PHYS 1443 – Section 001
Lecture #2

Wednesday, May 31, 2006
Dr. Jaehoon Yu

- Brief history of physics
- Standards and units
- Dimensional Analysis
- Fundamentals
- One Dimensional Motion: Average Velocity; Acceleration; Motion under constant acceleration; Free Fall
- Motion in Two Dimensions: Vector Properties and Operations; Motion under constant acceleration; Projectile Motion

Announcements

- Reading assignment #1: Read and follow through all sections in appendices A and B by Thursday, June 1
- There will be a quiz on tomorrow, Thursday, June 1, on this reading assignment.

Brief History of Physics

- AD 18th century:
  - Newton's Classical Mechanics: A theory of mechanics based on observations and measurements
- AD 19th Century:
  - Electricity, Magnetism, and Thermodynamics
- Late AD 19th and early 20th century (Modern Physics Era)
  - Einstein's theory of relativity: Generalized theory of space, time, and energy (mechanics)
  - Quantum Mechanics: Theory of atomic phenomena
- Physics has come very far, very fast, and is still progressing, yet we've got a long way to go
  - What is matter made of?
  - How do matters get mass?
  - How and why do matters interact with each other?
  - How is universe created?

Needs for Standards and Units

- Three basic quantities for physical measurements
  - Length, Mass, and Time
- Need a language that everyone can understand each other
  - Consistency is crucial for physical measurements
  - The same quantity measured by one must be comprehendible and reproducible by others
  - Practical matters contribute
- A system of unit called SI (*System International*) was established in 1960
  - Length in meters (*m*)
  - Mass in kilo-grams (*kg*)
  - Time in seconds (*s*)

Definition of Base Units

SI Units	Definitions
1 *m (Length)* = *100 cm*	One meter is the length of the path traveled by light in vacuum during a time interval of 1/299,792,458 of a second.
1 *kg (Mass)* = *1000 g*	It is equal to the mass of the international prototype of the kilogram, made of platinum-iridium in International Bureau of Weights and Measure in France.
1 *s (Time)*	One second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Cesium 133 (C^{133}) atom.

- *There are prefixes that scales the units larger or smaller for convenience (see pg. 7)*
- *Units for other quantities, such as Kelvins for temperature, for easiness of use*

Prefixes, expressions and their meanings

- deca (da): 10^1
- hecto (h): 10^2
- kilo (k): 10^3
- mega (M): 10^6
- giga (G): 10^9
- tera (T): 10^{12}
- peta (P): 10^{15}
- exa (E): 10^{18}

- deci (d): 10^{-1}
- centi (c): 10^{-2}
- milli (m): 10^{-3}
- micro (μ): 10^{-6}
- nano (n): 10^{-9}
- pico (p): 10^{-12}
- femto (f): 10^{-15}
- atto (a): 10^{-18}

International Standard Institutes

- International Bureau of Weights and Measure http://www.bipm.fr/
  - Base unit definitions: http://www.bipm.fr/enus/3_SI/base_units.html
  - Unit Conversions: http://www.bipm.fr/enus/3_SI/
- US National Institute of Standards and Technology (NIST) http://www.nist.gov/

How do we convert quantities from one unit to another?

Unit 1 = Conversion factor X Unit 2

1 inch	2.54	cm
1 inch	0.0254	m
1 inch	2.54×10^{-5}	km
1 ft	30.3	cm
1 ft	0.303	M
1 ft	3.03×10^{-4}	km
1 hr	60	minutes
1 hr	3600	seconds
And many	More	Here….

Examples 1.3 and 1.4 for Unit Conversions

- Ex 1.3: A silicon chip has an area of 1.25in^2. Express this in cm^2.

What do we need to know?

$$1.25\ \text{in}^2 = 1.25\ \text{in}^2 \times \left(\frac{2.54\ \text{cm}}{1\ \text{in}}\right)^2$$
$$= 1.25\ \cancel{\text{in}^2} \times \left(\frac{6.45\ \text{cm}^2}{1\ \cancel{\text{in}^2}}\right)$$
$$= 1.25 \times 6.45\ \text{cm}^2 = 8.06\ \text{cm}^2$$

- Ex 1.4: Where the posted speed limit is 65 miles per hour (mi/h or mph), what is this speed (a) in meters per second (m/s) and (b) kilometers per hour (km/h)?

$$1\ \text{mi} = (5280\ \text{ft})\left(\frac{12\ \text{in}}{1\ \text{ft}}\right)\left(\frac{2.54\ \text{cm}}{1\ \text{in}}\right)\left(\frac{1\ \text{m}}{100\text{cm}}\right) = 1609\ \text{m} = 1.609\ \text{km}$$

(a) $$65\ \text{mi/h} = (65\ \text{mi})\left(\frac{1609\ \text{m}}{1\ \text{mi}}\right)\left(\frac{1}{1\ \text{h}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right) = 29.1\ \text{m/s}$$

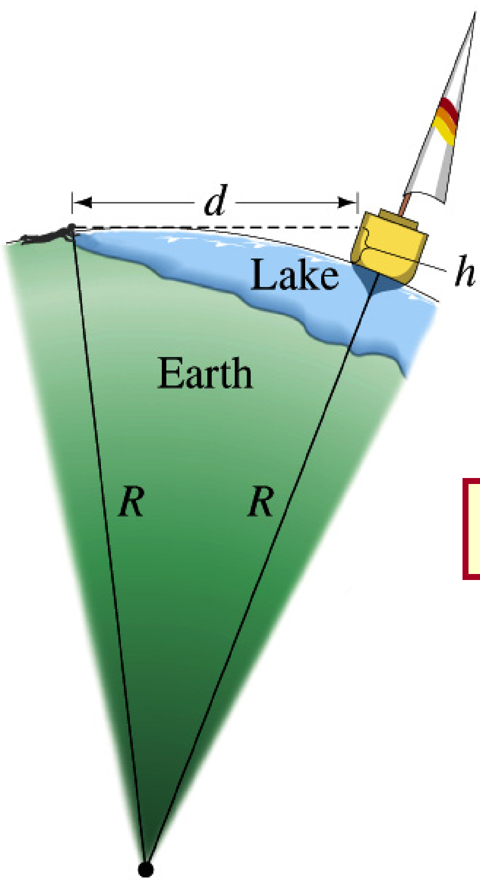
(b) $$65\ \text{mi/h} = (65\ \text{mi})\left(\frac{1.609\ \text{km}}{1\ \text{mi}}\right)\left(\frac{1}{1\ \text{h}}\right) = 104\ \text{km/h}$$

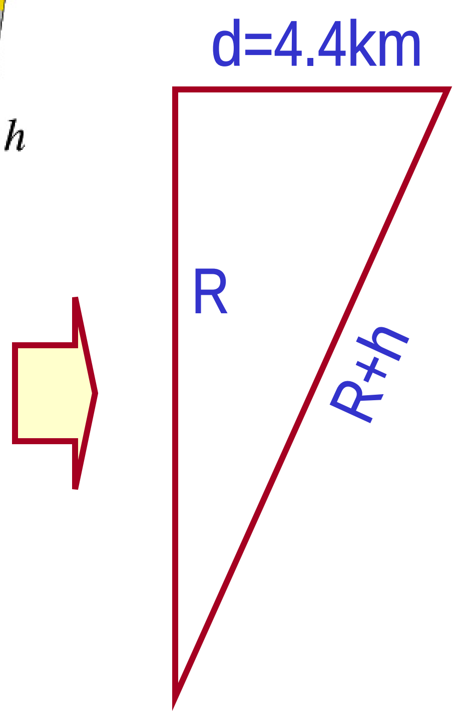
Estimates & Order-of-Magnitude Calculations

- Estimate = Approximation
  - Useful for rough calculations to determine the necessity of higher precision
  - Usually done under certain assumptions
  - Might require modification of assumptions, if higher precision is necessary
- Order of magnitude estimate: Estimates done to the precision of 10s or exponents of 10s;
  - Three orders of magnitude: 10^3=1,000
  - Round up for Order of magnitude estimate; $8\times10^7 \sim 10^8$
  - Similar terms: "Ball-park-figures", "guesstimates", etc

Example 1.8

Estimate the radius of the Earth using triangulation as shown in the picture when d=4.4km and h=1.5m.





Pythagorian theorem

$$(R+h)^2 \approx d^2 + R^2$$

$$R^2 + 2hR + h^2 \approx d^2 + R^2$$

Solving for R

$$R \approx \frac{d^2 - h^2}{2h}$$

$$= \frac{(4400m)^2 - (1.5m)^2}{2 \times 1.5m}$$

$$= 6500km$$

Uncertainties

- Physical measurements have limited precision, however good they are, due to:
  - Stat.{ – Number of measurements
  - Syst.{ – Quality of instruments (meter stick vs micro-meter)
  - – Experience of the person doing measurements
  - – Etc
- In many cases, uncertainties are more important and difficult to estimate than the central (or mean) values

Significant Figures

- Significant figures denote the precision of the measured values
  - Significant figures: non-zero numbers or zeros that are not place-holders
    - 34 has two significant digits, 34.2 has 3, 0.001 has one because the 0's before 1 are place holders, 34.100 has 5, because the 0's after 1 indicates that the numbers in these digits are indeed 0's.
    - When there are many 0's, use scientific notation:
      - $31400000 = 3.14 \times 10^{7}$
      - $0.00012 = 1.2 \times 10^{-4}$

Significant Figures

- Operational rules:
  - Addition or subtraction: Keep the <u>smallest number of decimal place</u> in the result, independent of the number of significant digits: 12.001+ 3.1= $\boxed{15.1}$
  - Multiplication or Division: Keep the <u>smallest significant figures</u> in the result: 12.001 x 3.1 = $\boxed{37}$, because the smallest significant figures is ?.

Dimension and Dimensional Analysis

- An extremely useful concept in solving physical problems
- Good to write physical laws in mathematical expressions
- No matter what units are used the base quantities are the same
  - *Length* (distance) is length whether meter or inch is used to express the size: Usually denoted as *[L]*
  - The same is true for *Mass ([M])* and *Time ([T])*
  - One can say "Dimension of Length, Mass or Time"
  - Dimensions are used as algebraic quantities: Can perform two algebraic operations; multiplication or division

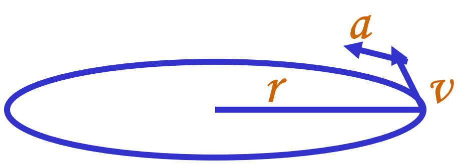
Dimension and Dimensional Analysis

- One can use dimensions only to check the validity of one's expression: Dimensional analysis
  - Eg: Speed $[v] = [L]/[T]=[L][T^{-1}]$
    - *Distance (L) traveled by a car running at the speed V in time T*
    - $L = V*T = [L/T]*[T]=[L]$
- More general expression of dimensional analysis is using exponents: eg. $[v]=[L^nT^m] =[L]\{T^{-1}]$ *where* $n = 1$ *and* $m = -1$

Examples

- Show that the expression *[v] = [at]* is dimensionally correct
  - Speed: *[v]* =L/T
  - Acceleration: *[a]* =L/T^2
  - Thus, *[at]* = (L/T^2)xT=LT$^{(-2+1)}$ =LT^{-1} =L/T= *[v]*

•Suppose the acceleration a of a circularly moving particle with speed v and radius r is proportional to r^n and v^m. What are n and m?



$$a = kr^n v^m$$

Dimensionless constant

Length

Speed

$$L^1T^{-2} = (L)^n \left(\frac{L}{T}\right)^m = L^{n+m}T^{-m}$$

$$-m = -2 \Rightarrow m = 2$$

$$n + m = n + 2 \equiv 1 \Rightarrow n = -1$$

$$a = kr^{-1}v^2 = \frac{v^2}{r}$$

Some Fundamentals

- Kinematics: Description of Motion without understanding the cause of the motion
- Dynamics: Description of motion accompanied with understanding the cause of the motion
- Vector and Scalar quantities:
  - Scalar: Physical quantities that require magnitude but no direction
    - Speed, length, mass, height, volume, area, magnitude of a vector quantity, etc
  - Vector: Physical quantities that require both magnitude and direction
    - Velocity, Acceleration, Force, Momentum
    - It does not make sense to say "I ran with velocity of 10miles/hour."
- Objects can be treated as point-like if their sizes are smaller than the scale in the problem
  - Earth can be treated as a point like object (or a particle)in celestial problems
    - Simplification of the problem (The first step in setting up to solve a problem…)
  - Any other examples?

Some More Fundamentals

- Motions:Can be described as long as the position is known at any time (or position is expressed as a function of time)
  – Translation: Linear motion along a line
  – Rotation: Circular or elliptical motion
  – Vibration: Oscillation
- Dimensions
  – 0 dimension: A point
  – 1 dimension: Linear drag of a point, resulting in a line ➔ Motion in one-dimension is a motion on a line
  – 2 dimension: Linear drag of a line resulting in a surface
  – 3 dimension: Perpendicular Linear drag of a surface, resulting in a stereo object

Displacement, Velocity and Speed

One dimensional displacement is defined as:

$$\Delta x \equiv x_f - x_i$$

Displacement is the difference between initial and final potions of motion and is a vector quantity. How is this different than distance?

Average velocity is defined as:

$$v_x \equiv \frac{x_f - x_i}{t_f - t_i} = \frac{\Delta x}{\Delta t}$$

Displacement per unit time in the period throughout the motion

Average speed is defined as:

$$v \equiv \frac{\text{Total Distance Traveled}}{\text{Total Time Spent}}$$

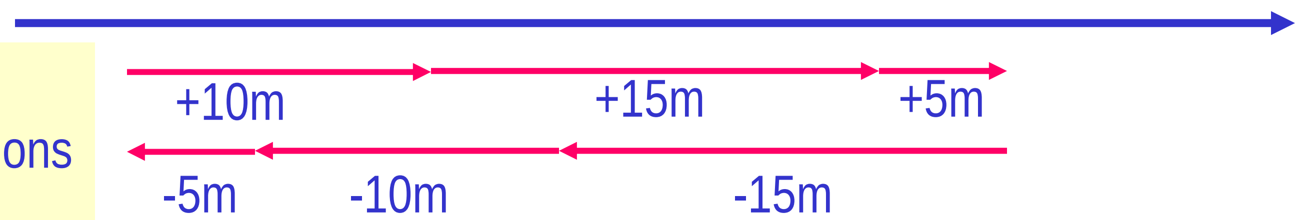
Can someone tell me what the difference between speed and velocity is?

Difference between Speed and Velocity

- Let's take a simple one dimensional translation that has many steps:

Let's call this line as X-axis

Let's have a couple of motions in a total time interval of 20 sec.



Total Displacement: $\Delta x \equiv x_f - x_i = x_i - x_i = 0(m)$

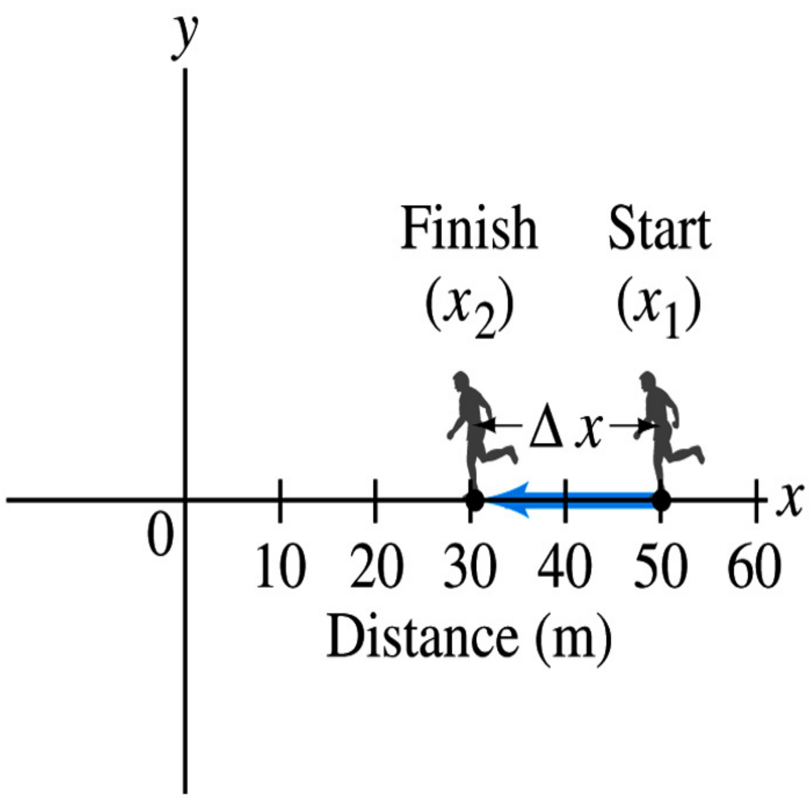
Average Velocity: $v_x \equiv \dfrac{x_f - x_i}{t_f - t_i} = \dfrac{\Delta x}{\Delta t} = \dfrac{0}{20} = 0(m/s)$

Total Distance Traveled: $D = 10+15+5+15+10+5 = 60(m)$

Average Speed: $v \equiv \dfrac{\text{Total Distance Traveled}}{\text{Total Time Interval}} = \dfrac{60}{20} = 3(m/s)$

Example 2.1

The position of a runner as a function of time is plotted as moving along the x axis of a coordinate system. During a 3.00-s time interval, the runner's position changes from x_1=50.0m to x_2=30.5 m, as shown in the figure. What was the runner's average velocity? What was the average speed?



- Displacement:

$$\Delta x \equiv x_f - x_i = x_2 - x_1 = 30.5 - 50.0 = -19.5(m)$$

- Average Velocity:

$$v_x \equiv \frac{x_f - x_i}{t_f - t_i} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} = \frac{-19.5}{3.00} = -6.50(m/s)$$

- Average Speed:

$$v \equiv \frac{\text{Total Distance Traveled}}{\text{Total Time Interval}}$$

$$= \frac{50.0 - 30.5}{3.00} = \frac{+19.5}{3.00} = +6.50(m/s)$$

Instantaneous Velocity and Speed

- Can average quantities tell you the detailed story of the whole motion?
- Instantaneous velocity is defined as:

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

  – What does this mean?
    - Displacement in an infinitesimal time interval
    - Mathematically: Slope of the position variation as a function of time

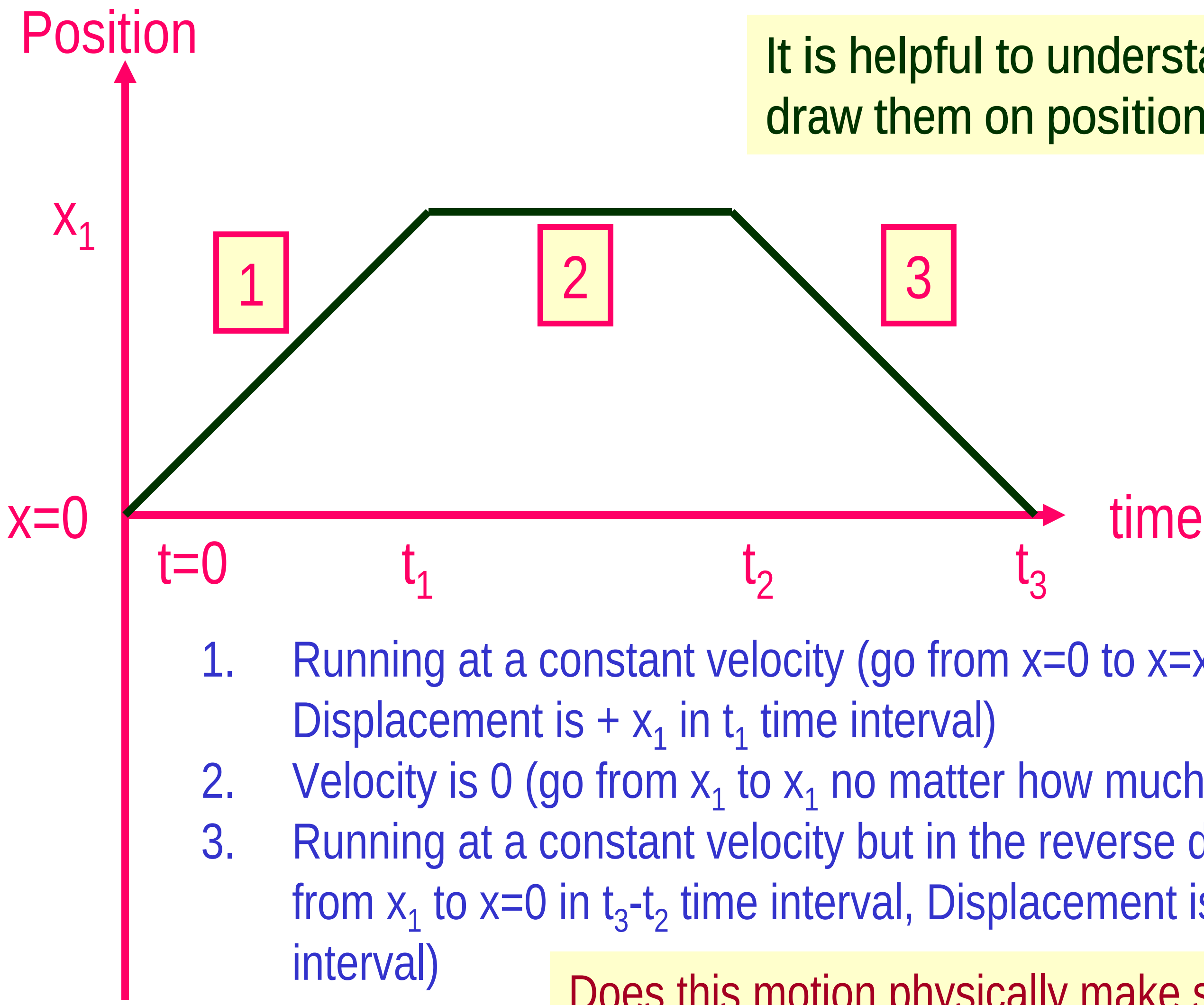
•Instantaneous speed is the size (magnitude) of the velocity vector:

$$|v_x| = \left|\lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t}\right| = \left|\frac{dx}{dt}\right|$$

*Magnitude of Vectors are expressed in absolute values

Position vs Time Plot

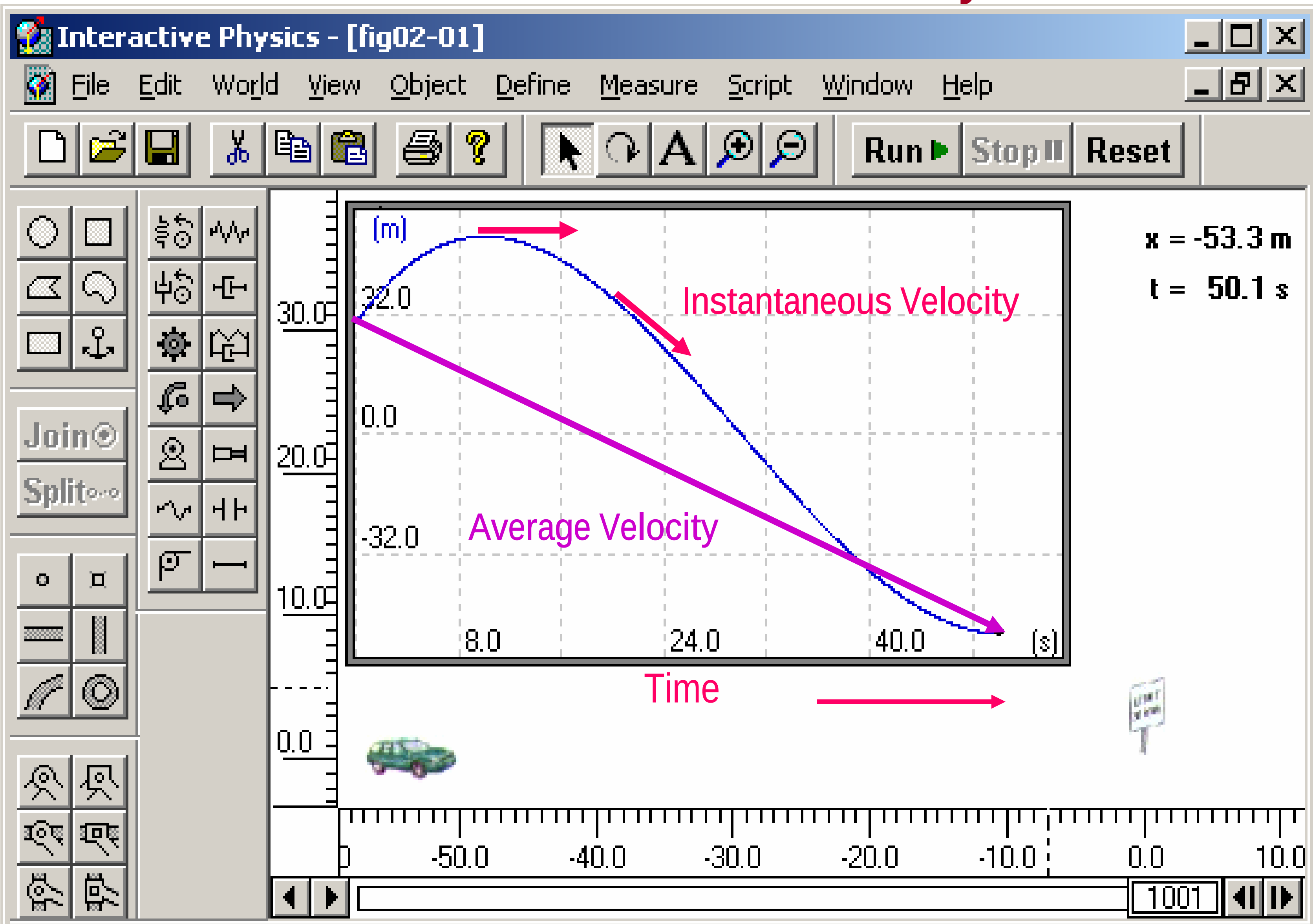
It is helpful to understand motions to draw them on position vs time plots.



1. Running at a constant velocity (go from x=0 to $x=x_1$ in t_1, Displacement is + x_1 in t_1 time interval)
2. Velocity is 0 (go from x_1 to x_1 no matter how much time changes)
3. Running at a constant velocity but in the reverse direction as 1. (go from x_1 to x=0 in t_3-t_2 time interval, Displacement is - x_1 in t_3-t_2 time interval)

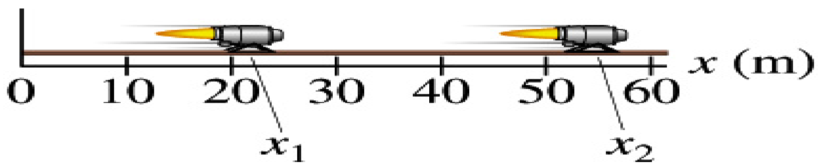
Does this motion physically make sense?

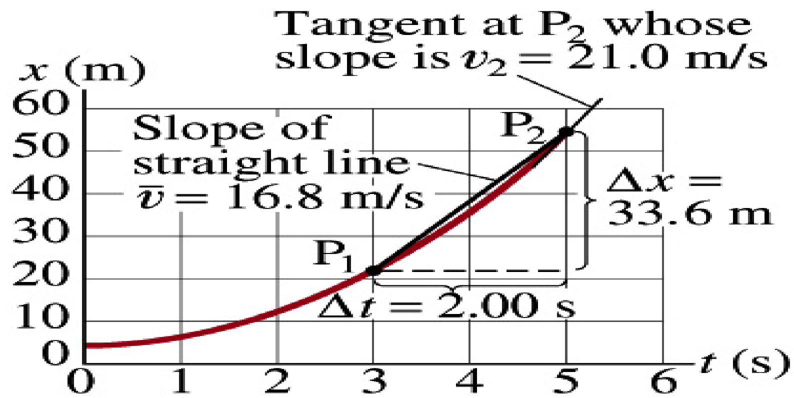
Instantaneous Velocity



Example 2.3

A jet engine moves along a track. Its position as a function of time is given by the equation $x=At^2+B$ where A=2.10m/s^2 and B=2.80m.





(a) Determine the displacement of the engine during the interval from t_1=3.00s to t_2=5.00s.

$$x_1 = x_{t_1=3.00} = 2.10\times(3.00)^2 + 2.80 = 21.7m \qquad x_2 = x_{t_2=5.00} = 2.10\times(5.00)^2 + 2.80 = 55.3m$$

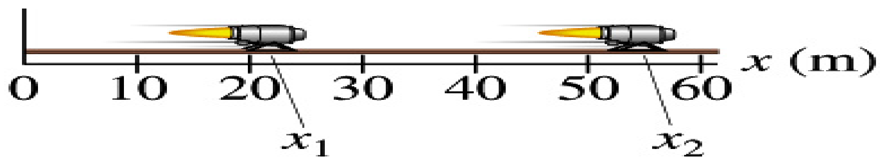
Displacement is, therefore:

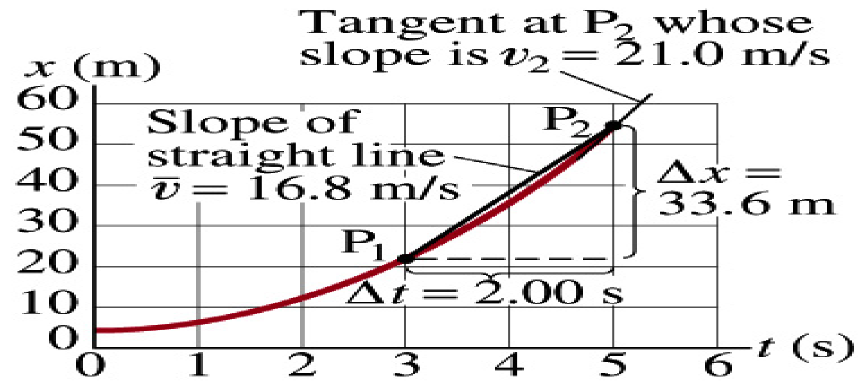
$$\Delta x = x_2 - x_1 = 55.3 - 21.7 = +33.6(m)$$

(b) Determine the average velocity during this time interval.

$$\bar{v}_x = \frac{\Delta x}{\Delta t} = \frac{33.6}{5.00-3.00} = \frac{33.6}{2.00} = 16.8(m/s)$$

Example 2.3 cont'd





(c) Determine the instantaneous velocity at $t=t^2=5.00$s.

Calculus formula for derivative $\boxed{\frac{d}{dt}\left(Ct^n\right)=nCt^{n-1}}$ and $\boxed{\frac{d}{dt}\left(C\right)=0}$

The derivative of the engine's equation of motion is

$$v_x = \lim_{\Delta t \to 0}\frac{\Delta x}{\Delta t} = \frac{dx}{dt} = \frac{d}{dt}\left(At^2+B\right) = 2At$$

The instantaneous velocity at t=5.00s is

$$v_x\left(t=5.00s\right) = 2A\times 5.00 = 2.10\times 10.0 = 21.0\left(m/s\right)$$

Displacement, Velocity and Speed

Displacement $$\Delta x \equiv x_f - x_i$$

Average velocity $$v_x \equiv \frac{x_f - x_i}{t_f - t_i} = \frac{\Delta x}{\Delta t}$$

Average speed $$v \equiv \frac{\text{Total Distance Traveled}}{\text{Total Time Spent}}$$

Instantaneous velocity $$v_x = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

Instantaneous speed $$|v_x| = \left| \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} \right| = \left| \frac{dx}{dt} \right|$$