $< 9.8\ \mathrm{m/s^2}$

(2) $9.8 \text{ m}/\text{s}^2$

(3) $> 9.8 \text{ m}/\text{s}^2$

Comment:

If we toss an object upward, it will reach a maximum height and will fall down. At any given height, the speed of the object is the same, whether it is travelling upward or downward.