PHYS 1443 – Section 003
Lecture #1

Wednesday, Sept. 4, 2002

Dr. Jaehoon Yu

1. What is Physics?
2. What do we want from this class?
3. Summary of Chap. 1
4. Significant Figures and Uncertainties
5. One dimensional motion
   - Fundamentals
   - Displacement, Velocity, and Speed
   - Acceleration
   - Kinetic Equation of Motion

Today's homework is homework #2, due 1am, next Wednesday!!

Who am I?

- Name: Dr. Jaehoon Yu (You can call me **Dr. Yu**)
- Office: Rm 242A, Science Hall
- Extension: x2814, E-mail: *jaehoonyu@uta.edu*
- My profession:High Energy Physics
  - Collide particles (protons on anti-protons or electrons on anti-electrons, positrons) at the energies equivalent to 10,000 Trillion degrees
  - To understand
    - Fundamental constituents of matter
    - Interactions or forces between the constituents
    - Creation of Universe (**Big Bang** Theory)
  - A pure scientific research activity
    - Direct use of the fundamental laws we find may take longer than we want but
    - Indirect product of research contribute to every day lives; eg. WWW

Information & Communication Source

- My web page: http://www-hep.uta.edu/~yu/
  - Contact information & Class Schedule
  - Syllabus
  - Holidays and Exam days
  - Evaluation Policy
  - Class Style & homework: 34 of you have registered, will lock the enrollment one week from today
  - Other information
- Primary communication tool is e-mail: Register for PHYS1443-003-FALL02 e-mail distribution list as soon possible: Only 9 of you have registered to the list
- Class roster: 45 of you have been officially registered to this course but I have a total of 52. Please register ASAP.

Why do Physics?

Exp.
- To understand nature through experimental observations and measurements (**Research**)

Theory
- Establish limited number of fundamental laws, usually with mathematical expressions
- Predict the nature's course

? Theory and Experiment work hand-in-hand

? Theory works generally under restricted conditions

? Discrepancies between experimental measurements and theory are good for improvements

? Improves our everyday lives, though some laws can take a while till we see amongst us

What do we want from this class?

- Physics is everywhere around you.
- Understand the fundamental principles that surrounds you in everyday lives…
- Identify what law of physics applies to what phenomena…
- Understand the impact of such physical laws
- Learn how to research and analyze what you observe.
- Learn how to express observations and measurements in mathematical language.
- Learn how to express your research in systematic manner in writing
- I don't want you to be scared of PHYSICS!!!
- It really is nothing but a description of nature in mathematical language for ease of use

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

- 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** (*International System of units in French*) 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*	The 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)*	The 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*

Building Blocks of Matters, Density, and Avogadro's Number

- Matter can be sliced to its fundamental constituents
  - Matter → Molecule → Atom → Nucleus → Protons and Neutrons → Quarks
    - Atomic number (ID) of a substance = Number of Protons
    - Substances with the same Atomic number but different mass exist in nature and are called **Isotopes**
    - Atomic mass of a substance = average N_p+N_n of all isotopes
- A property of matter is density of matter (ρ): Amount of mass contained within unit volume (e.g.: $\rho_{Al}=2.7 g/cm^3$)

$$r \equiv \frac{M(kg)}{V(m^3)}$$

- One *mole (mol)* of a substance ← Definition of a standard for consistency
  - The amount of the substance that contains as many particles (atoms, molecules, etc) as there are in 12g of C^{12} Isotope
  - This number, based on experiment, is:
    - Avogadro's number: 6.02×10^{23} particles/mol

Example 1.1

- A cube of *Al* whose volume V=0.2 cm^3
  - Density: ρ = 2.7 g/cm^3
- What is the number of Al atoms contained in the cube?

1. What is the mass of the cube?

$$m = rV = 2.7(g/cm^3)\times 0.2(cm^3) = 0.54(g)$$

2. What is the mass of 1 mol of Al?

$$m_{Al} = 27(g/mol) = 27g/6.02\times 10^{23}(atoms)$$

3. So using proportion:

➔ 27*g* : 6.02x10^{23}(atoms) = 0.54*g* : N(atoms)

$$N = \frac{m}{m_{Al}} = \frac{0.54g}{27(g/mol)} = 0.02mol$$

$$= 0.02\times 6.02\times 10^{23}(atoms) = 1.2\times 10^{22}(atoms)$$

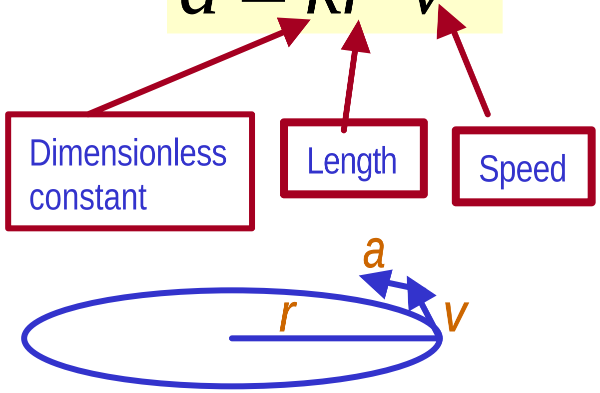
Dimension and Dimensional Analysis

- 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 algebraic operations, addition, subtraction, multiplication or division
- 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 1.2 & 1.3

- 1.2: Show that the expression *[v] = [at]* is dimensionally correct
  - Based on table 1.6
    - Speed: *[v]* =L/T
    - Acceleration: *[a]* =L/T^2
    - Thus, *[at]* = (L/T^2)xT=LT$^{(-2+1)}$ =LT^{-1} =L/T= *[v]*
- 1.3: Suppose *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*?

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



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

$$-m = -2$$

$$m = 2$$

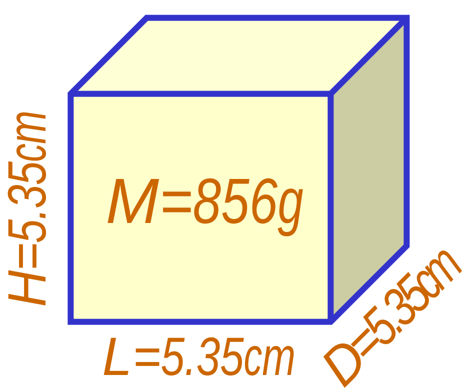
$$n + m = n + 2 = 1$$

$$n = -1$$

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

Unit Conversion: Example 1.4

- US and UK still use British Engineering units: foot, lbs, and seconds
  - 1.0 in= 2.54 cm, 1ft=0.3048m=30.48cm
  - 1m=39.37in=3.281ft~1yd, 1mi=1609m=1.609km
  - 1lb=0.4535kg=453.5g, 1oz=28.35g=0.02835kg
  - Online unit converter: http://www.digitaldutch.com/unitconverter/
- Example 1.4: Determine density in basic SI units (*m,kg*)



$$r = \frac{M}{V}$$

$$V = L \times D \times H = (5.35\ cm) \times (5.35\ cm) \times (5.35\ cm) = (5.35)^3\ cm^3$$

$$= 153.13\ cm^3 = \frac{153.13\ cm^3}{(100\ cm/m)^3} = 153.13 \times 10^{-6}\ m^3$$

$$M = 856\ g = \frac{856\ g}{1000\ g/kg} = 0.856\ kg$$

$$r = \frac{M}{V} = \frac{0.856\ kg}{153.13 \times 10^{-6}\ m^3} = 5.59 \times 10^3\ kg/m^3$$

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

Uncertainties and Significant Figures

- Physical measurements have limited precision, however good it is, due to:
  - Syst.{ – Quality of instruments (meter stick vs micro-meter)
  - – Experience of the person doing measurements
  - Stat.{ – Number of measurements
  - Etc
  - In many cases, uncertainties are more important and difficult to estimate than the central (or mean) values
- Significant figures denote this 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.
  - Operational rules:
    - Addition or subtraction: Keep the smallest number of **decimal place** in the result, independent of the number of significant digits: 34.001+120.1=154.1
    - Multiplication or Division: Keep the smallest **significant figures** in the result: 34.001x120.1 = 4083, because the smallest significant figures is 4.

Example 1.8

- Area of a rectangle and the uncertainty:

L=(21.3+/-0.2)cm

W=(9.80+/-0.1)cm

1. Find the minimum:

$A_{Low}=(L-\Delta L)x(W-\Delta W)$
$= (21.1\ cm)x(9.7cm) = 205$ (round-up)

2. Find the maximum:

$A_{High}=(L+\Delta L)x(W+\Delta W)$
$= (21.5\ cm)x(9.9cm) = 213$ (round-up)

3. Take the average between minimum and maximum:

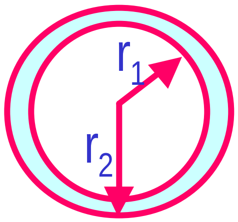
$$\langle A\rangle=(A_{low+}\,A_{high})/2=209(cm^2)$$

4. Take the difference between either min or max to <A> is the uncertainty ΔA: $\Delta A=+/-4cm^2$

5. Thus the result is: $A=\langle A\rangle +/- \Delta A=(209+/-4)\ cm^2$

Problems 1.4 and 1.13

- The mass of a material with density, ρ, required to make a hollow spherical shell with inner radius, r_1, and outer radius, r_2?



$$V_{sphere} = \frac{4p}{3} r^3$$

$$M_{sphere} = r V_{sphere} = \frac{4p}{3} r r^3$$

$$M_{inner} = r V_{inner} = \frac{4p}{3} r r_1^3$$

$$M_{outer} = r V_{outer} = \frac{4p}{3} r r_2^3$$

$$M_{shell} = M_{outer} - M_{inner}$$
$$= \frac{4p}{3} r \left(r_2^3 - r_1^3\right)$$

- Prove that displacement of a particle moving under uniform acceleration is, $s=ka^m t^n$, is dimensionally correct if k is a dimensionless constant, $m=1$, and $n=2$.

Displacement: Dimension of Length
Acceleration a:Dimension of L/T^2

$$[l] = \left[\frac{l}{t^2}\right]^m [t]^n = \left[lt^{-2}\right]^m [t]^n = [l]^m [t]^{-2m+n}$$

$$\therefore m = 1, n - 2m = 0;$$

$$\therefore n = 2m = 2$$

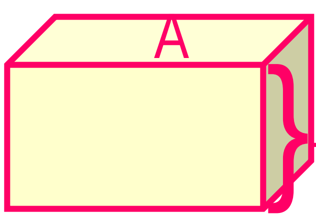
Problems 1.25 & 1.31

- Find the density, ρ, of lead, in SI unit, whose mass is 23.94*g* and volume, *V*, is 2.10cm^3.

$$\text{Density;} \quad r \equiv \frac{?}{V} = \frac{23.94\ g}{2.10\ cm^3} = 11.4 \times \frac{\frac{1}{1000} kg}{\left(\frac{1}{100} m\right)^3} = 11.4 \times 10^3\ kg/m^3$$

- Find the thickness of the layer covered by a gallon (V=3.78x10^{-3} m^3) of paint spread on an area of on the wall 25.0m^2.

- Thickness is in the dimension of Length.
- A gallon (V=3.78x10^{-3} m^3) of paint is covering 25.0m^2.



$$Thickness \equiv \frac{V}{A} = \frac{3.78 \times 10^{-3}\ m^3}{25.0\ m^2} = 1.51 \times 10^{-4}\ m$$

Thickness (OK, it is a very skewed view!!)

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, 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
  - 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

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:

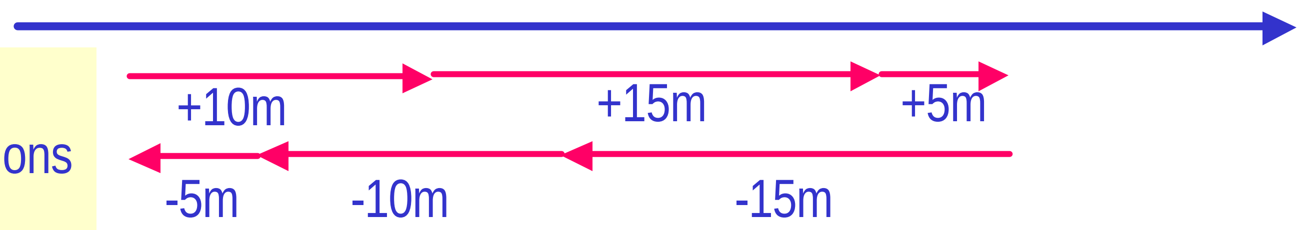
$$v \equiv \frac{\text{Total Distance Traveled}}{\text{Total Time Interval}}$$

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



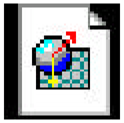
Let's have a couple of motions in a total time interval of 20 sec.

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

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

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

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



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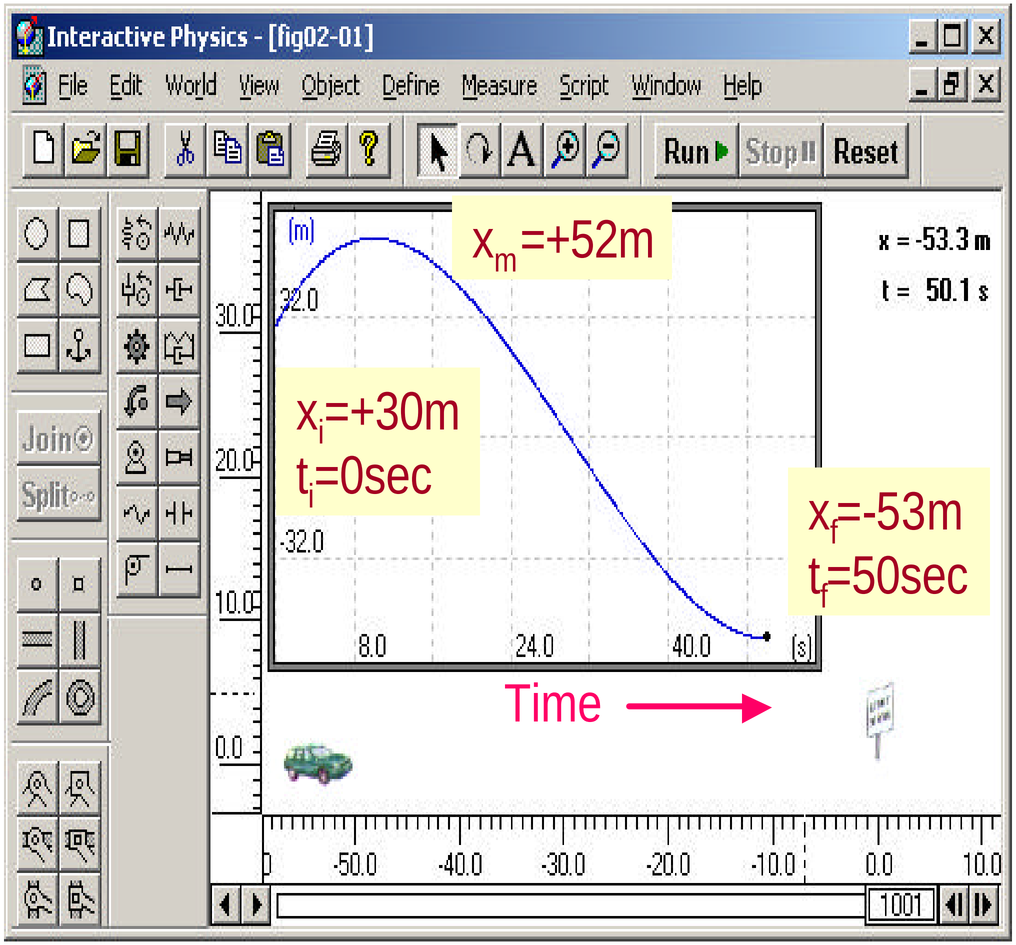
Example 2.1



- Find the displacement, average velocity, and average speed.
- Displacement:

$$\Delta x \equiv x_f - x_i = -53 - 30 = -83(m)$$

- Average Velocity:

$$v_x \equiv \frac{x_f - x_i}{t_f - t_i} = \frac{\Delta x}{\Delta t} = \frac{-83}{50} = -1.7(m/s)$$

- Average Speed:

$$v \equiv \frac{\text{Total Distance Traveled}}{\text{Total Time Interval}} = \frac{22+52+53}{50} = \frac{127}{50} = 2.5(m/s)$$

Instantaneous Velocity and Speed

- Here is where calculus comes in to help understanding the concept of "instantaneous quantities"

•Instantaneous velocity is defined as:

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

–What does this mean?

•Displacement in an infinitesimal time interval

•Mathematically: Slope of the position variation as a function of time

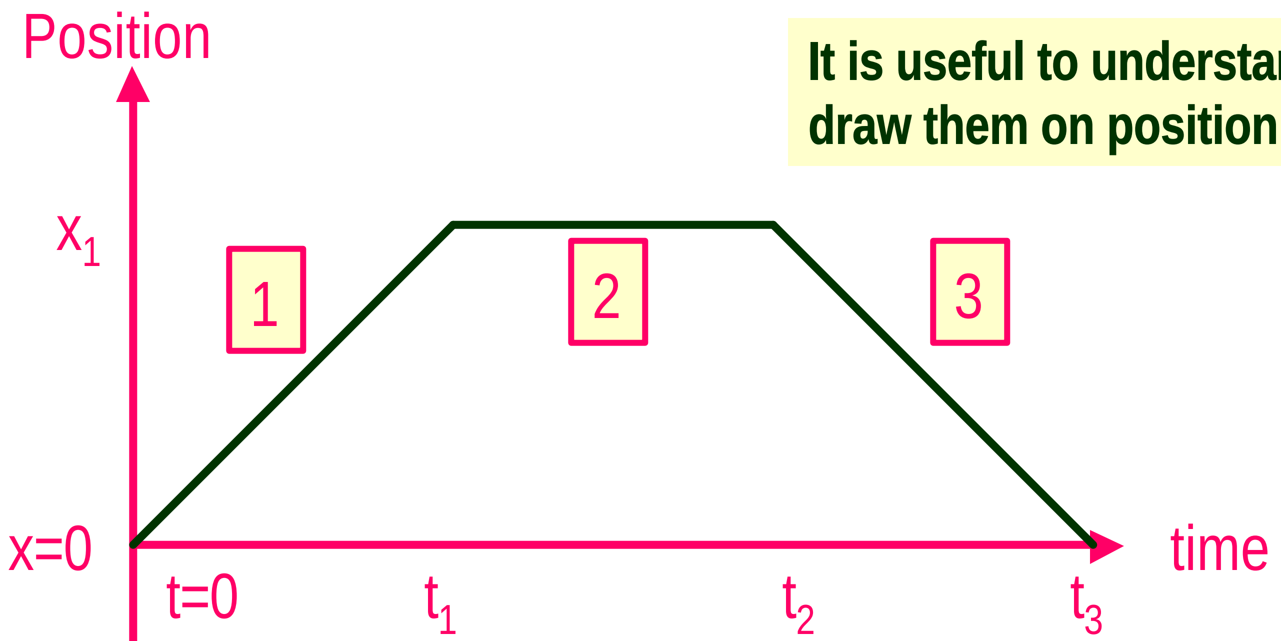
•Instantaneous speed is the size (magnitude) of the velocity vector:

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

*Magnitude of Vectors are Expressed in absolute values

Position vs Time Plot

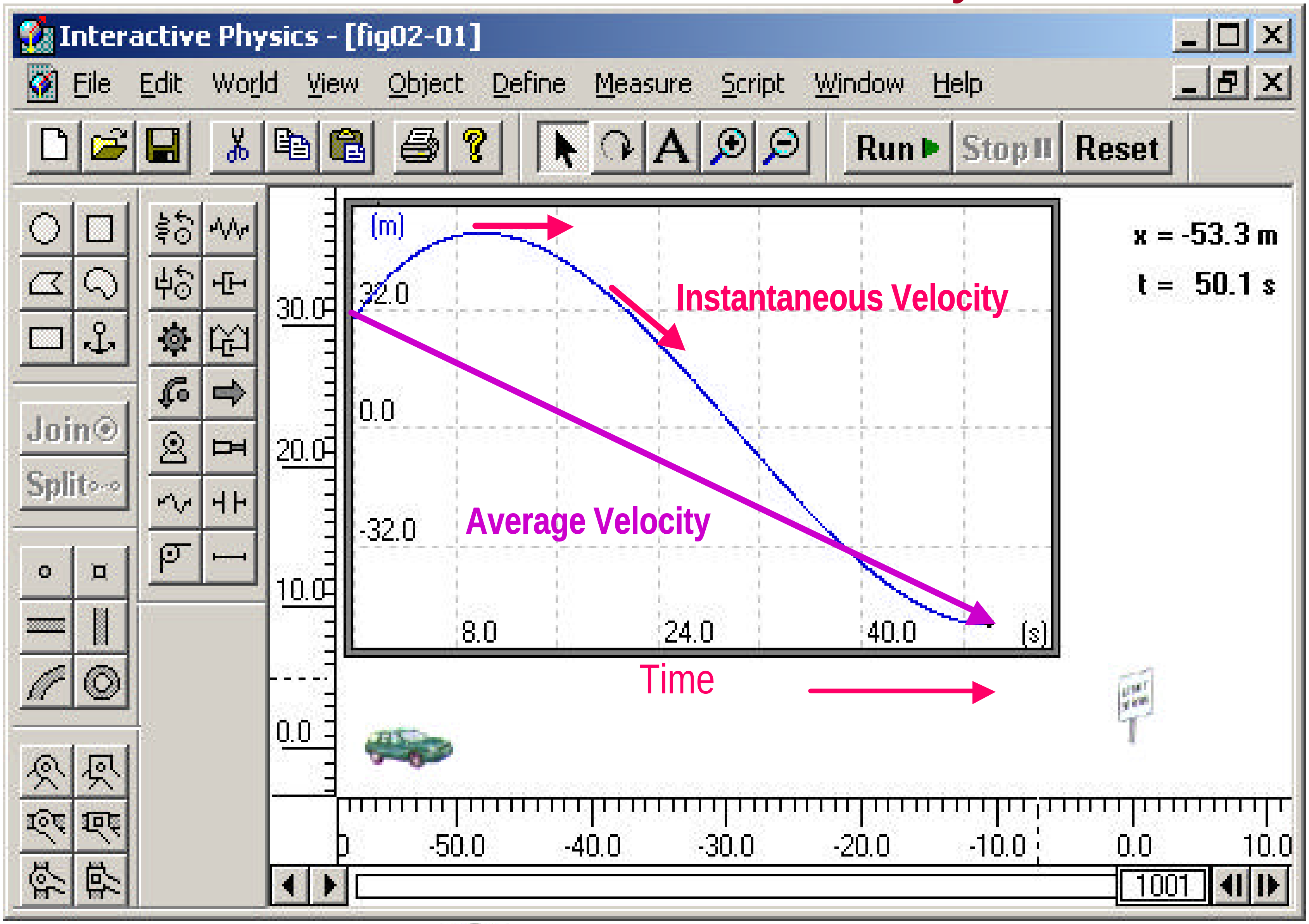
It is useful to understand motions to draw them on position vs time plots.



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 2.2

- Particle is moving along x-axis following the expression: $x = -4t + 2t^2$
- Determine the displacement in the time intervals t=0 to t=1s and t=1 to t=3s:

For interval t=0 to t=1s

$$x_{t=0} = 0, x_{t=1} = -4\times(1) + 2\times(1)^2 = -2$$
$$\Delta x_{t=0,1} = x_{t=1} - x_{t=0} = -2 - 0 = -2(m)$$

For interval t=1 to t=3s

$$x_{t=1} = -2, x_{t=3} = -4\times(3) + 2\times(3)^2 = 6$$
$$\Delta x_{t=1,3} = x_{t=3} - x_{t=1} = 6 + 2 = 8(m)$$

- Compute the average velocity in the time intervals t=0 to t=1s and t=1 to t=3s:

$$v_x = \frac{\Delta x_{t=0,1}}{\Delta t} = \frac{-2}{1}(m/s)$$
$$v_x = \frac{\Delta x_{t=1,3}}{\Delta t} = \frac{8}{2} = +4(m/s)$$

- Compute the instantaneous **velocity at t=2.5s:**

Instantaneous velocity at any time *t*

$$v_x(t) = \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt} = \frac{d}{dt}\left(-4t + 2t^2\right) = -4 + 4t$$

Instantaneous velocity at *t*=2.5s

$$v_x(t = 2.5) = -4 + 4\times(2.5) = +6(m/s)$$

Acceleration

Change of velocity in time (what kind of quantity is this?)

- Average acceleration:

$$a_x \equiv \frac{v_{xf} - v_{xi}}{t_f - t_i} = \frac{\Delta v_x}{\Delta t}$$ analogs to $$v_x \equiv \frac{x_f - x_i}{t_f - t_i} = \frac{\Delta x}{\Delta t}$$

- Instantaneous acceleration:

$$a_x \equiv \lim_{\Delta t \to 0} \frac{\Delta v_x}{\Delta t} = \frac{dv_x}{dt} = \frac{d}{dt}\left(\frac{dx}{dt}\right) = \frac{d^2 x}{dt^2}$$ analogs to $$v_x \equiv \lim_{\Delta t \to 0} \frac{\Delta x}{\Delta t} = \frac{dx}{dt}$$

- In calculus terms: A slope (derivative) of velocity with respect to time or change of slopes of position as a function of time

Example 2.4

- Velocity, v_x, is express in: $v_x(t) = (40 - 5t^2)m/s$
- Find average acceleration in time interval, t=0 to t=2.0s

$$v_{xi}(t_i = 0) = 40\ (m/s)$$
$$v_{xf}(t_f = 2.0) = (40 - 5 \times 2^2) = 20\ (m/s)$$
$$a_x = \frac{v_{xf} - v_{xi}}{t_f - t_i} = \frac{\Delta v_x}{\Delta t} = \frac{20 - 40}{2 - 0} = -10\ (m/s^2)$$

- Find instantaneous acceleration at any time t and t=2.0s

Instantaneous Acceleration at any time

$$a_x(t) \equiv \frac{dv_x}{dt} = \frac{d}{dt}(40 - 5t^2) = -10t$$

Instantaneous Acceleration at any time t=2.0s

$$a_x(t = 2.0) = -10 \times (2.0) = -20(m/s^2)$$

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Meanings of Acceleration

- When an object is moving in a constant velocity ($v=v_0$), there is no acceleration ($a=0$)
  - Is there any acceleration when an object is not moving?
- When an object is moving faster as time goes on, ($v=v(t)$), acceleration is positive ($a>0$)
- When an object is moving slower as time goes on, ($v=v(t)$), acceleration is negative ($a<0$)
- In all cases, velocity is positive, unless the direction of the movement changes.
- Is there acceleration if an object moves in a constant speed but changes direction?

The answer is YES!!