What is Physics

Physics is a attempt by men and women to explain **why** the physical world around us behaves in the way that it does.

- Physics provides the foundation upon which other physical sciences are based.
- Basic science such as physics also provides the foundation for engineering and much of the technology we see around us.

A major aim of physics is to discover basic laws which describe nature. This discovery is sometimes through experiment and sometimes through great leaps of the imagination (though always verified by experiment). As physicists, we then try to apply these laws in new situations to predict behavior of nature.

Some guiding principles:
- The laws of physics are few.
- The laws are (relatively) simple.

The Numbers

Physics is an experimental science, and we need to use numbers to describe the results of experiments.

- We want the measurements to be **accurate**
- We want the measurements to be **reproducible**
- As a first step, **we need to agree on the definition of the units** we use to make the measurements in the first place

For the study of Mechanics, we will need three quantities, or units, to describe the behavior of objects: time, position, and mass.

Le Systeme International d'Unites:

- Time is measured in seconds s
- Distance is measured in meters m
- Mass is measured in kilograms kg

Unit Conversions and Significant Figures

Unit conversions: Multiply by a conversion factor

Convert 60mi/h to m/s:

$$(60\frac{\text{mi}}{\text{h}})\times\left(\frac{1609\text{m}}{1\text{mi}}\right)\times\left(\frac{1\text{h}}{3600\text{s}}\right)=27\frac{\text{m}}{\text{s}}$$

Significant Figures

21.21 has 4 significant figures

0.025 has 2 significant figures

(21.21 x 0.025) has 2 significant figures = 0.53

The space shuttle orbits the earth at an altitude of 300 km.
What is the altitude in miles?

Hint: Conversion factor = (1mile / 1.609km)

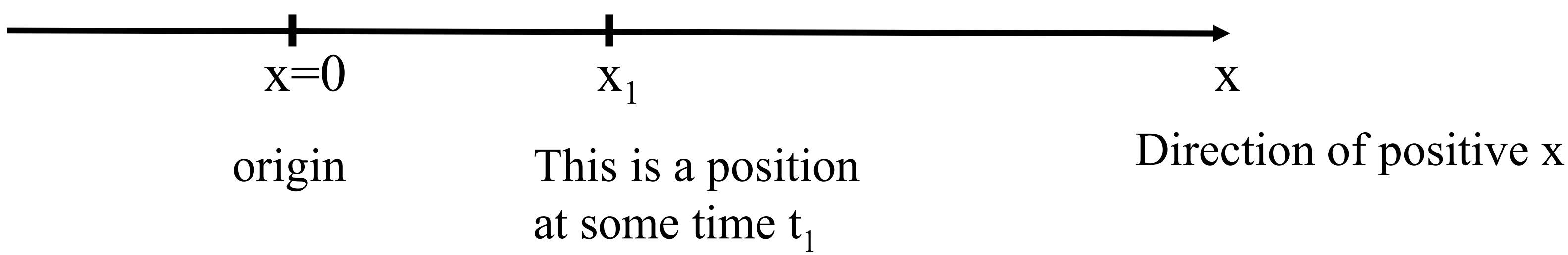
Answer: 186 mi

Describing Motion

<u>We will begin our study of the motion of objects by first trying to describe their motion. This study is called kinematics.</u>

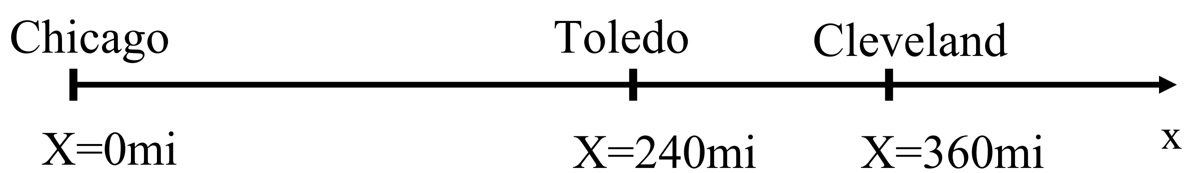
- We will not worry (at least for now) why the objects are moving - that is, what is causing them to move the way they do
- We will first consider linear motion, and restrict ourselves the simple case of motion in a straight line.
- To describe this motion we need to know two things about an object
  - The position of the object, and the time at which it has this position

To describe motion along a straight line we will use an axis. An axis is simply a line with an origin (which represents the zero position) and an arrow which represents the direction of positive motion. We will use the variable x to represent the position at some arbitrary point along the axis.



Motion in a Straight Line

Person goes on a trip from Chicago to Cleveland.
•Gets to Cleveland in 6 hours
•Oops, left wallet in Toledo rest stop
•Goes back, gets wallet, returns to Cleveland. This takes 4 additional hours



What is the total distance traveled?

D = 360mi (chic to clev) + 120mi (cleve to tol) + 120mi (tol to cleve)

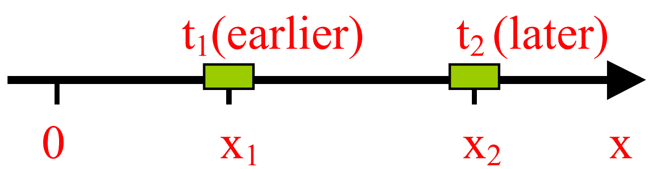
D = 600 mi

Motion in a Straight Line

Another way of describing how your position has changed: **Displacement**

Displacement = Position at final time minus Position at initial time.

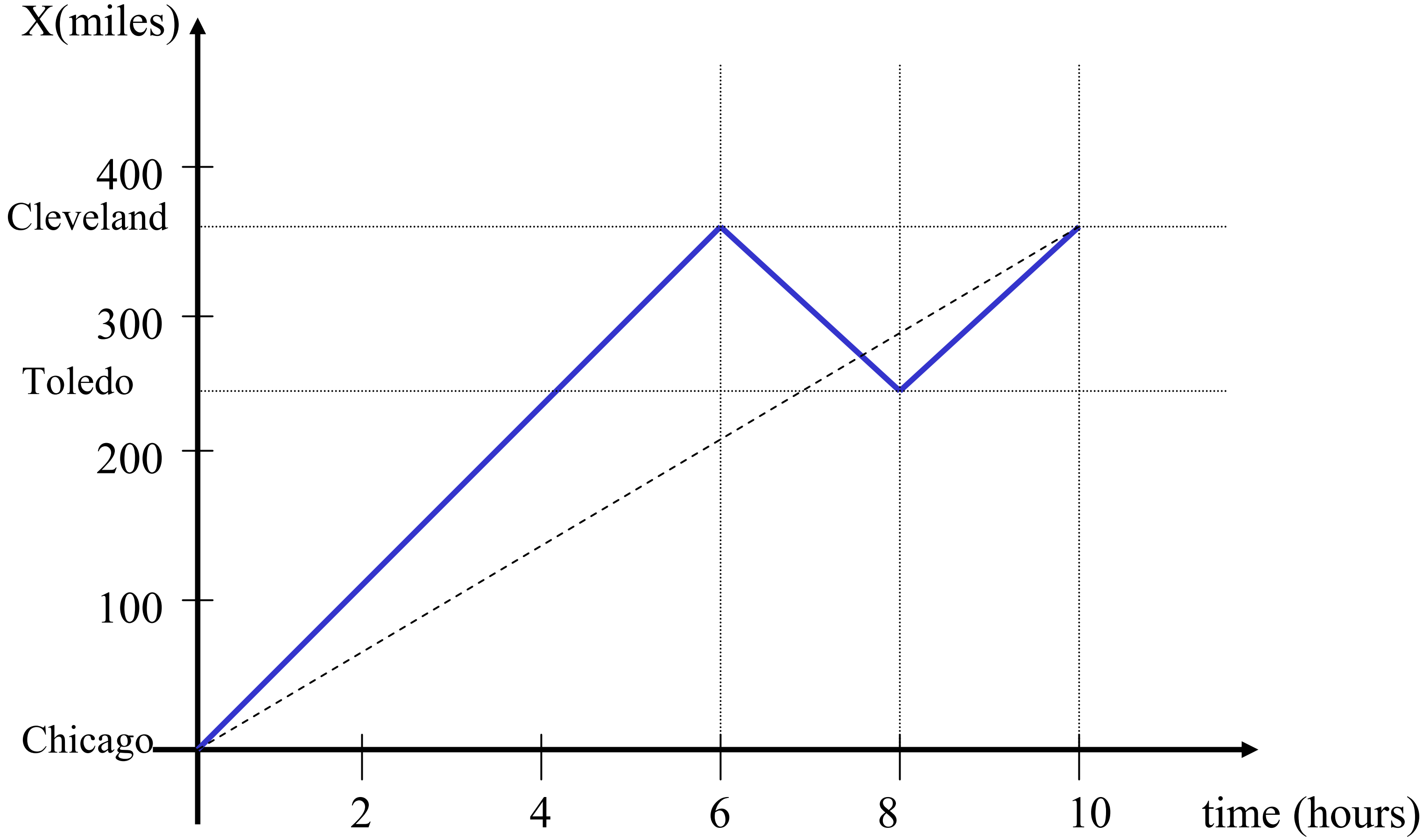
$$\text{Displacement} \qquad \Delta x = x_2 - x_1$$



For the above trip from Chicago to Cleveland, the **displacement** from time=0 hrs to time=10 hrs is:

$$\Delta x = x(t = 10\text{hrs}) - x(t = 0\text{hrs}) = 360\text{mi - }0\text{mi} = 360\text{mi}$$

Another way of representing trip: Position vs time graph



Speed vs Velocity:

How fast was the person going in the trip from chicago to cleveland?
Two ways of thinking about this:

- **Speed** = How fast position changes with time

$$S_{avg} = \frac{\text{Total Distance}}{\text{Time Interval}} = \frac{600\text{mi}}{10\text{h}} = 60\text{mi/h}$$

- **Velocity** = How fast displacement changes with time

$$V_{avg} = \frac{\text{Displacement}}{\text{Time Interval}} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} = \frac{360\text{mi}}{10\text{h}} = 36\text{mi/h}$$

Graphical interpretation of the Average velocity?
=> Slope of the dashed line from initial to final position.

What if we calculated the velocity over a shorter time interval?

Consider a time t and a later time $t + \Delta t$

then at time t, the position is x(t), and at time $t + \Delta t$, the position is $x(t + \Delta t)$

the average velocity is then :

$$V_{avg} = \frac{x(t + \Delta t) - x(t)}{(t + \Delta t) - t} = \frac{x(t + \Delta t) - x(t)}{\Delta t}$$

If you let Δt get smaller and smaller, then the average velocity becomes the instantaneous velocity, and

$$V_{inst} = V(t) = \lim_{\Delta t \to 0}\left[\frac{x(t + \Delta t) - x(t)}{\Delta t}\right] = \frac{dx}{dt}$$

Graphical interpretation of Instantaneous velocity?
=> **Slope of the tangent to the x vs t curve**, at the time t.

Plot of the Velocity vs time curve

From 0 hr to 6 hr, the slope is constant, so average velocity equals instantaneous velocity:

$$V_{inst} = V_{avg} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} = \frac{360\text{mi} - 0}{6\text{h} - 0\text{h}} = 60\text{mi/h}$$

From 6hr to 8hr, the velocity is also constant:

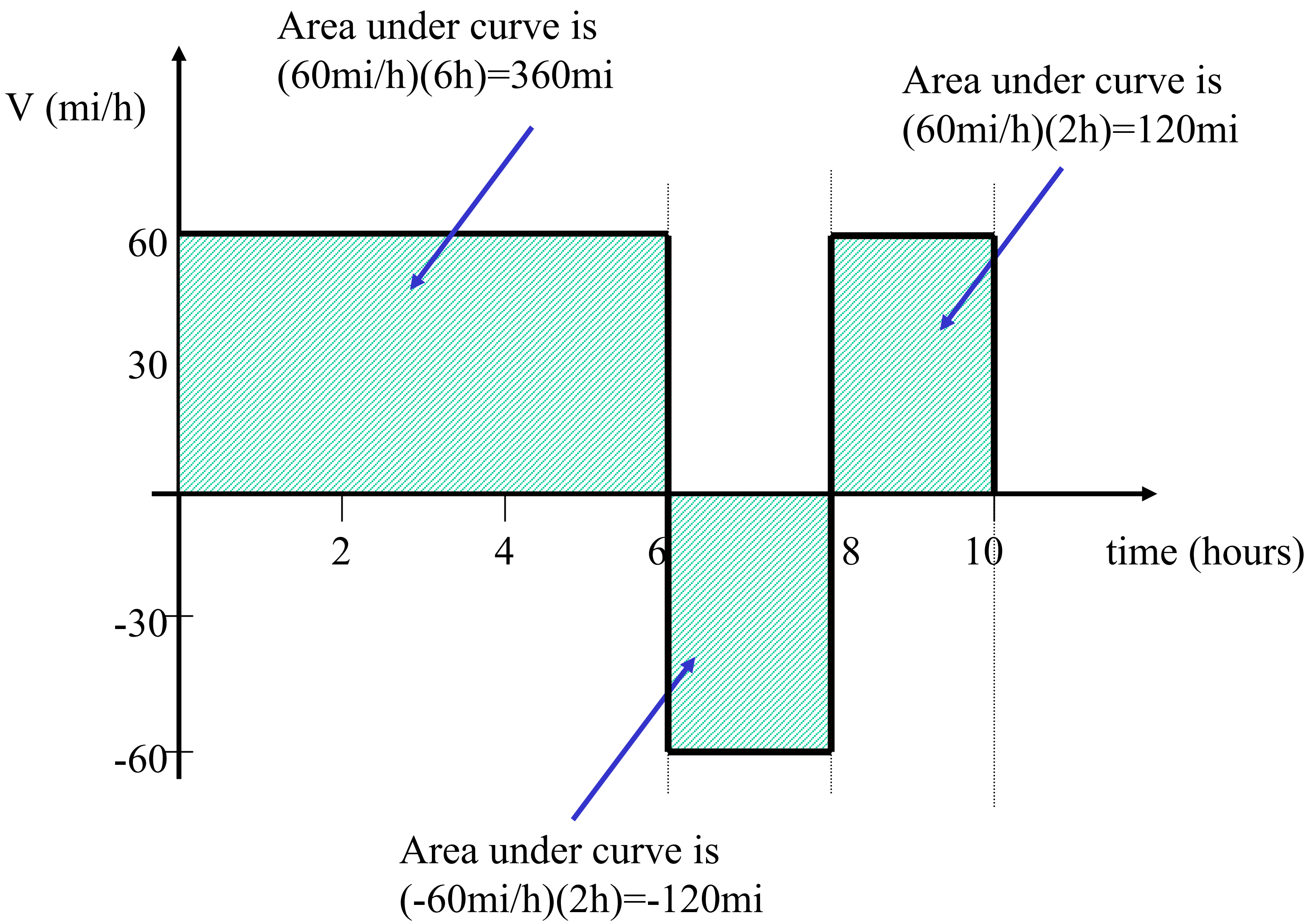
$$V_{inst} = V_{avg} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} = \frac{240\text{mi} - 360\text{mi}}{8\text{h} - 6\text{h}} = -60\text{mi/h}$$

From 8hr to 10hr, the velocity is also constant:

$$V_{inst} = V_{avg} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} = \frac{360\text{mi} - 240\text{mi}}{10\text{h} - 8\text{h}} = 60\text{mi/h}$$

Now plot the velocity vs time curve!

Plot of the Velocity vs time curve



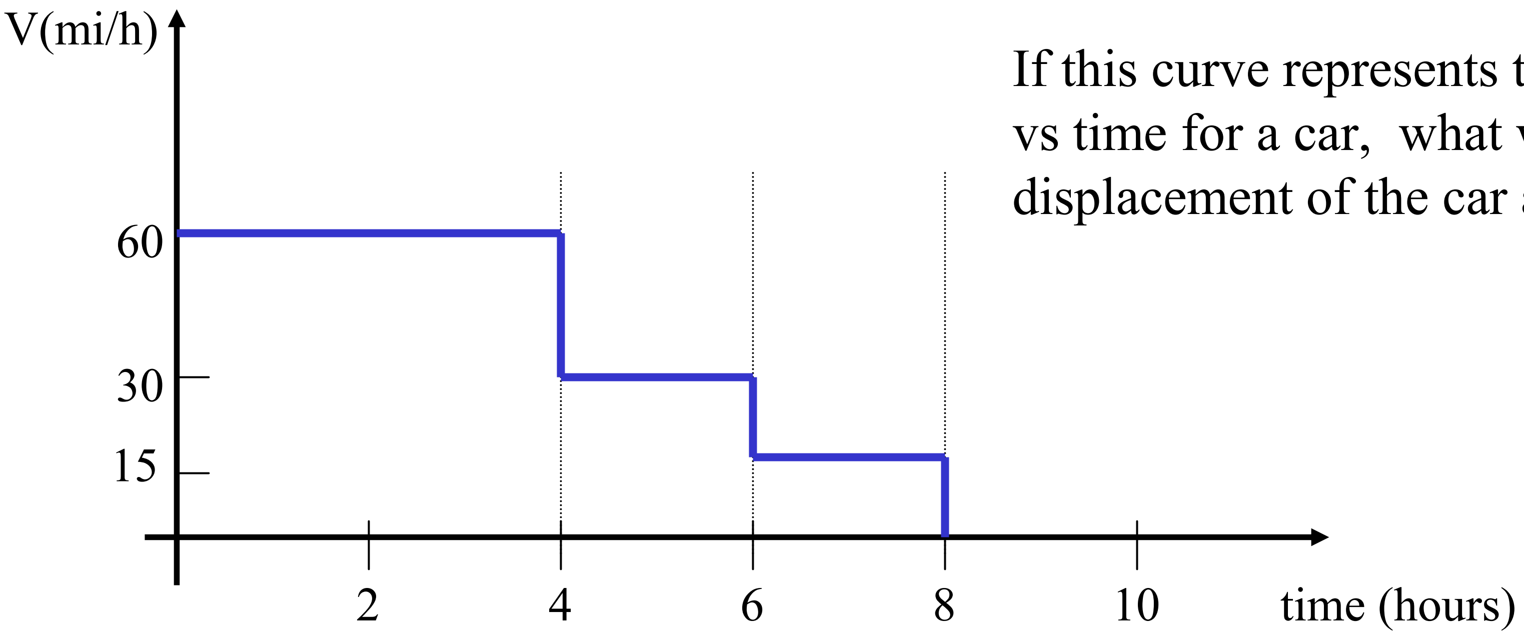
The total displacement between any two times is equal to the area under the V vs t graph between those two times:

$$\text{If} \quad V = \frac{dx}{dt} \quad \text{then} \quad x = \int V(t)\,dt + C$$

where C is a constant of integration

$$x(t_2) - x(t_2) = \int_{t_1}^{t_2} V(t)dt$$

If given the Velocity vs time curve, you should be able to determine the displacement!



If this curve represents the velocity vs time for a car, what was the displacement of the car after 8h?

Displacement = (60mi/h)(4h) + (30mi/h)(2h) + (15mi/h)(2h)
= 240mi + 60mi + 30mi
= 330mi

Acceleration: Rate of change in velocity of an object in a given time interval

$$a_{avg} = \frac{\text{Change in velocity}}{\text{Time Interval}} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

Just as with displacement and velocity, if you let Δt get smaller and smaller, then the average acceleration becomes the instantaneous acceleration, and

$$a_{inst} = a(t) = \lim_{\Delta t \to 0}\left[\frac{v(t+\Delta t) - v(t)}{\Delta t}\right] = \frac{dv(t)}{dt}$$

$$v(t_2) - v(t_2) = \int_{t_1}^{t_2} a(t)dt$$

Example: In a race, start from rest, speed up to a velocity of 10m/s after 5.0s. Then you slow down to rest in 2.0s.

What is the average acceleration during the **first** 5.0s?

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{10\text{m/s} - 0}{5.0 - 0} = 2.0\text{m/s}^2$$

What is the average acceleration during the **final** 2.0s?

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{0 - 10\text{m/s}}{7.0 - 5.0} = -5.0\text{m/s}^2$$

Note:

- Minus sign during final 2.0s means that acceleration is opposite the positive x-direction
- Acceleration has a direction (so does velocity - more on this later)
- During the run, the velocity is always positive, but acceleration is first positive, and then negative

Example: Start from rest, run *backwards* speed up to v = -5.0m/s in 5.0s. What is the average acceleration?

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{-5.0\text{m/s} - 0}{5.0 - 0} = -1.0\text{m/s}^2$$

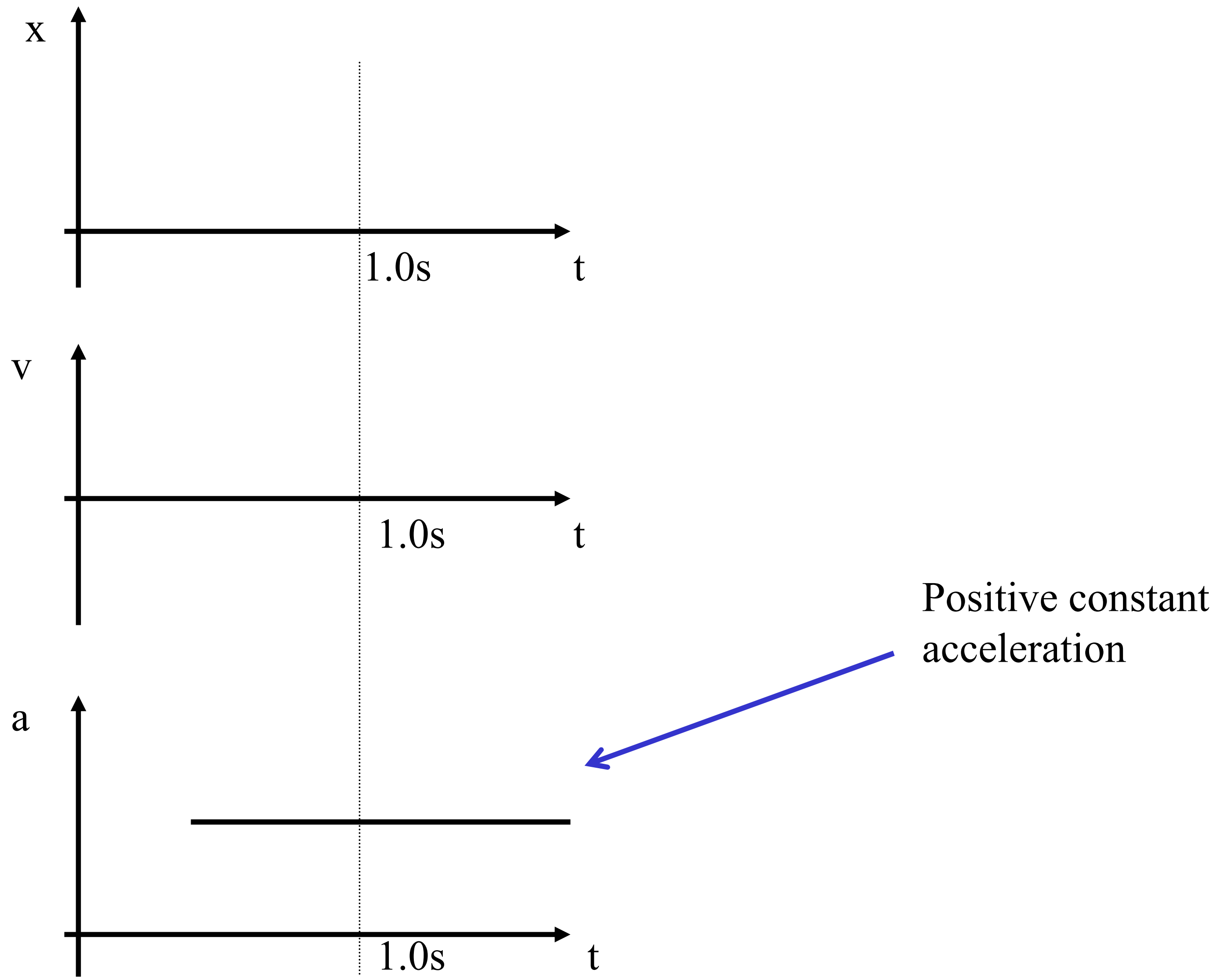
What does the negative acceleration mean?

=> Velocity is getting more negative

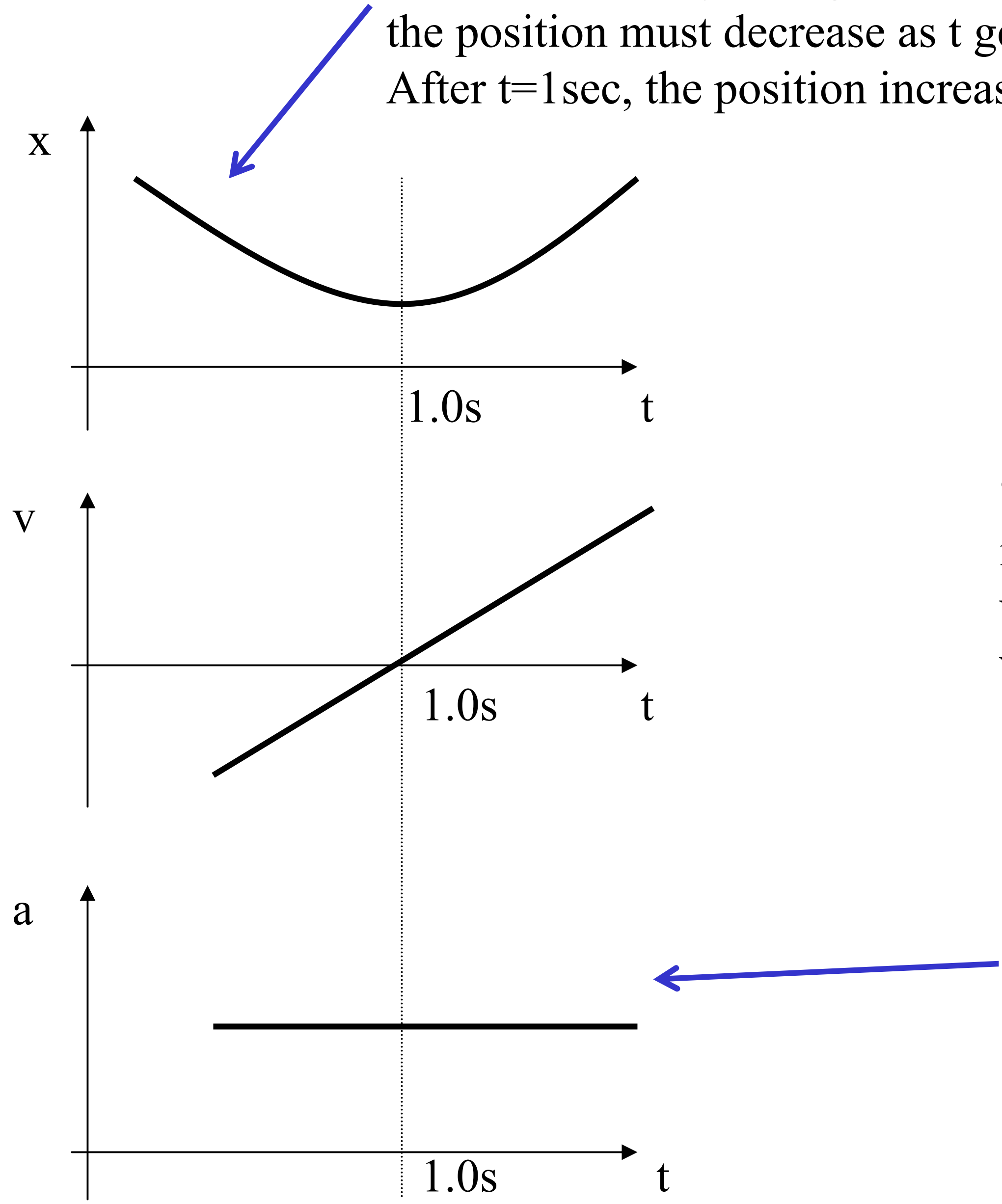
Example: Still running backwards at -5.0m/s, slow down to a stop in 2.0s. What is the average acceleration?

$$a_{avg} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{(0) - (-5.0\text{m/s})}{7.0 - 5.0} = \frac{+5.0}{2.0} = +2.5\text{m/s}^2$$

Example: Sketch a graph that is a possible description of the position of a particle, moving along the x axis, and a t=1.0s, has zero velocity and positive acceleration



Since the velocity is negative for times less than 1 sec the position must decrease as t gets closer to 1 sec. After t=1sec, the position increases. Why?



Since the acceleration is positive, the velocity increases with time

Positive constant acceleration

Motion with Constant Acceleration

1) $a(t) = a_{avg} = constant$

2) Definition of a: $$a = \frac{v_2 - v_1}{t_2 - t_1}$$

3) Let : $t_1 = 0$, $v_1 \equiv v_0$, $t_2 \equiv t$, $v_2 \equiv v$

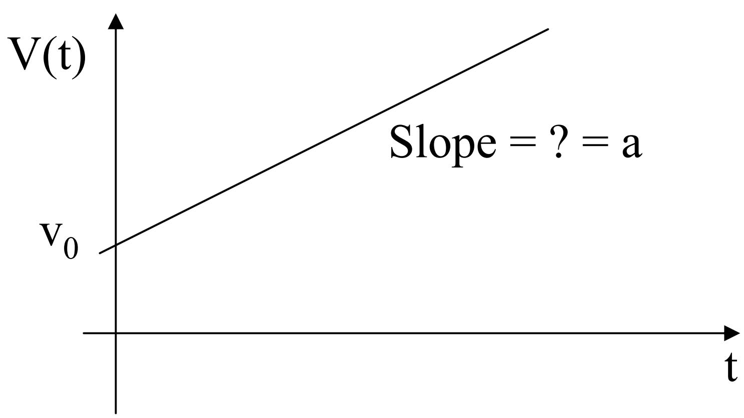
then: $$a = \frac{v_2 - v_1}{t_2 - t_1} = \frac{v - v_0}{t - 0} = \frac{v - v_0}{t}$$

or: $$v = v_0 + at$$

4) What does this look like graphically?

=> Remember a is a constant

=> Assume a is positive



Motion with Constant Acceleration

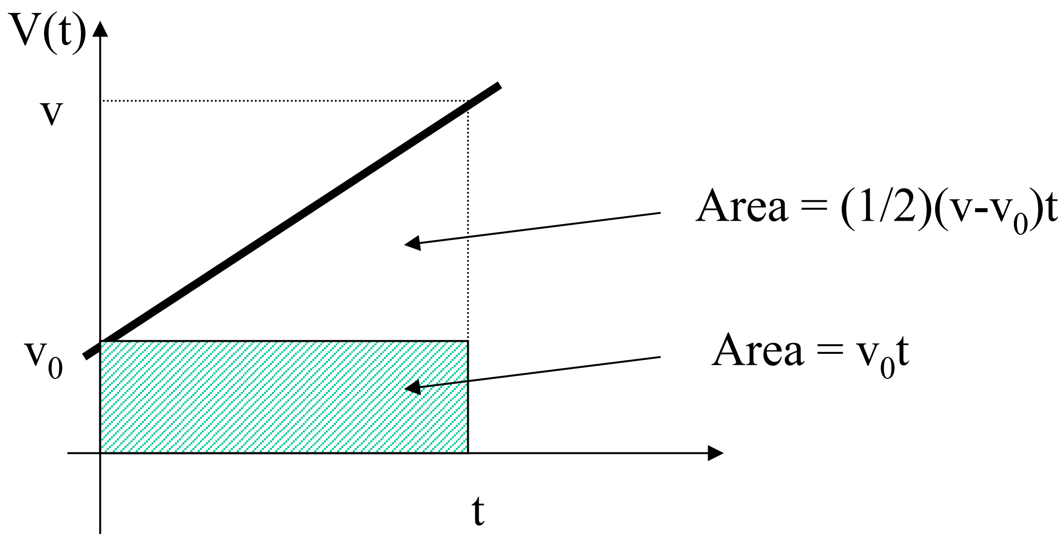
5) How do we get x at time t?

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

$$x(t_2) - x(t_1) = \int_{t_1}^{t_2} V(t)dt$$

$$x(t_2) - x(t_1) = \text{area under } v(t) \text{ curve}$$

$$\text{from } t = t_1 \text{ to } t = t_2$$



Just as before we let:

$$t_1 = 0$$

$$x_1 \equiv x_0$$

$$t_2 \equiv t$$

$$x_2 \equiv x$$

Motion with Constant Acceleration

5) How do we get x at time t?

$$x(t_2) - x(t_1) = x - x_0$$

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

but since $v = v_0 + at$

$$x - x_0 = v_0 t + \frac{1}{2}(\not{v}_0 + at - \not{v}_0)t$$

or

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

Motion with Constant Acceleration

6) Finally, use $v = v_0 + at$ or $t = \dfrac{v - v_0}{a}$

Substitute this into: $x = x_0 + v_0 t + \dfrac{1}{2} a t^2$

After some simple algebra:

$$v^2 = v_0^2 + 2a(x - x_0)$$

Summary:

Equation 1: $$v = v_0 + at$$

Equation 2: $$v^2 = v_0^2 + 2a(x - x_0)$$

Equation 3: $$x = x_0 + v_0 t + \frac{1}{2}at^2$$

What does equation 1 mean?

" Under constant acceleration, the velocity v will be the initial velocity v_0 plus the added velocity we get due to the acceleration. This added velocity must be 'a' m/s for every second."

What does equation 2 mean?

" The position x of an object under constant acceleration at some time t will be the initial position x_0 plus the change in position due to the initial velocity acting over t seconds plus the added displacement due to the acceleration over t seconds."