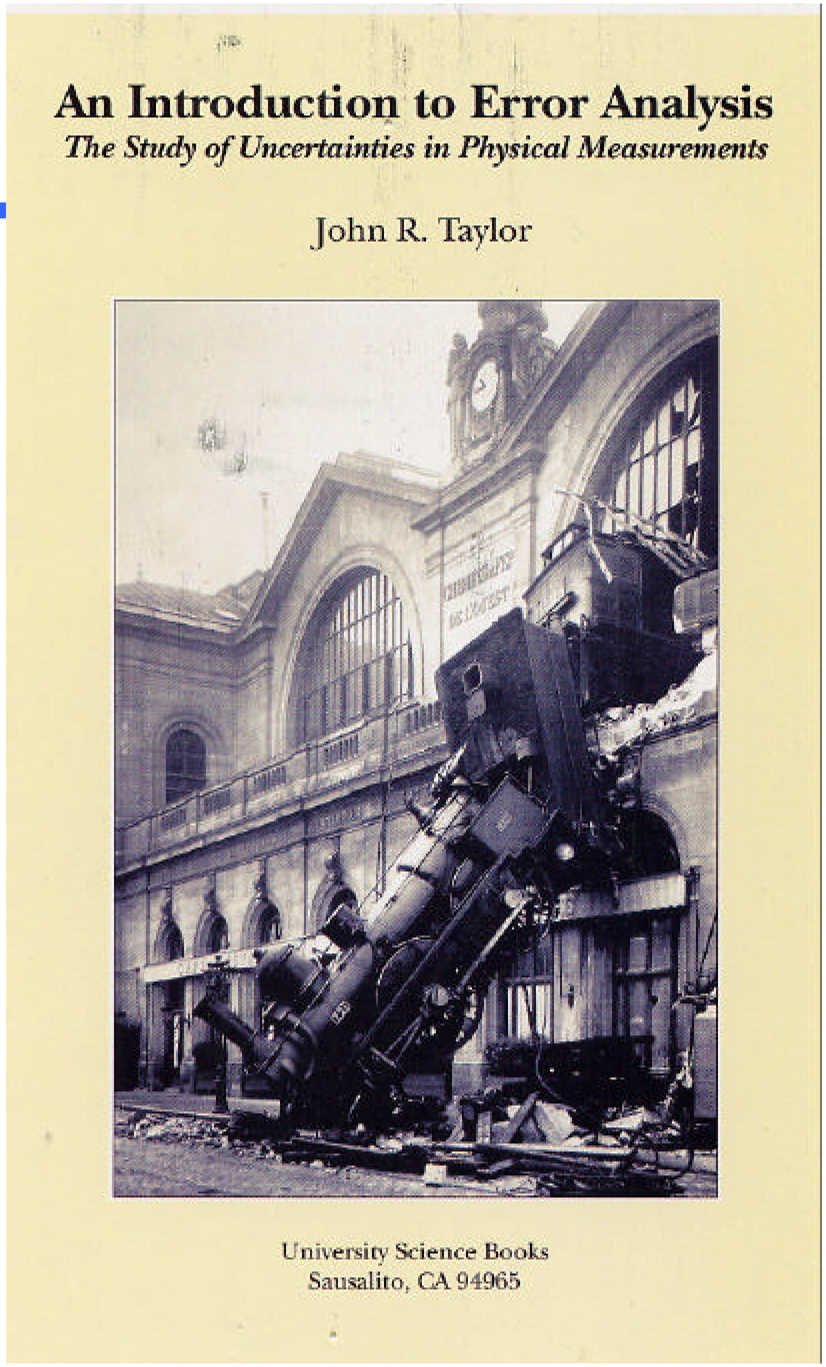
This course: learn how things work

- make trains run at high speed (later)
- make sure they stop (soon)

Physics + Math

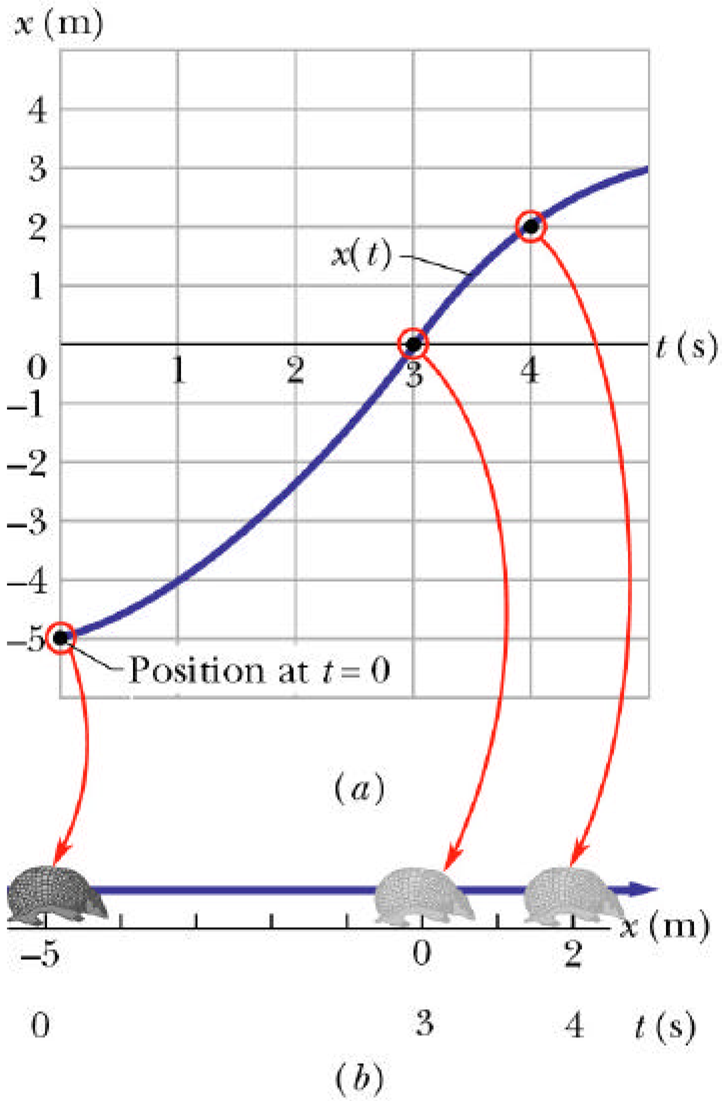
- Today ... learn about describing motion
- Starting, stopping, and everything in between
- Beyond basic issues
  - uncertainties --- errors
  - evaluating them left for labs



Today's Lecture: See Ch 2, 3

- Position, velocity, and acceleration in one dimensional motion
- Motion in 2 and 3 dimensions
  - vectors

Position versus time



- **Pix from text shows location versus time**

Definitions of velocity and acceleration

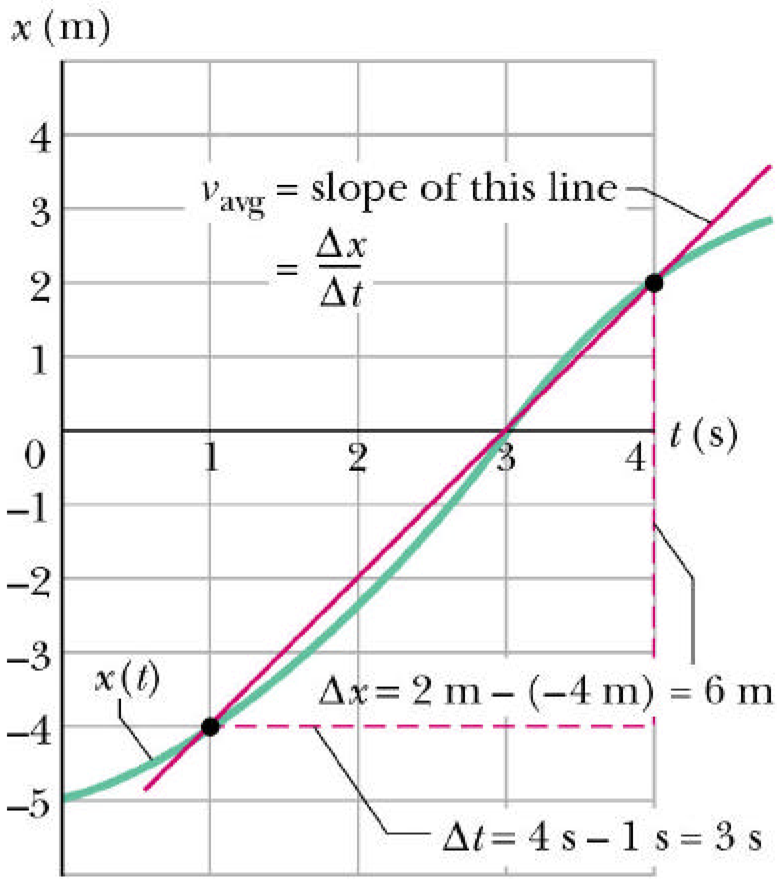
Average velocity

$$\bar{v} \equiv \frac{\Delta x}{\Delta t}$$

Average acceleration

$$\bar{a} \equiv \frac{\Delta v}{\Delta t}$$

Velocity



- **Average velocity**
  - ◆ **Interval dependent**
- **Instantaneous velocity**
  - ◆ **Limit of interval = 0**

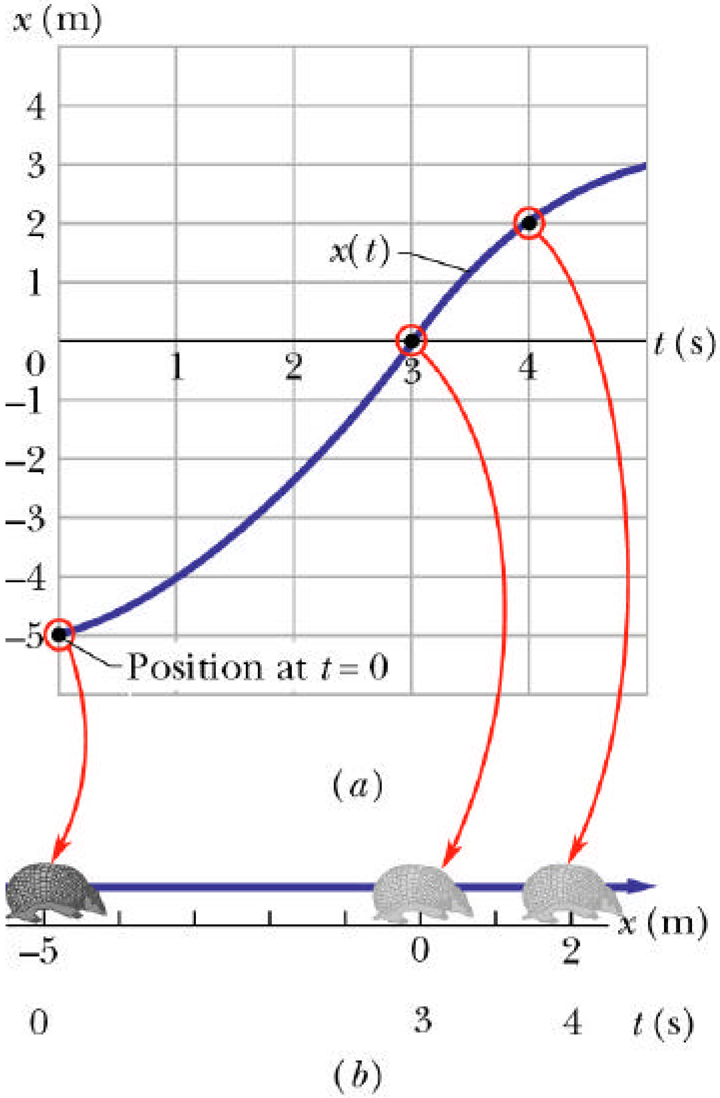
$$v_{avg} = \bar{v} = \frac{\Delta x}{\Delta t}$$

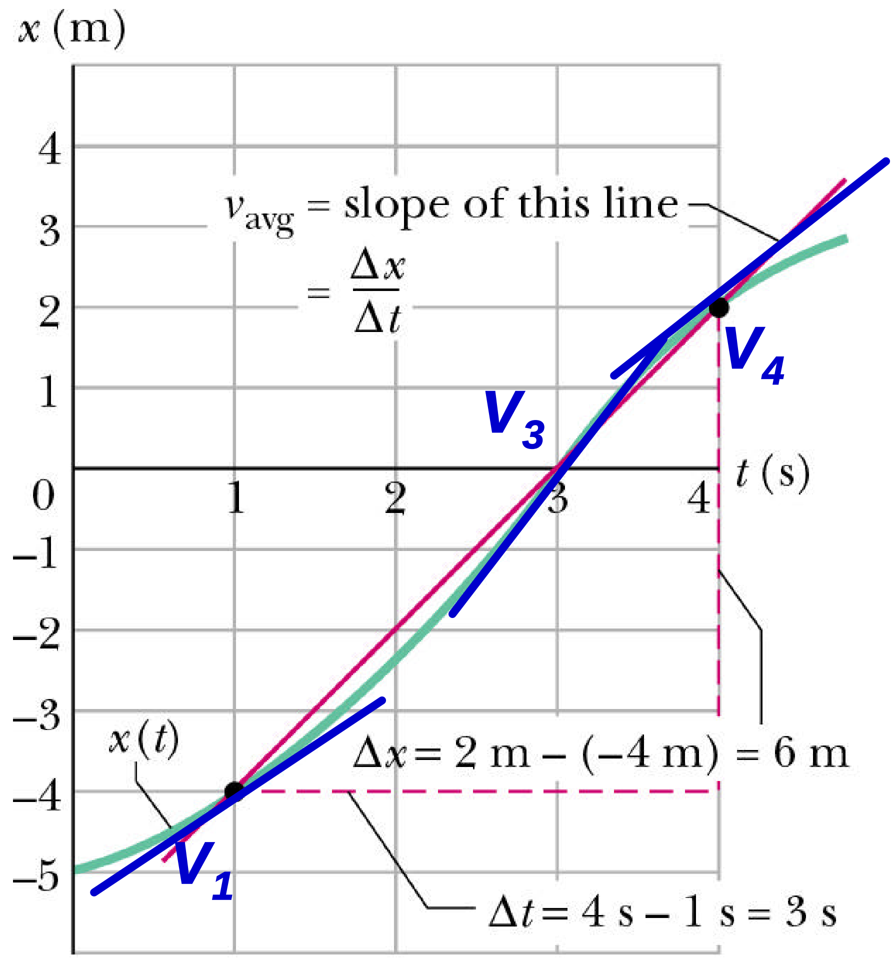
Case shown $\bar{v} = \frac{6m}{3s} = 2\, m/s$

$$v_{inst} = v = \lim_{\Delta t \to 0}\left[\frac{\Delta x}{\Delta t}\right] = \frac{dx}{dt}$$

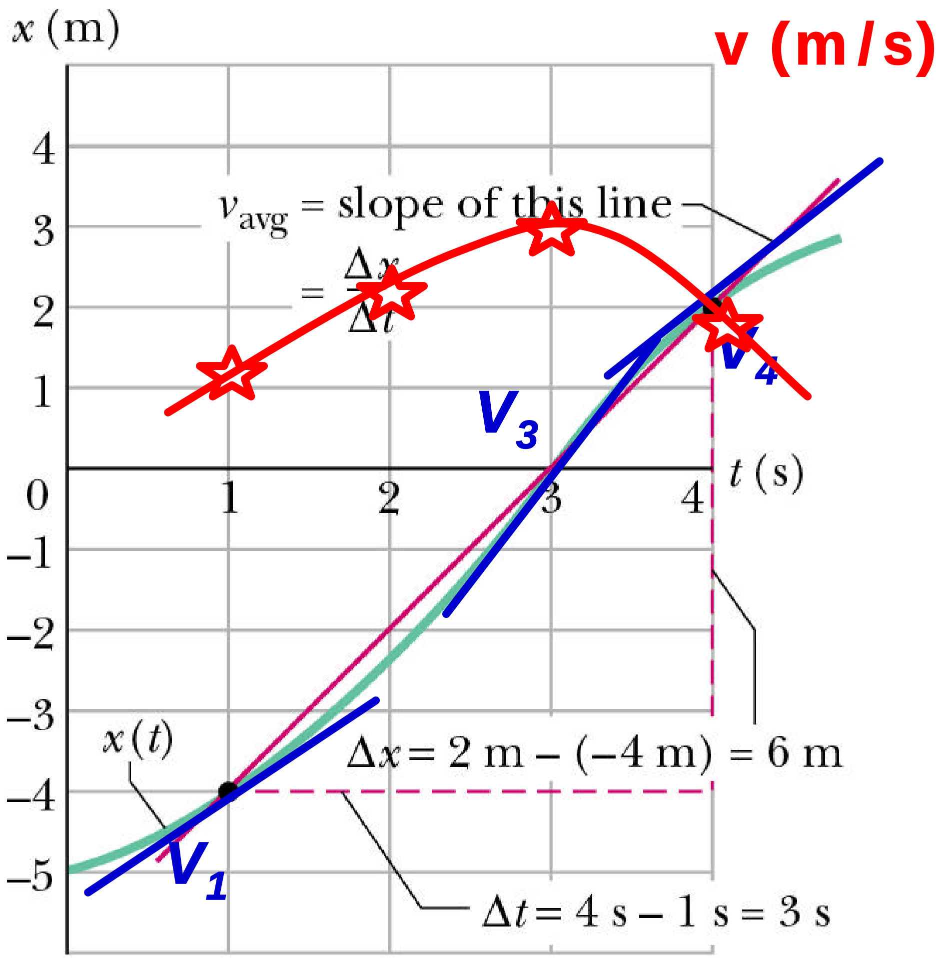
Instantaneous velocity

$$v_{inst} = v = \lim_{\Delta t \to 0}\left[\frac{\Delta x}{\Delta t}\right] = \frac{dx}{dt}$$





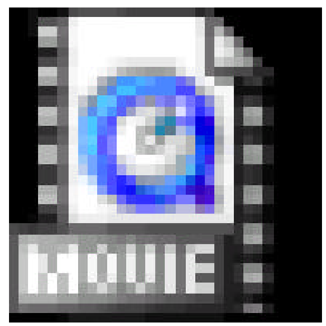
Velocity as slope of x vs t



- Instantaneous velocity can also change with time
- For this case, it does!
- Red points show v=dx/dt (in m/s) as a function of time
- Note that velocity changes !!

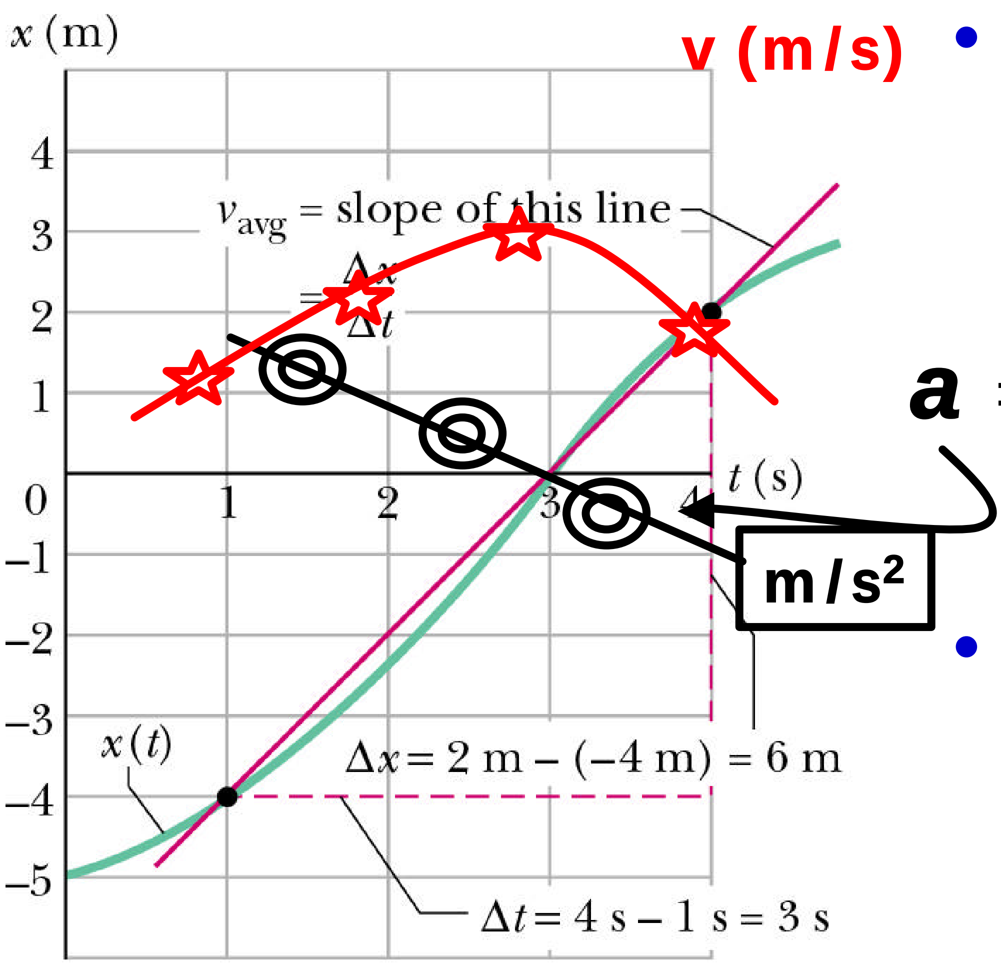
Movie illustration

Position, velocity, and acceleration in one-dimensional motion



x-v-a-1min.MOV

Acceleration = rate of velocity change



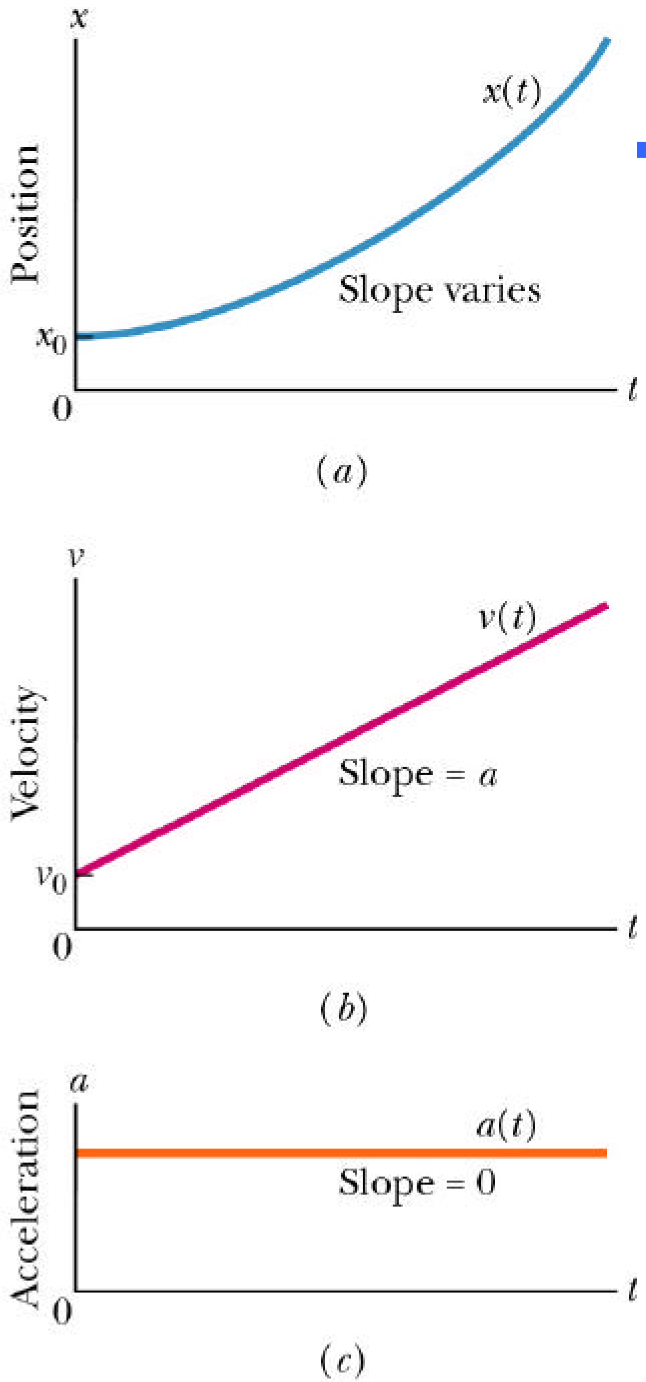
- **Note that velocity changes = acceleration (a) !!**

$$a = \lim_{\Delta t \to 0} \left[\frac{\Delta v}{\Delta t} \right] \equiv \frac{dv}{dt}$$

- **Units of acceleration**

$$\frac{m/s}{s} = \frac{m}{s^2}$$

Constant acceleration



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

$$v = v_0 + at$$

$$a = \text{constant}$$

Table 2-1 in text: constant acceleration

$$v = v_0 + at$$ **Derived already**

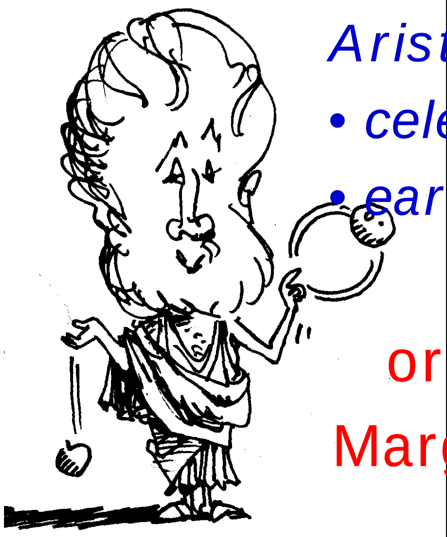
$$x = x_0 + v_0 t + \frac{1}{2} a t^2$$ **Derived already**

$$v^2 = v_0^2 + 2a(x - x_0)$$ **eliminate *t* *from eqns***

$$x - x_0 = \frac{1}{2}(v_0 + v)t$$ ***eliminate a from eqns***

$$x - x_0 = vt - \frac{1}{2} a t^2$$ ***eliminate v_0 from eqns***

Real Up and Down 1D Motion (on Earth)



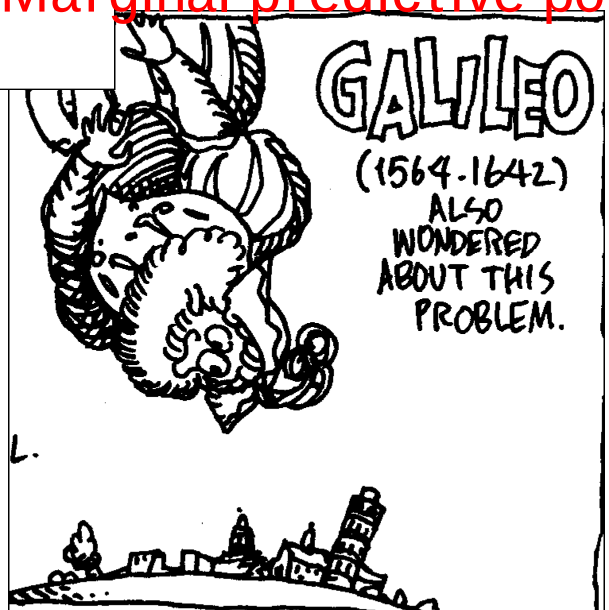
Aristotle(384-322BCE):

- *celestial motion circular*
- *earthly motion linear*

GOT IT WRONG

or at least incomplete

Marginal predictive power!



GOT IT RIGHT!

If all other forces (friction, air drag, …) are small and can be neglected, then for a <u>free body</u>

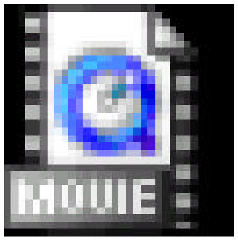
- **horizontal motion has zero acceleration**
- **vertical motion has a universal value of acceleration:**

$a = g = 9.8\ m/s^2 = 32\ ft/s^2$

<u>DOWN!</u>

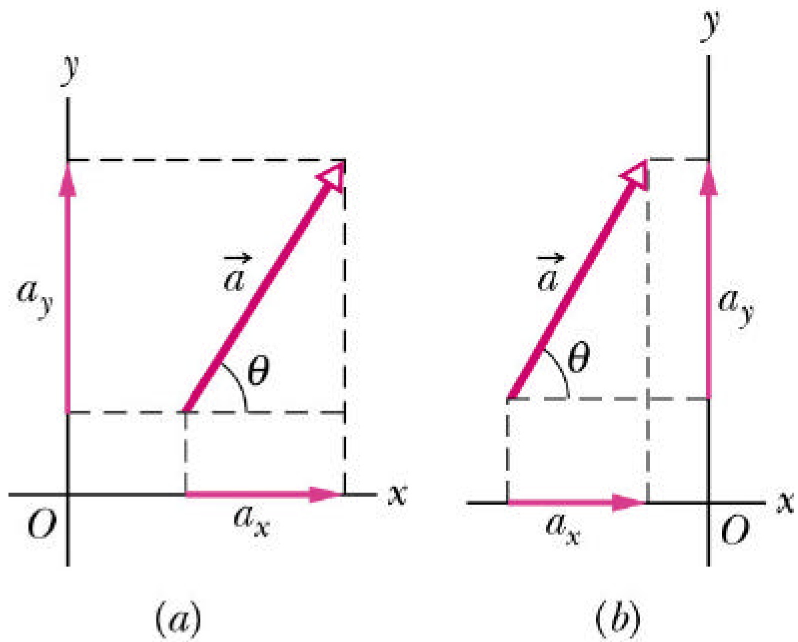
Physics Examples of 1D Motion

- **Ignore complications of friction, air drag, etc– <u>free bodies</u> move in <u>simple</u> ways!**
- **Horizontal Motion**
  - **Horizontal: zero acceleration**
- **Vertical Motion**
  - **"Free fall": substantial and <u>constant</u> acceleration**
  - **Universal gravitational acceleration at Earth surface: $g=9.8\ m/s^2$**

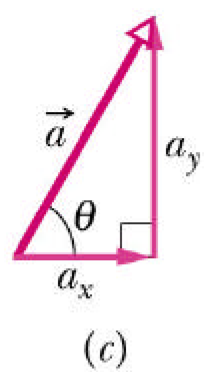


grav acc - ball.MOV

More than 1 dimension: VECTORS
Chapter 3



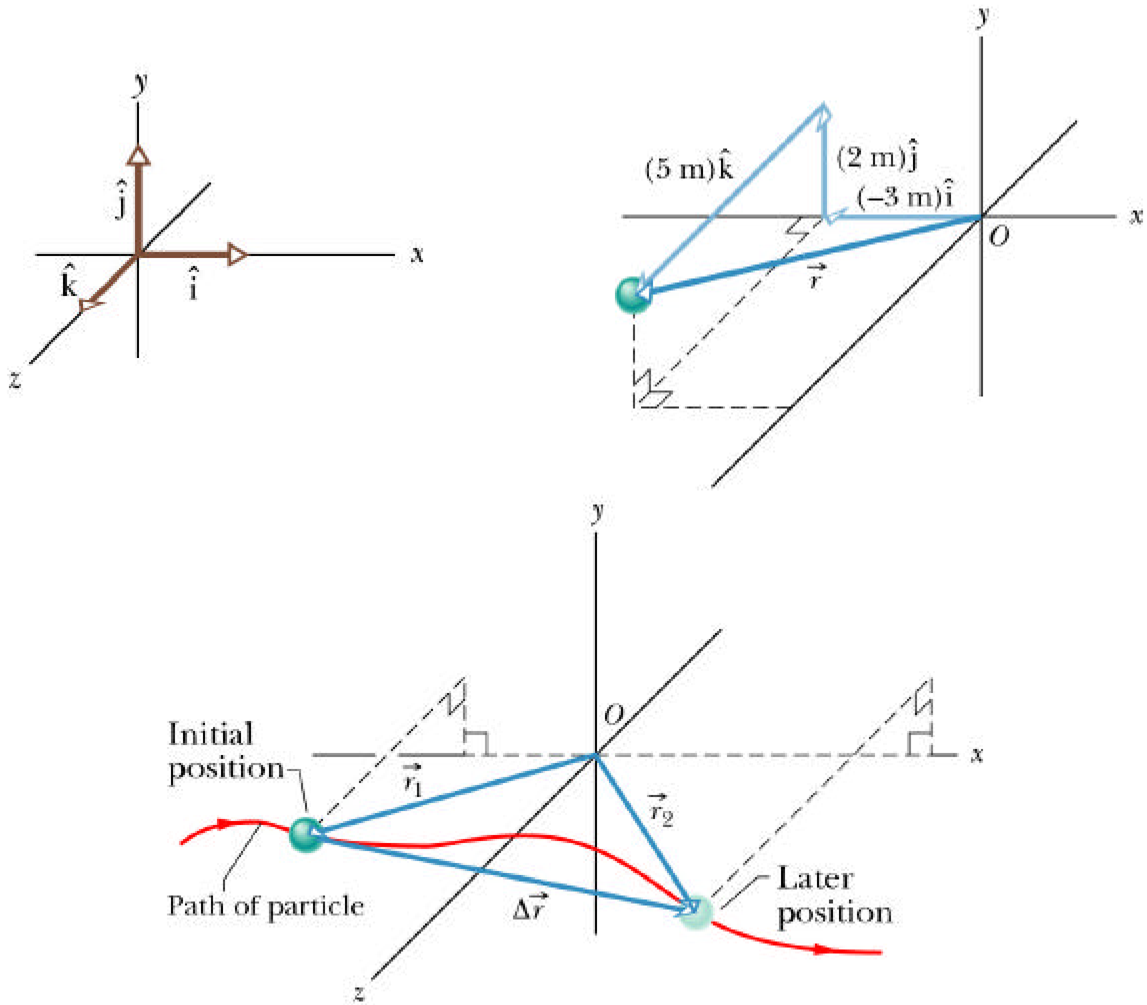
- Mathematically represent quantities with size & direction
- Vector points from one point to another in graph
- Vector <u>completely</u> specified by its <u>components along axes</u>
- Magnitude represented by <u>length of vector</u>
- Angle(s) required to provide direction
- Properties <u>independent</u> of vector location



$$\mathbf{a}_x = \mathbf{a} \cos q \qquad \mathbf{a}_y = \mathbf{a} \sin q$$

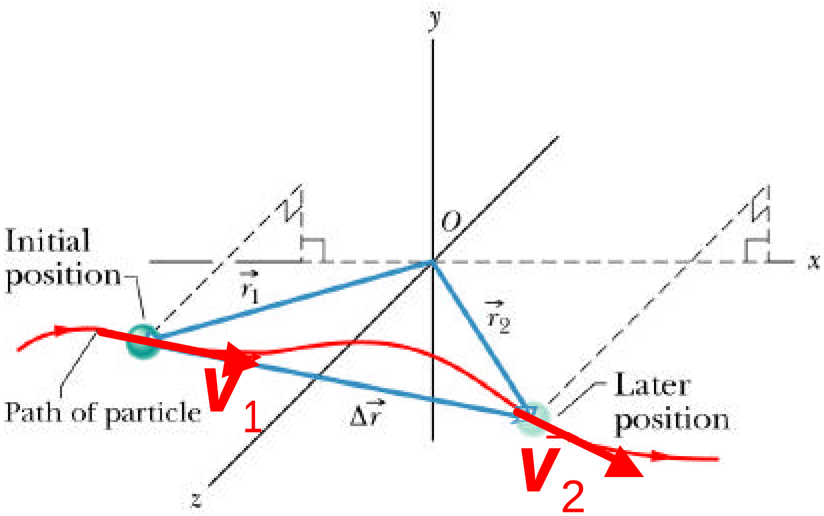
$$\mathbf{a} = \sqrt{\mathbf{a}_x^2 + \mathbf{a}_y^2} \qquad \tan q = \frac{\mathbf{a}_y}{\mathbf{a}_x}$$

Position Vectors – 3D



- Real object in real space requires 3D description
  - 3 components or projections
- Get away with fewer when it happens to move
  - along a line (1D)
  - in a plane (2D)

Position, velocity, acceleration vectors



$$\vec{r}$$

$$\vec{v} = \frac{d\vec{r}}{dt}$$

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2}$$

- **Position vector from origin to present location**
- **Velocity vector is <u>along trajectory</u>**
- **Acceleration vector can be any direction**

Vector equation shorthand

Simple short way of writing <u>three</u> equations

example:

$$\vec{r}\ (= x\hat{i} + y\hat{j} + z\hat{k}) \qquad x$$

$$\vec{v} = \frac{d\vec{r}}{dt} \quad \Rightarrow \quad v_x = \frac{dx}{dt}$$

$$\vec{a} = \frac{d\vec{v}}{dt} = \frac{d^2\vec{r}}{dt^2} \qquad a_x = \frac{dv_x}{dt} = \frac{d^2x}{dt^2}$$

Chapters 2 and 3

- **Make sure you understand them**
- **We will use <u>all</u> of the mathematical concepts**
- **Get comfortable with using vectors**
  - **Work through examples on your own**
  - **Work out problems to satisfy yourself**
- **Vector products … understand …**
  - **We will use them later (for work, energy, …)**
  - **Assume you know the math**