Introduction to Mechanics, Heat, and Sound /FIC 318

Introduction

- Syllabus and teaching strategy
- Physics
  - Introduction
  - Mathematical review
    - trigonometry
    - vectors
- Motion in one dimension

Chapter 1

YOGYAKARTA STATE UNIVERSITY

Syllabus and teaching strategy

Lecturer:

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Office Hours:

Everyday 08:00 Am-03:00 PM, on main campus,
Physics Laboratory Building, Room 212,
or by appointment.

Grading:

Reading Quizzes	15%
Quiz section performance/Homework	15%
Best Hour Exam	20%
Second Best Hour Exam	20%
Final	30%

PLUS: 5% online homework

Reading Quizzes:

It is important for you to come to class prepared!
BONUS POINTS: Reading Summaries

Homework:

The quiz sessions meet once a week; quizzes will count towards your grade.
BONUS POINTS: online homework http://fisikauny.ac.id

Exams:

There will be THREE (3) Hour Exams (only two will count) and one Final Exam.
Additional **BONUS POINTS** will be given out for class activity.

I. Physics: Introduction

- Fundamental Science
  - foundation of other physical sciences
- Divided into five major areas
  - Mechanics
  - Thermodynamics
  - Electromagnetism
  - Relativity
  - Quantum Mechanics

1. Measurements

- Basis of testing theories in science
- Need to have consistent systems of units for the measurements
- Uncertainties are inherent
- Need rules for dealing with the uncertainties

Systems of Measurement

- Standardized systems
  - agreed upon by some authority, usually a governmental body
- SI -- Systéme International
  - agreed to in 1960 by an international committee
  - main system used in this course
  - also called mks for the first letters in the units of the fundamental quantities

Systems of Measurements

- cgs -- Gaussian system
  - named for the first letters of the units it uses for fundamental quantities
- US Customary
  - everyday units (ft, etc.)
  - often uses weight, in pounds, instead of mass as a fundamental quantity

Basic Quantities and Their Dimension

- Length [L]
- Mass [M]
- Time [T]

Why do we need standards?

Length

- Units
  - SI -- meter, m
  - cgs -- centimeter, cm
  - US Customary -- foot, ft
- Defined in terms of a meter -- the distance traveled by light in a vacuum during a given time (1/299 792 458 s)

Mass

- Units
  - SI -- kilogram, kg
  - cgs -- gram, g
  - USC -- slug, slug
- Defined in terms of kilogram, based on a specific Pt-Ir cylinder kept at the International Bureau of Standards

Standard Kilogram

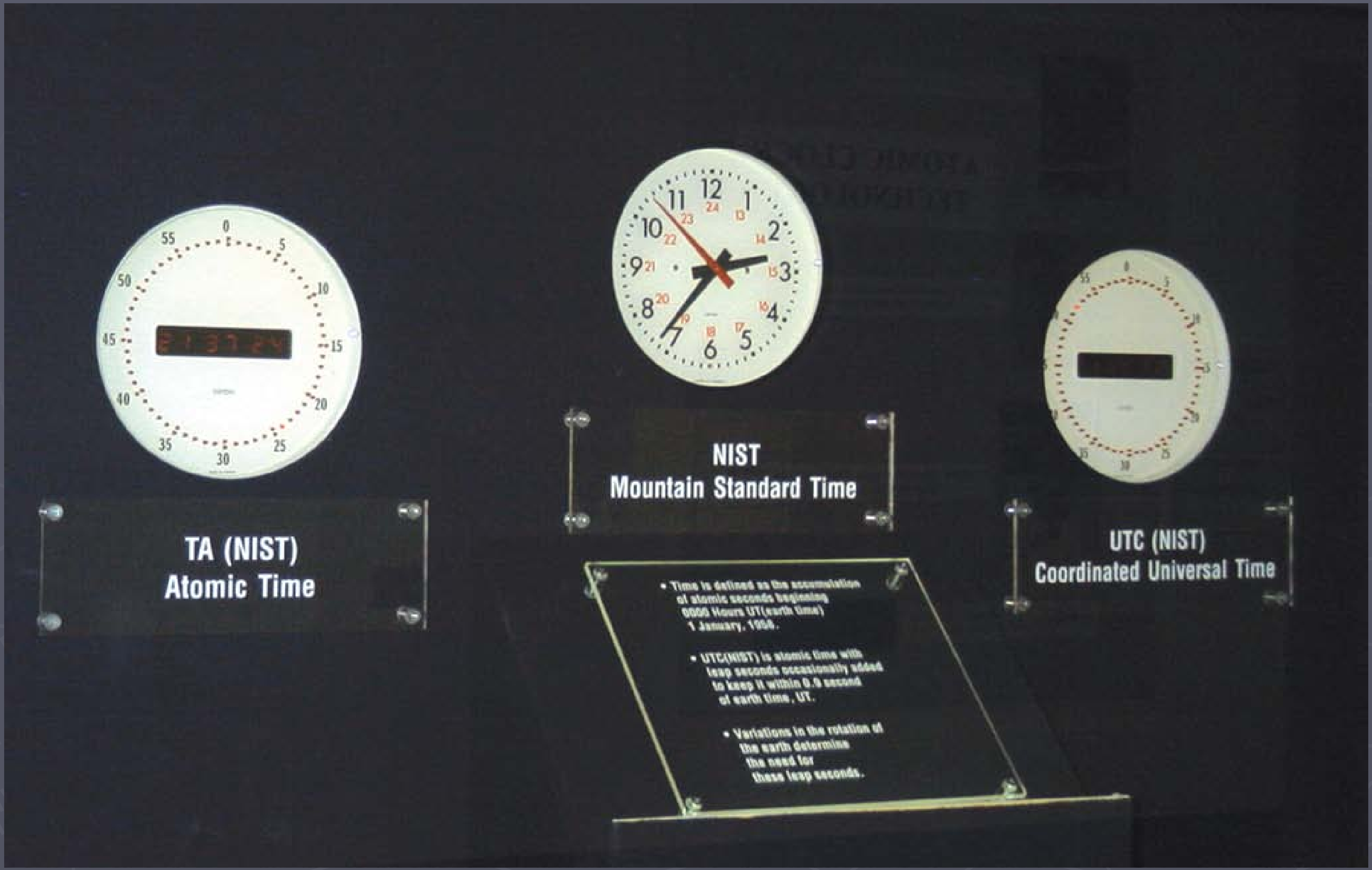
Why is it hidden under two glass domes?

Time

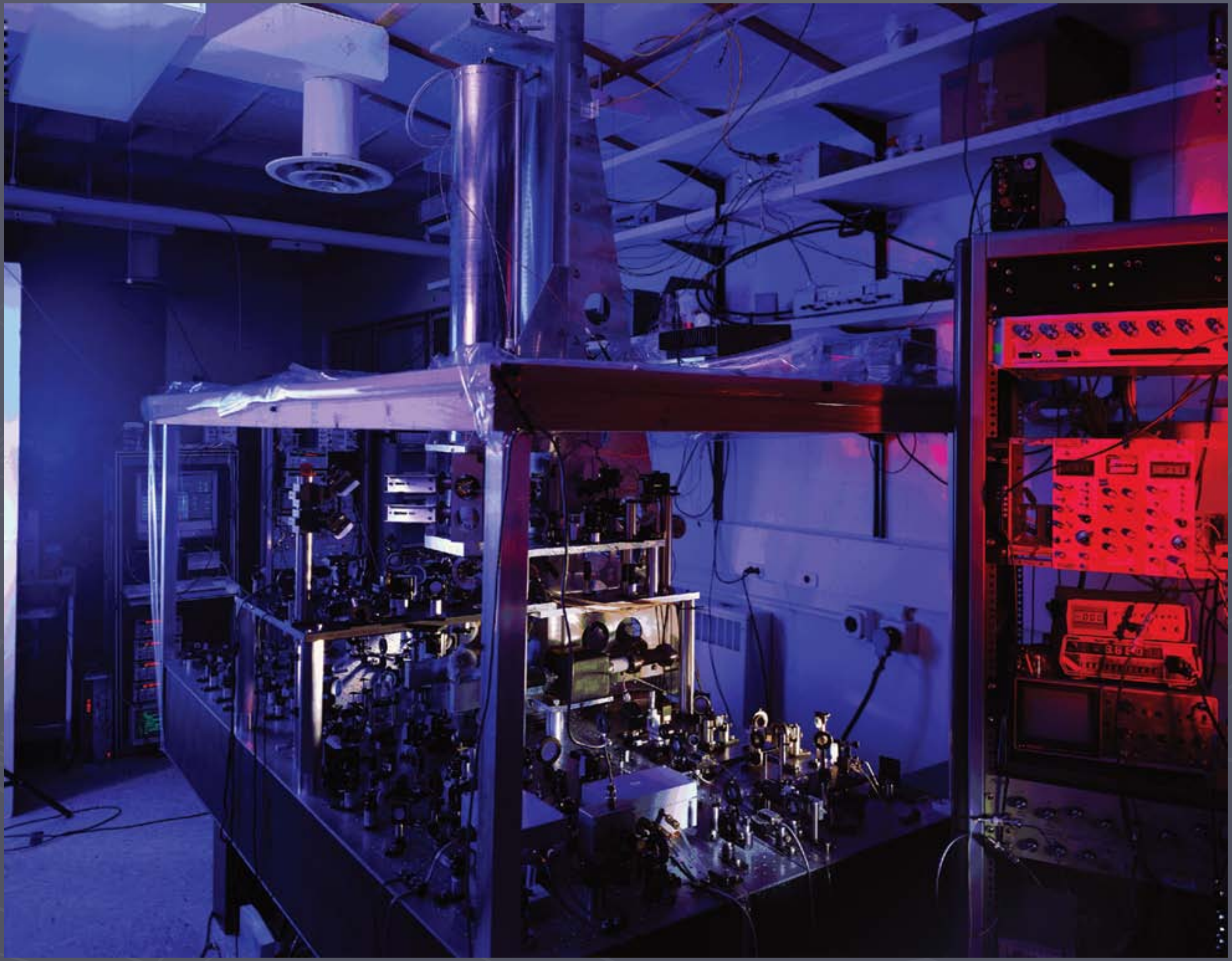
- Units
  - seconds, s in all three systems
- Defined in terms of the oscillation of radiation from a cesium atom

(9 192 631 700 times frequency of light emitted)

Time Measurements



US “Official” Atomic Clock



2. Dimensional Analysis

- Dimension denotes the physical nature of a quantity
- Technique to check the correctness of an equation
- Dimensions (length, mass, time, combinations) can be treated as algebraic quantities
  - add, subtract, multiply, divide
  - quantities added/subtracted only if have same units
- Both sides of equation must have the same dimensions

Dimensional Analysis

- Dimensions for commonly used quantities

Length	L	m (SI)
Area	L^2	m^2 (SI)
Volume	L^3	m^3 (SI)
Velocity (speed)	L/T	m/s (SI)
Acceleration	L/T^2	m/s^2 (SI)

- Example of dimensional analysis

$$\text{distance} = \text{velocity} \cdot \text{time}$$
$$L = (L/\cancel{T}) \cdot \cancel{T}$$

3. Conversions

- When units are not consistent, you may need to convert to appropriate ones
- Units can be treated like algebraic quantities that can cancel each other out

1 mile = 1609 m = 1.609 km
1m = 39.37 in = 3.281 ft

1 ft = 0.3048 m = 30.48 cm
1 in = 0.0254 m = 2.54 cm

Example 1. Scotch tape:

Example 2. Trip to Canada:

Legal freeway speed limit in Canada is 100 km/h.
What is it in miles/h?

$$100\frac{km}{h} = 100\frac{\cancel{km}}{h}\cdot\frac{1\,mile}{1.609\,\cancel{km}} \approx 62\frac{miles}{h}$$

Prefixes

- Prefixes correspond to powers of 10
- Each prefix has a specific name/abbreviation

Power	Prefix	Abbrev.		
10^{15}	peta	P		
10^{9}	giga	G	Distance from Earth to nearest star	40 Pm
10^{6}	mega	M	Mean radius of Earth	6 Mm
10^{3}	kilo	k	Length of a housefly	5 mm
10^{-2}	centi	P	Size of living cells	10 µm
10^{-3}	milli	m	Size of an atom	0.1 nm
10^{-6}	micro	µ		
10^{-9}	nano	n		

Example: An aspirin tablet contains 325 mg of acetylsalicylic acid. Express this mass in grams.

Given:

m = 325 mg

Find:

m (grams)=?

Solution:

Recall that prefix “milli” implies 10^{-3}, so

$$m = 325\,mg = 325 \times 10^{-3}\,g = 0.325\,g$$

4. Uncertainty in Measurements

- There is uncertainty in every measurement, this uncertainty carries over through the calculations
  - need a technique to account for this uncertainty
- We will use rules for significant figures to approximate the uncertainty in results of calculations

Significant Figures

- A significant figure is one that is reliably known
- All non-zero digits are significant
- Zeros are significant when
  - between other non-zero digits
  - after the decimal point and another significant figure
  - can be clarified by using scientific notation

$$17400 = 1.74 \times 10^4$$ 3 significant figures

$$17400. = 1.7400 \times 10^4$$ 5 significant figures

$$17400.0 = 1.74000 \times 10^4$$ 6 significant figures

Operations with Significant Figures

- Accuracy -- number of significant figures

  Example: meter stick: $\pm 0.1\,cm$

- When multiplying or dividing, round the result to the same accuracy as the least accurate measurement

  2 significant figures

  Example: rectangular plate: 4.5 *cm* by 7.3 *cm*

  area: ~~32.85 cm^2~~ 33 cm^2

- When adding or subtracting, round the result to the smallest number of decimal places of any term in the sum

  Example: 135 m + 6.213 m = 141 m

Order of Magnitude

- Approximation based on a number of assumptions
  - may need to modify assumptions if more precise results are needed

Question: McDonald’s sells about 250 million packages of fries every year. Placed back-to-back, how far would the fries reach?

Solution: There are approximately 30 fries/package, thus:

(30 fries/package)(250 · 10^6 packages)(3 in./fry) ~ 2 · 10^{10} in ~ 5 · 10^8 m,
which is greater then Earth-Moon distance (4 · 10^8 m)!

- Order of magnitude is the power of 10 that applies

Example: John has 3 apples, Jane has 5 apples.
Their numbers of apples are “of the same order of magnitude”

II. Math Review: Coordinate Systems

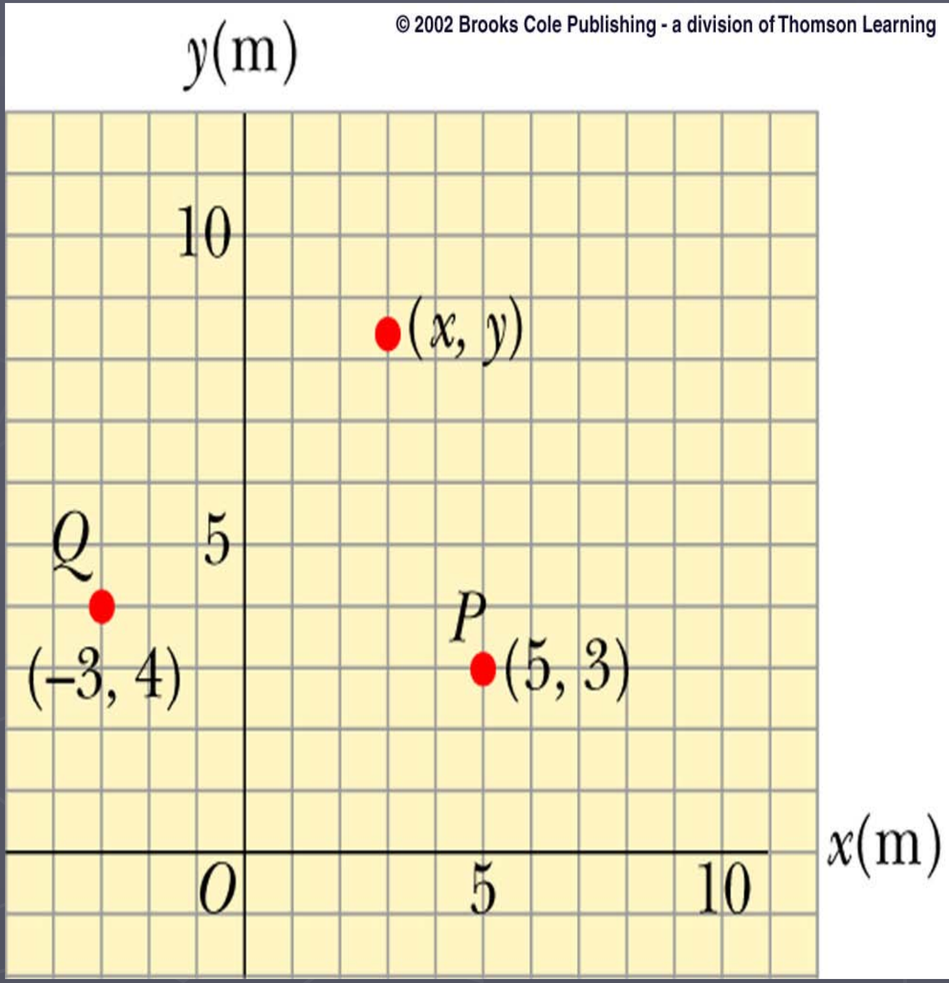
- Used to describe the position of a point in space
- Coordinate system (frame) consists of
  - a fixed reference point called the origin
  - specific axes with scales and labels
  - instructions on how to label a point relative to the origin and the axes

Types of Coordinate Systems

- Cartesian
- Plane polar

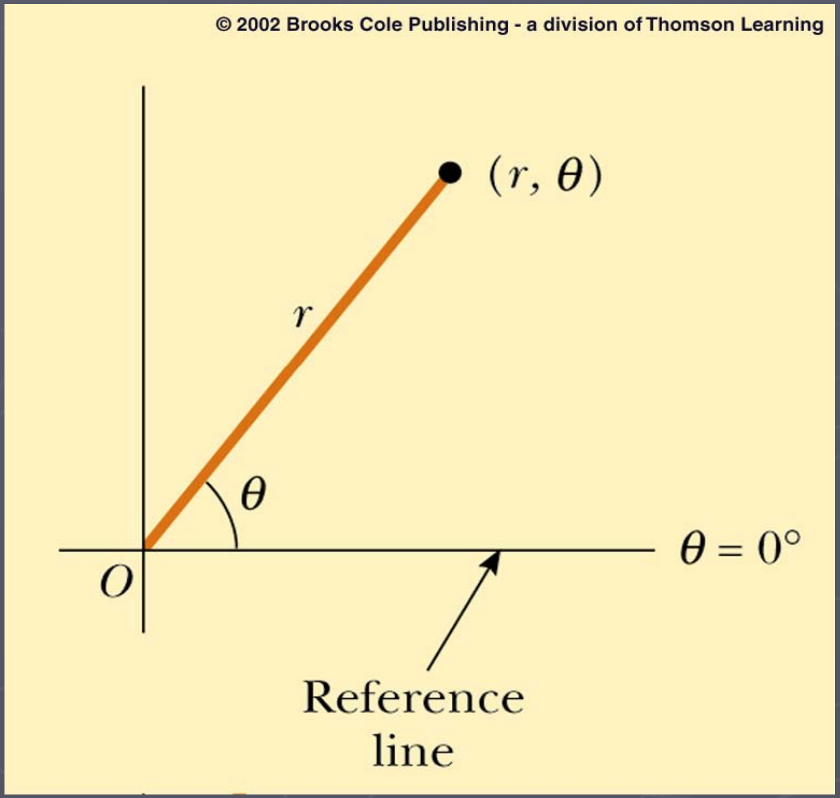
Cartesian coordinate system

- also called rectangular coordinate system
- x- and y- axes
- points are labeled (x,y)



Plane polar coordinate system

- origin and reference line are noted
- point is distance r from the origin in the direction of angle θ, ccw from reference line
- points are labeled (r,θ)



II. Math Review: Trigonometry

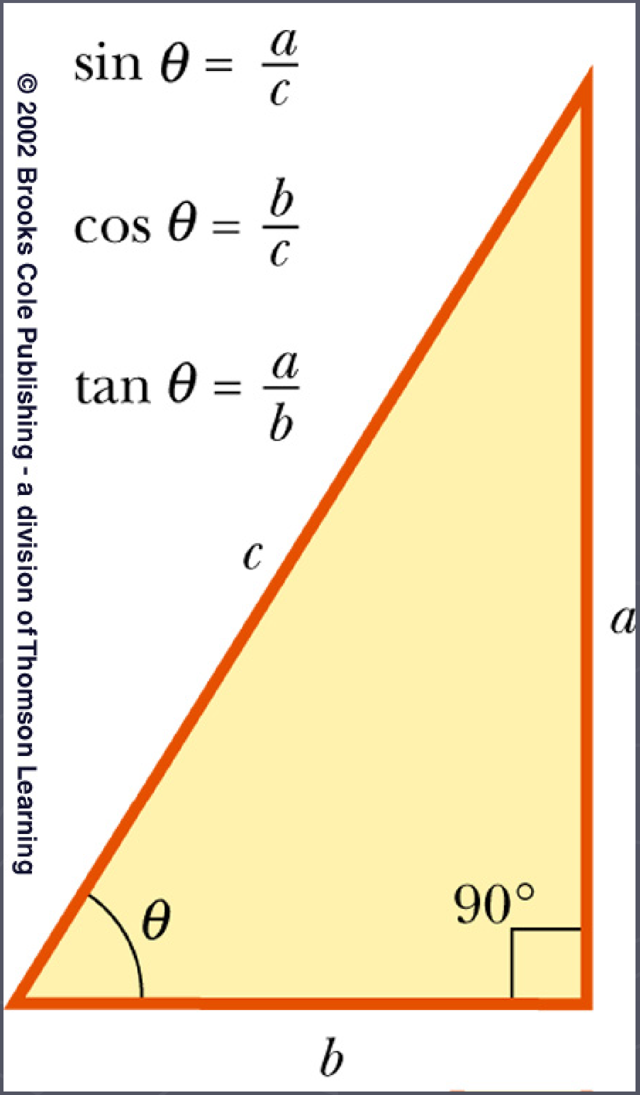
$$\sin \theta = \frac{opposite\ side}{hypotenuse}$$

$$\cos \theta = \frac{adjacent\ side}{hypotenuse}$$

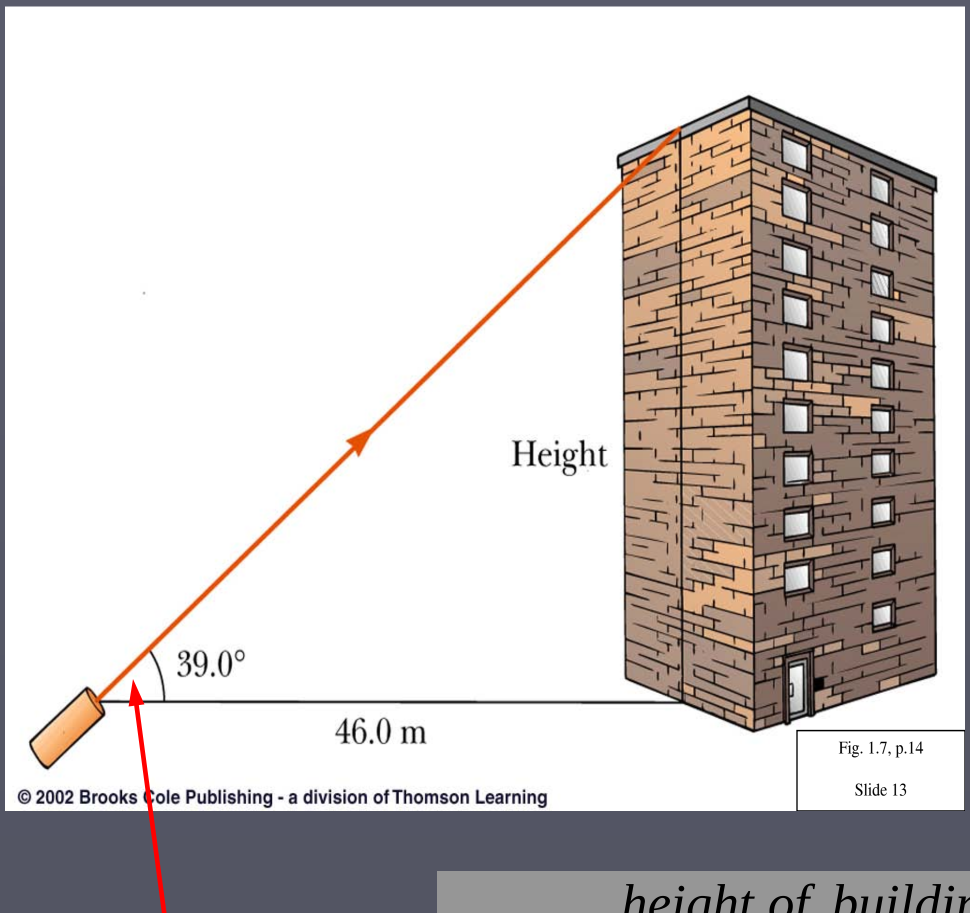
$$\tan \theta = \frac{opposite\ side}{adjacent\ side}$$

- Pythagorean Theorem

$$c^2 = a^2 + b^2$$



Example: how high is the building?



α

Known: angle and one side
Find: another side

Key: tangent is defined via two sides!

$$\tan\alpha = \frac{height\ of\ building}{dist.},$$

$$height = dist. \times \tan\alpha = (\tan 39.0^{\circ})(46.0\ m) = 37.3\ m$$

II. Math Review: Scalar and Vector Quantities

- Scalar quantities are completely described by magnitude only (temperature, length,…)
- Vector quantities need both magnitude (size) and direction to completely describe them (force, displacement, velocity,…)
  - Represented by an arrow, the length of the arrow is proportional to the magnitude of the vector
  - Head of the arrow represents the direction

Vector Notation

- When handwritten, use an arrow: $\vec{A}$
- When printed, will be in bold print: **A**
- When dealing with just the magnitude of a vector in print, an italic letter will be used: *A*

Properties of Vectors

- Equality of Two Vectors
  - Two vectors are **equal** if they have the same magnitude and the same direction
- Movement of vectors in a diagram
  - Any vector can be moved parallel to itself without being affected

More Properties of Vectors

- Negative Vectors
  - Two vectors are **negative** if they have the same magnitude but are 180° apart (opposite directions)
    - **A** = -**B**
- Resultant Vector
  - The **resultant** vector is the sum of a given set of vectors

Adding Vectors

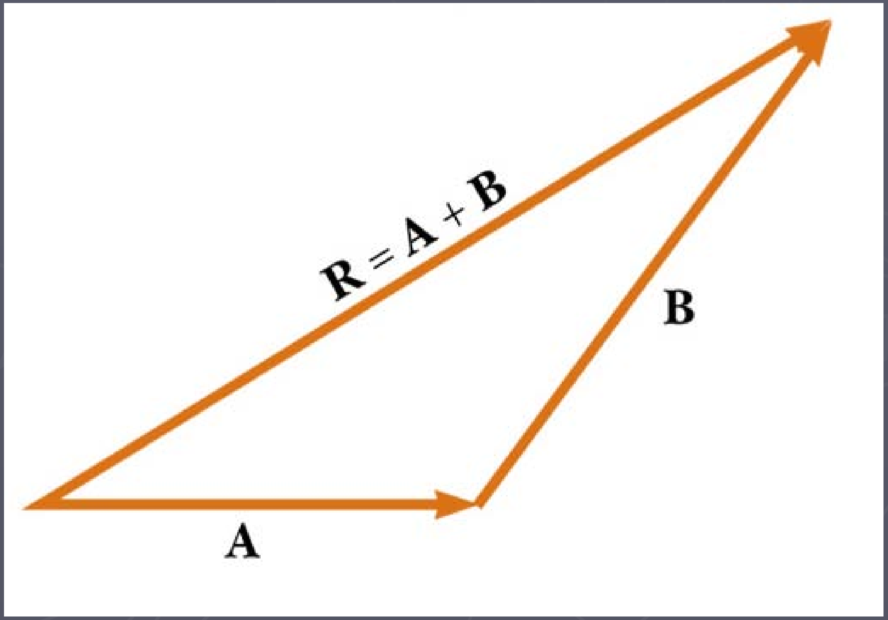
- When adding vectors, their directions must be taken into account
- Units must be the same
- Graphical Methods
  - Use scale drawings
- Algebraic Methods
  - More convenient

Adding Vectors Graphically (Triangle or Polygon Method)

- Choose a scale
- Draw the first vector with the appropriate length and in the direction specified, with respect to a coordinate system
- Draw the next vector with the appropriate length and in the direction specified, with respect to a coordinate system whose origin is the end of vector **A** and parallel to the coordinate system used for **A**

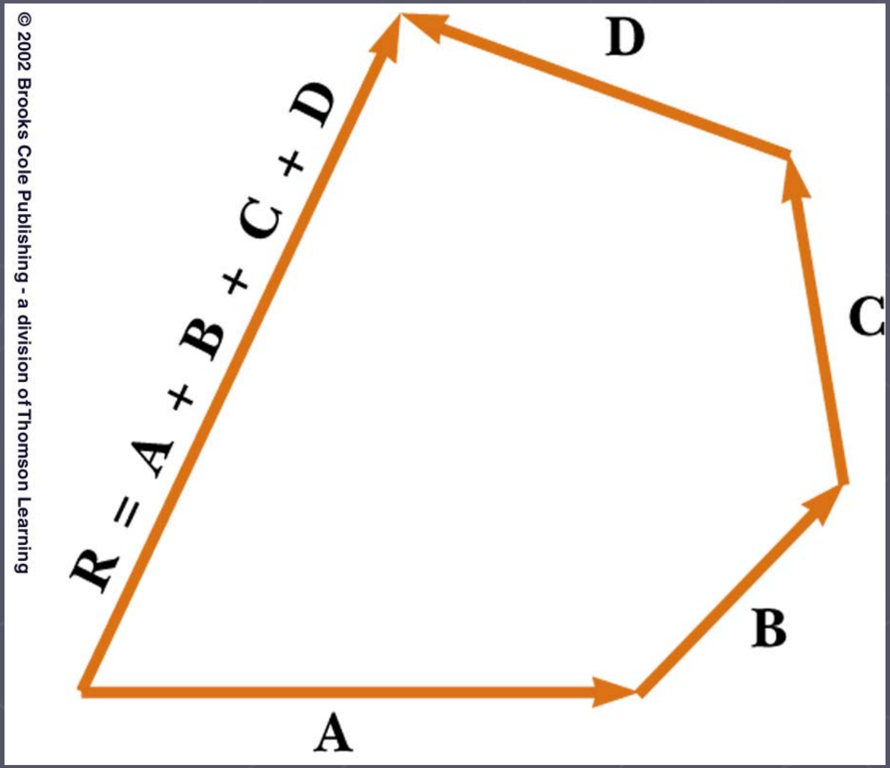
Graphically Adding Vectors

- Continue drawing the vectors "tip-to-tail"
- The resultant is drawn from the origin of **A** to the end of the last vector
- Measure the length of **R** and its angle
  - Use the scale factor to convert length to actual magnitude



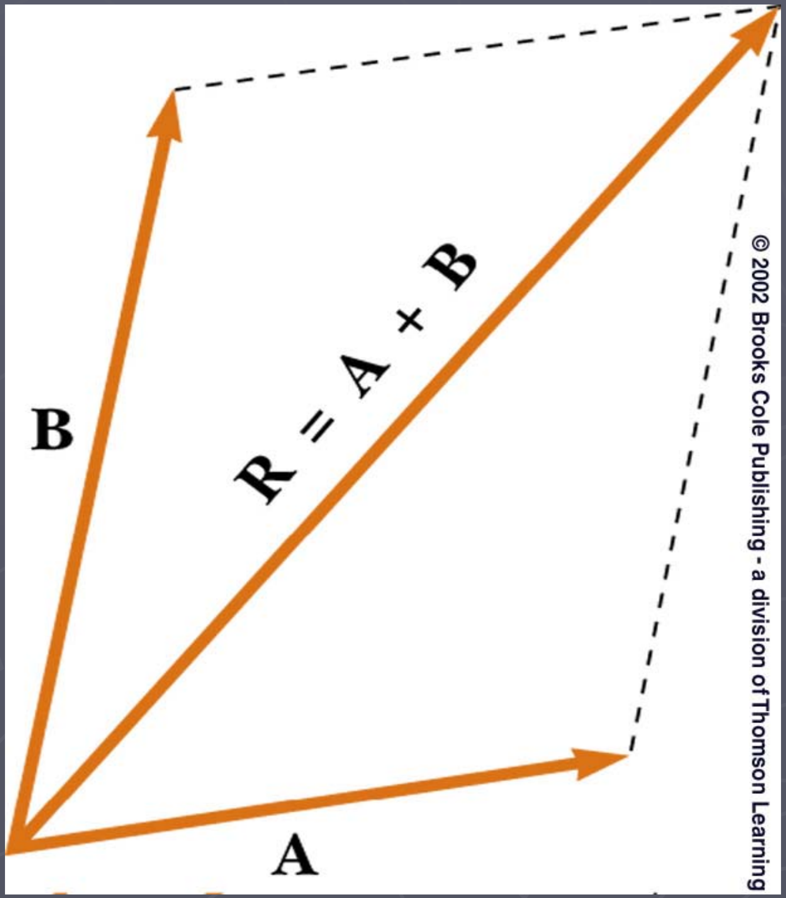
Graphically Adding Vectors

- When you have many vectors, just keep repeating the process until all are included
- The resultant is still drawn from the origin of the first vector to the end of the last vector



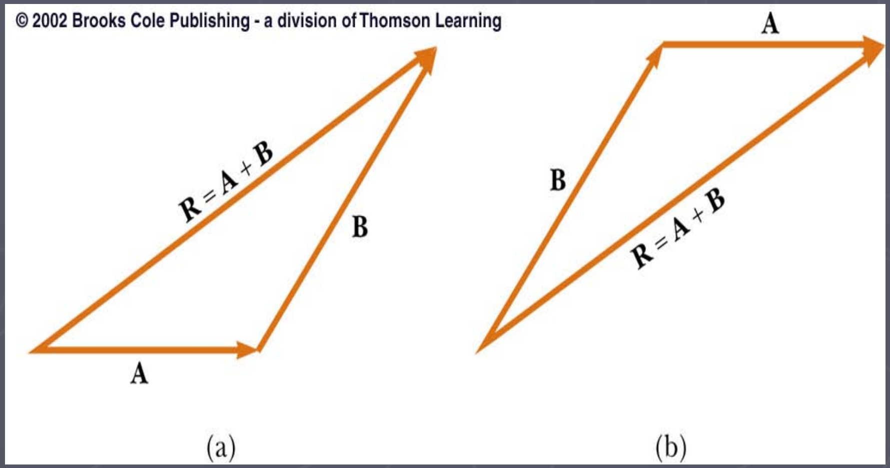
Alternative Graphical Method

- When you have only two vectors, you may use the **Parallelogram Method**
- All vectors, including the resultant, are drawn from a common origin
  - The remaining sides of the parallelogram are sketched to determine the diagonal, **R**



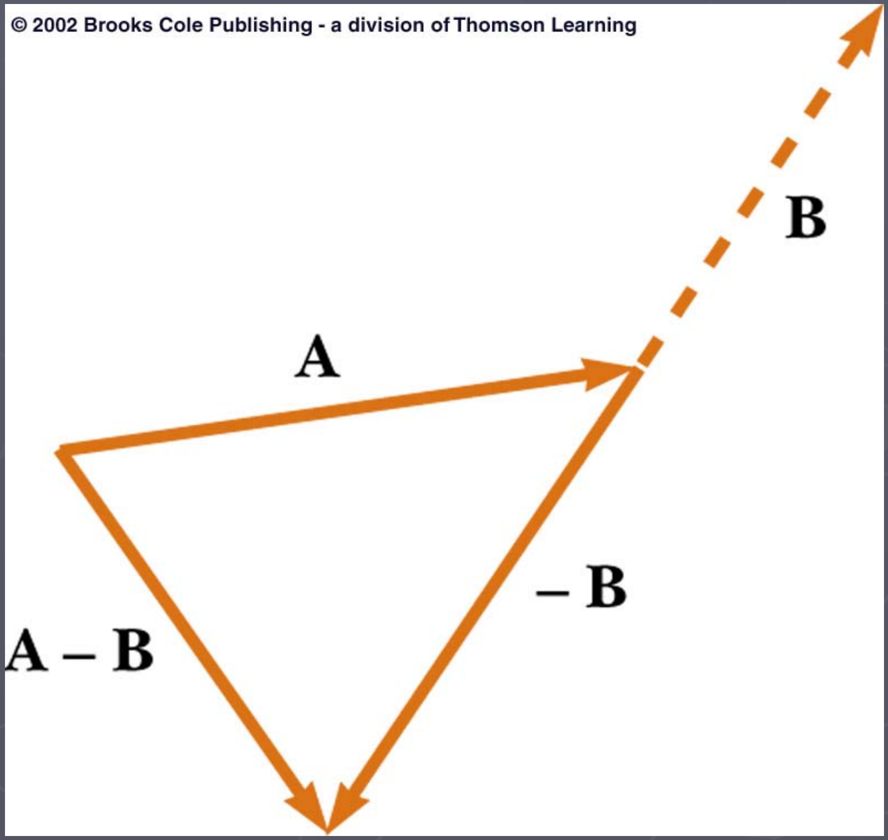
Notes about Vector Addition

- Vectors obey the **Commutative Law of Addition**
  - The order in which the vectors are added doesn't affect the result



Vector Subtraction

- Special case of vector addition
- If **A** – **B**, then use **A**+(-**B**)
- Continue with standard vector addition procedure

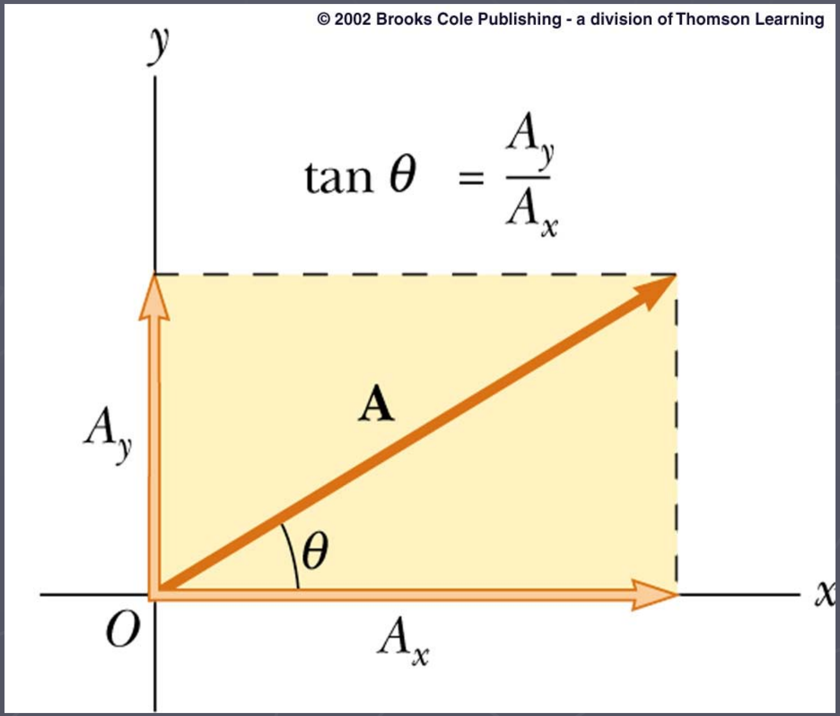


Multiplying or Dividing a Vector by a Scalar

- The result of the multiplication or division is a vector
- The magnitude of the vector is multiplied or divided by the scalar
- If the scalar is positive, the direction of the result is the same as of the original vector
- If the scalar is negative, the direction of the result is opposite that of the original vector

Components of a Vector

- A **component** is a part
- It is useful to use **rectangular components**
  - These are the projections of the vector along the x- and y-axes



Components of a Vector

- The x-component of a vector is the projection along the x-axis

$$A_x = A\cos\theta$$

- The y-component of a vector is the projection along the y-axis

$$A_y = A\sin\theta$$

- Then,

$$\vec{\mathbf{A}} = \vec{A}_x + \vec{A}_y$$

More About Components of a Vector

- The previous equations are valid ***only if θ is measured with respect to the x-axis***
- The components can be positive or negative and will have the same units as the original vector
- The components are the legs of the right triangle whose hypotenuse is **A**

$$A = \sqrt{A_x^2 + A_y^2} \quad \text{and} \quad \theta = \tan^{-1}\frac{A_y}{A_x}$$

  - May still have to find θ with respect to the positive x-axis

Adding Vectors Algebraically

- Choose a coordinate system and sketch the vectors
- Find the x- and y-components of all the vectors
- Add all the x-components
  - This gives R_x:

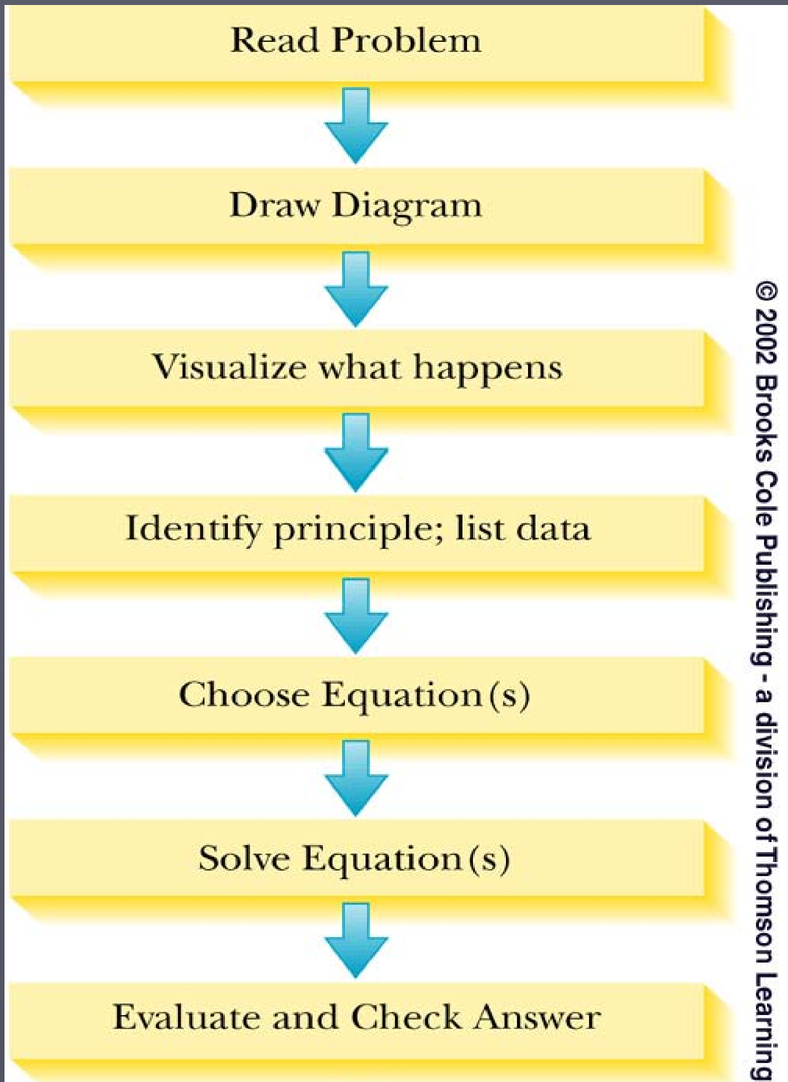
$$R_x = \sum v_x$$

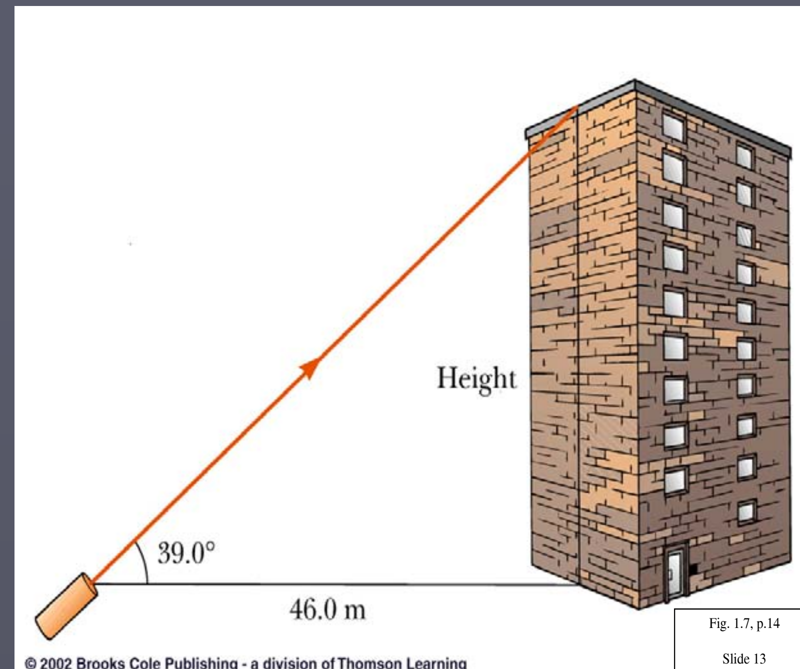
Adding Vectors Algebraically

- Add all the y-components
  - This gives R_y: $R_y = \sum v_y$
- Use the Pythagorean Theorem to find the magnitude of the Resultant: $R = \sqrt{R_x^2 + R_y^2}$
- Use the inverse tangent function to find the direction of R:

$$\theta = \tan^{-1}\frac{R_y}{R_x}$$

III. Problem Solving Strategy





Known: angle and one side
Find: another side
Key: tangent is defined via two sides!

$$\tan\alpha = \frac{height\ of\ building}{dist.},$$

$$height = dist. \times \tan\alpha = (\tan 39.0^\circ)(46.0\ m) = 37.3\ m$$

Problem Solving Strategy

- Read the problem
  - identify type of problem, principle involved
- Draw a diagram
  - include appropriate values and coordinate system
  - some types of problems require very specific types of diagrams

Problem Solving cont.

- Visualize the problem
- Identify information
  - identify the principle involved
  - list the data (given information)
  - indicate the unknown (what you are looking for)

Problem Solving, cont.

- Choose equation(s)
  - based on the principle, choose an equation or set of equations to apply to the problem
  - solve for the unknown
- Solve the equation(s)
  - substitute the data into the equation
  - include units

Problem Solving, final

- Evaluate the answer
  - find the numerical result
  - determine the units of the result
- Check the answer
  - are the units correct for the quantity being found?
  - does the answer seem reasonable?
    - check order of magnitude
  - are signs appropriate and meaningful?

IV. Motion in One Dimension

Dynamics

- The branch of physics involving the motion of an object and the relationship between that motion and other physics concepts
- ***Kinematics*** is a part of dynamics
  - In kinematics, you are interested in the *description* of motion
  - *Not* concerned with the cause of the motion

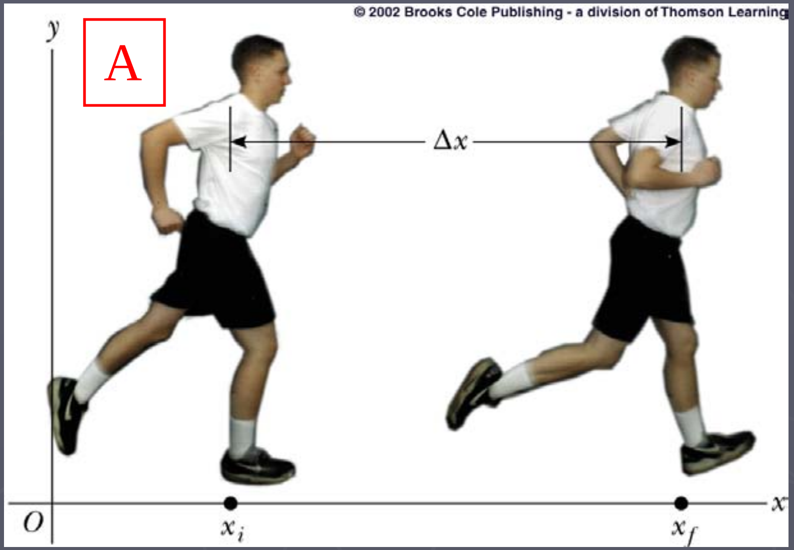
Position and Displacement

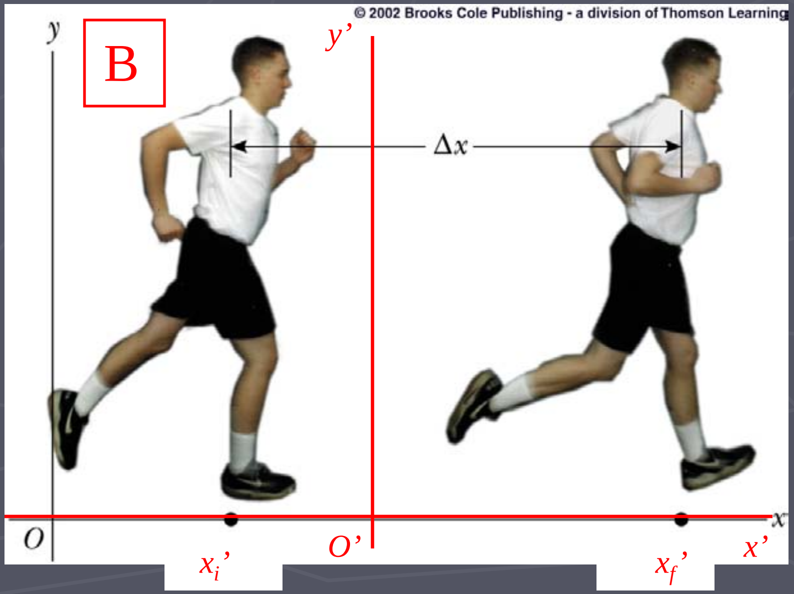
- Position is defined in terms of a **frame of reference**

Frame A: $x_i > 0$ and $x_f > 0$

Frame B: $x'_i < 0$ but $x'_f > 0$

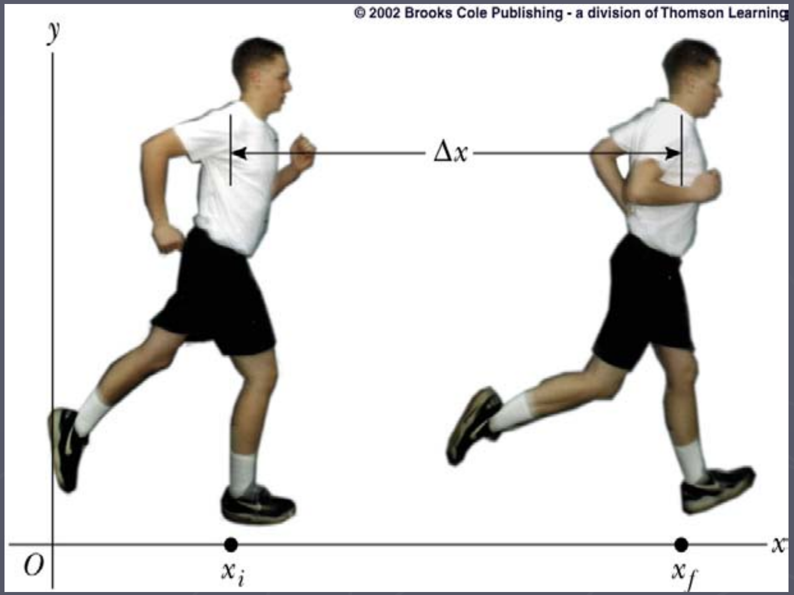
- One dimensional, so generally the x- or y-axis





Position and Displacement

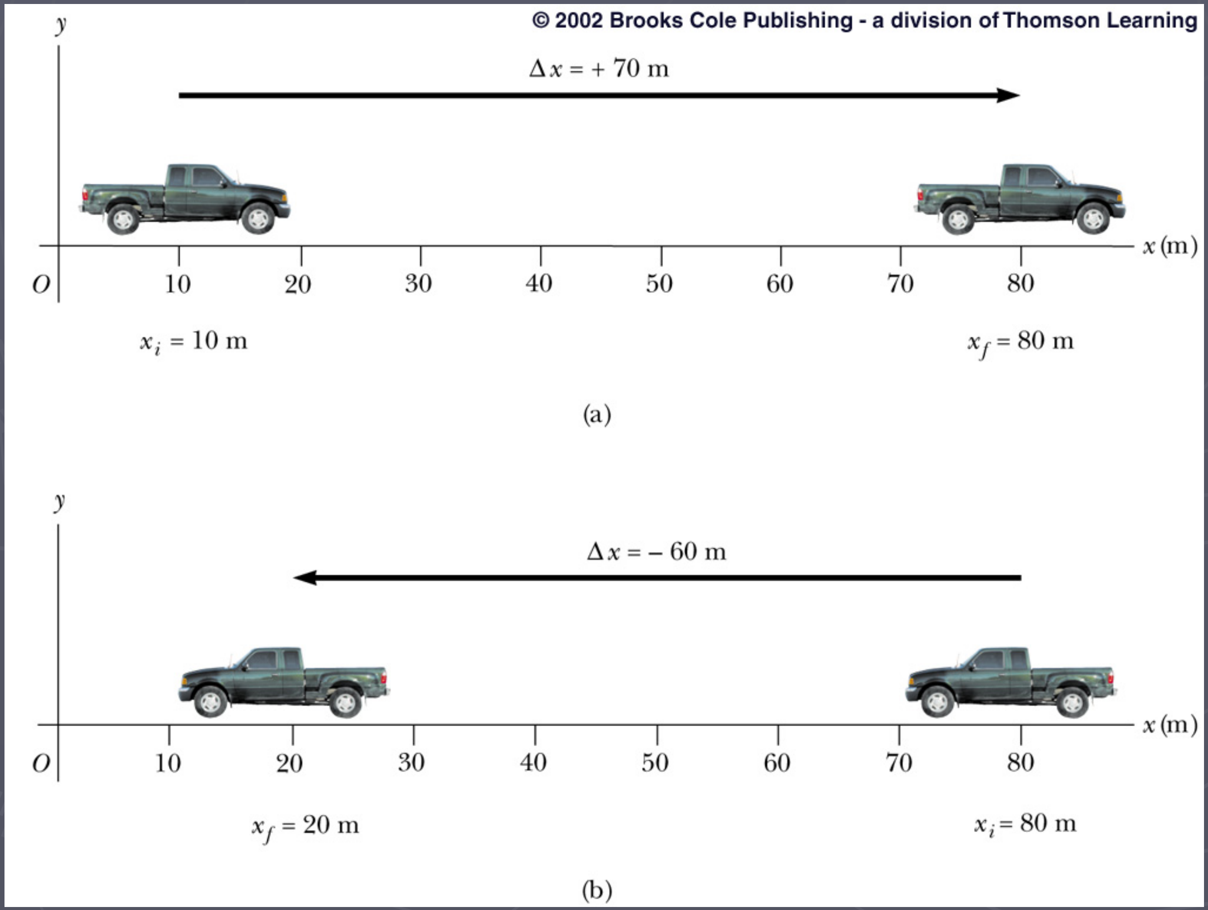
- Position is defined in terms of a **frame of reference**
  - One dimensional, so generally the x- or y-axis
- Displacement measures the change in position
  - Represented as Δx (if horizontal) or Δy (if vertical)
  - Vector quantity
    - + or - is generally sufficient to indicate direction for one-dimensional motion



Units	
SI	Meters (m)
CGS	Centimeters (cm)
US Cust	Feet (ft)

Displacement (example)

- Displacement measures the change in position
  - represented as Δx or Δy

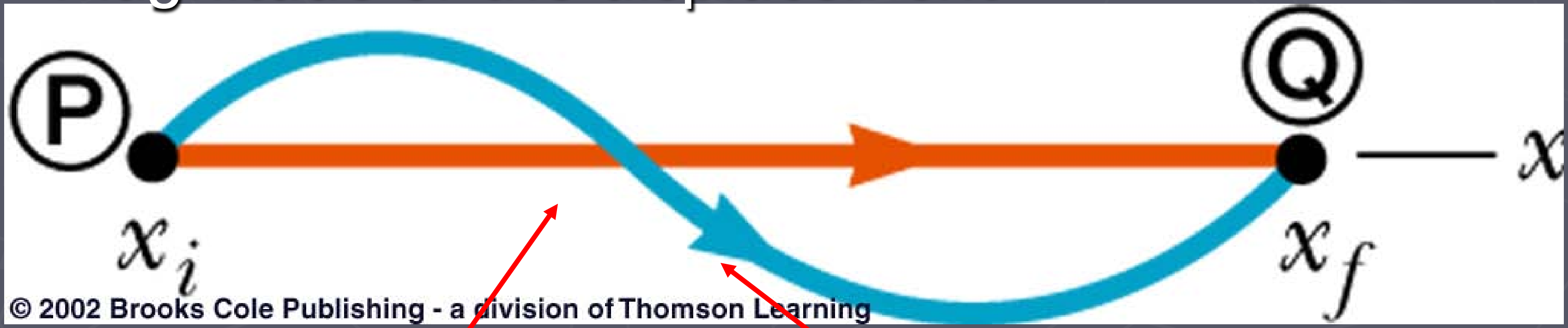


$$\Delta x_1 = x_f - x_i$$
$$= 80\,m - 10\,m$$
$$= \underline{+70\,m}$$ ✓

$$\Delta x_2 = x_f - x_i$$
$$= 20\,m - 80\,m$$
$$= \underline{-60\,m}$$ ✓

Distance or Displacement?

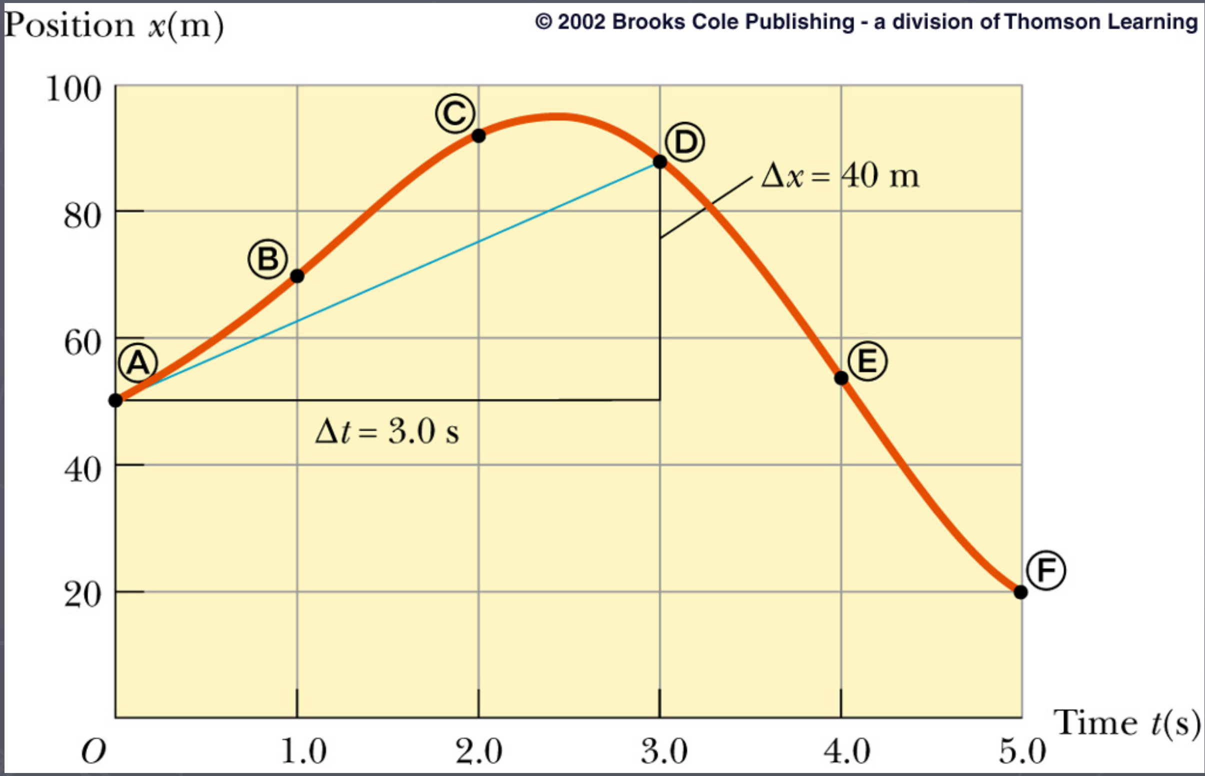
- Distance may be, but is not necessarily, the magnitude of the displacement



Displacement
(yellow line)

Distance
(blue line)

Position-time graphs



➤ Note: position-time graph is not necessarily a straight line, even though the motion is along x-direction

ConcepTest 1

An object (say, car) goes from one point in space to another. After it arrives to its destination, its displacement is

1. either greater than or equal to
2. always greater than
3. always equal to
4. either smaller or equal to
5. either smaller or larger

than the distance it traveled.

Please fill your answer as question 1 of General Purpose Answer Sheet

ConcepTest 1

An object (say, car) goes from one point in space to another. After it arrives to its destination, its displacement is

1. either greater than or equal to
2. always greater than
3. always equal to
4. either smaller or equal to
5. either smaller or larger

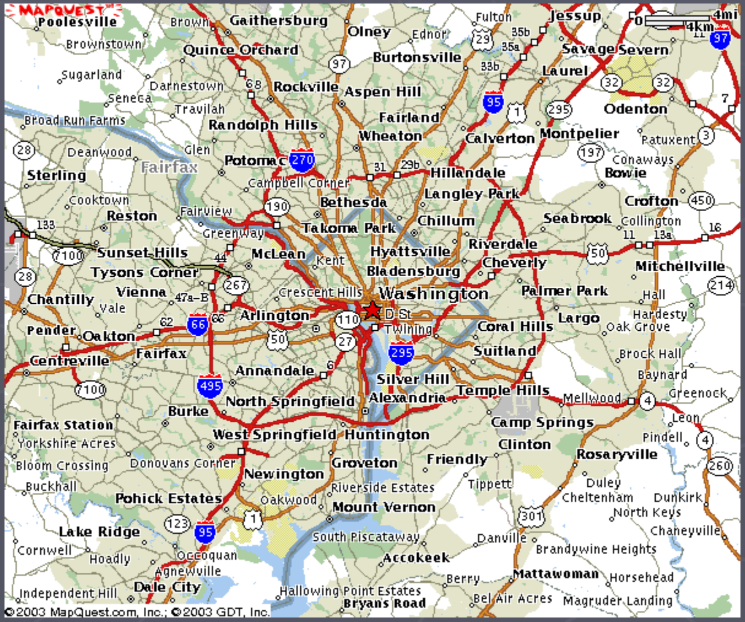
than the distance it traveled.

Please fill your answer as **question 2** of General Purpose Answer Sheet

ConcepTest 1 (answer)

An object (say, car) goes from one point in space to another. After it arrives to its destination, its displacement is

1. either greater than or equal to
2. always greater than
3. always equal to
4. either smaller or equal to ✓
5. either smaller or larger



than the distance it traveled.

Note: displacement is a vector from the final to initial points, distance is total path traversed

Average Velocity

- It takes time for an object to undergo a displacement
- The **average velocity** is rate at which the displacement occurs

$$\vec{v}_{average} = \frac{\Delta \vec{x}}{\Delta t} = \frac{\vec{x}_f - \vec{x}_i}{\Delta t}$$

- It is a vector, direction will be the same as the direction of the displacement (Δt is always positive)
  - + or - is sufficient for one-dimensional motion

More About Average Velocity

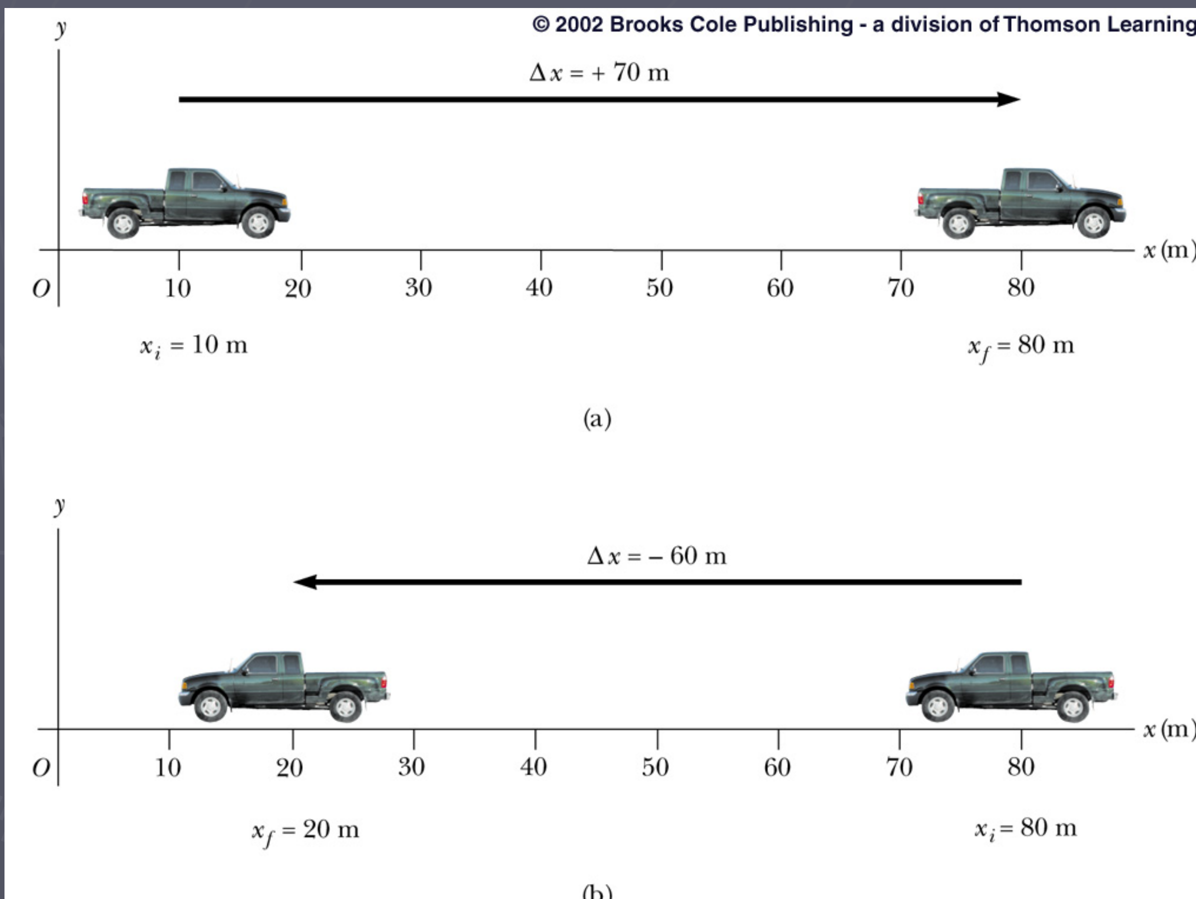
- Units of velocity:

Units	
SI	Meters per second (m/s)
CGS	Centimeters per second (cm/s)
US Customary	Feet per second (ft/s)

- Note: other units may be given in a problem, but generally will need to be converted to these

Example:

Suppose that in both cases truck covers the distance in 10 seconds:



$$\vec{v}_{1\,average} = \frac{\Delta\vec{x}_1}{\Delta t} = \frac{+70m}{10s}$$

$$= \underline{+7\,m/s}$$

$$\vec{v}_{2\,average} = \frac{\Delta\vec{x}_2}{\Delta t} = \frac{-60m}{10s}$$

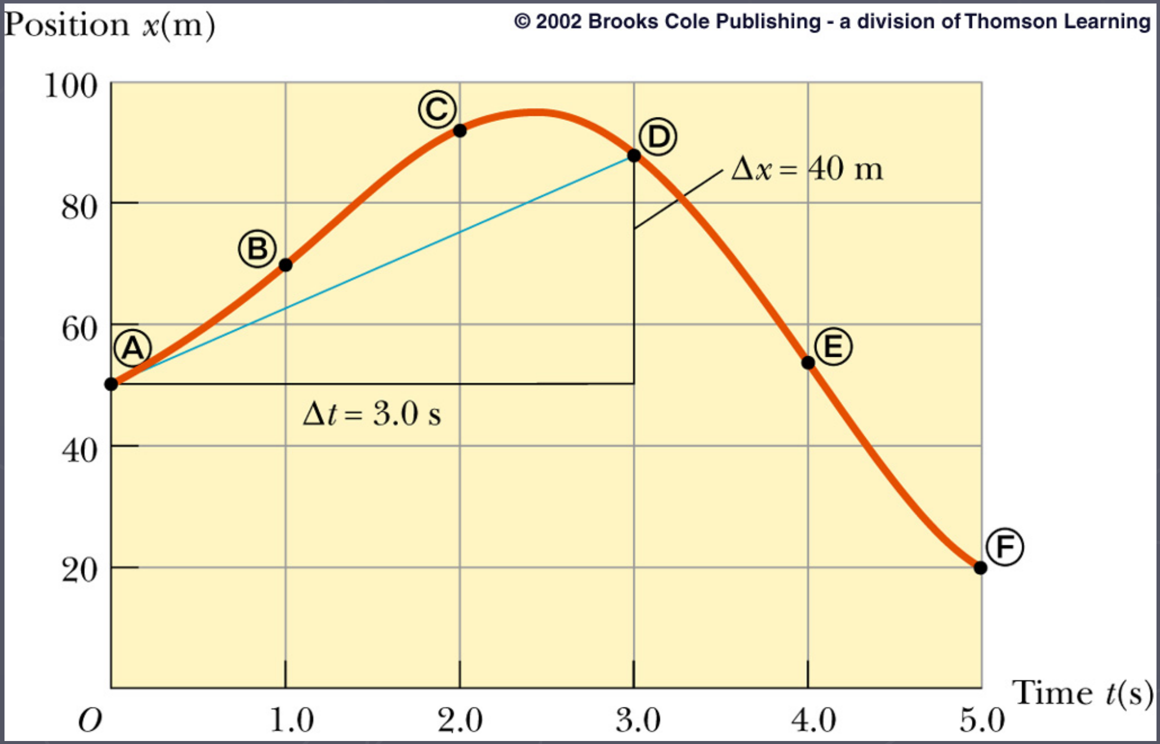
$$= \underline{-6\,m/s}$$

Speed

- Speed is a scalar quantity
  - same units as velocity
  - speed = total distance / total time
- May be, but is not necessarily, the magnitude of the velocity

Graphical Interpretation of Average Velocity

- Velocity can be determined from a position-time graph



$$\vec{v}_{average} = \frac{\Delta \vec{x}}{\Delta t} = \frac{+40m}{3.0s}$$

$$= \underline{+13\,m/s}$$

- Average velocity equals the slope of the line joining the initial and final positions

Instantaneous Velocity

- Instantaneous velocity is defined as the limit of the average velocity as the time interval becomes infinitesimally short, or as the time interval approaches zero

$$\vec{v}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{x}}{\Delta t} = \lim_{\Delta t \to 0} \frac{\vec{x}_f - \vec{x}_i}{\Delta t}$$

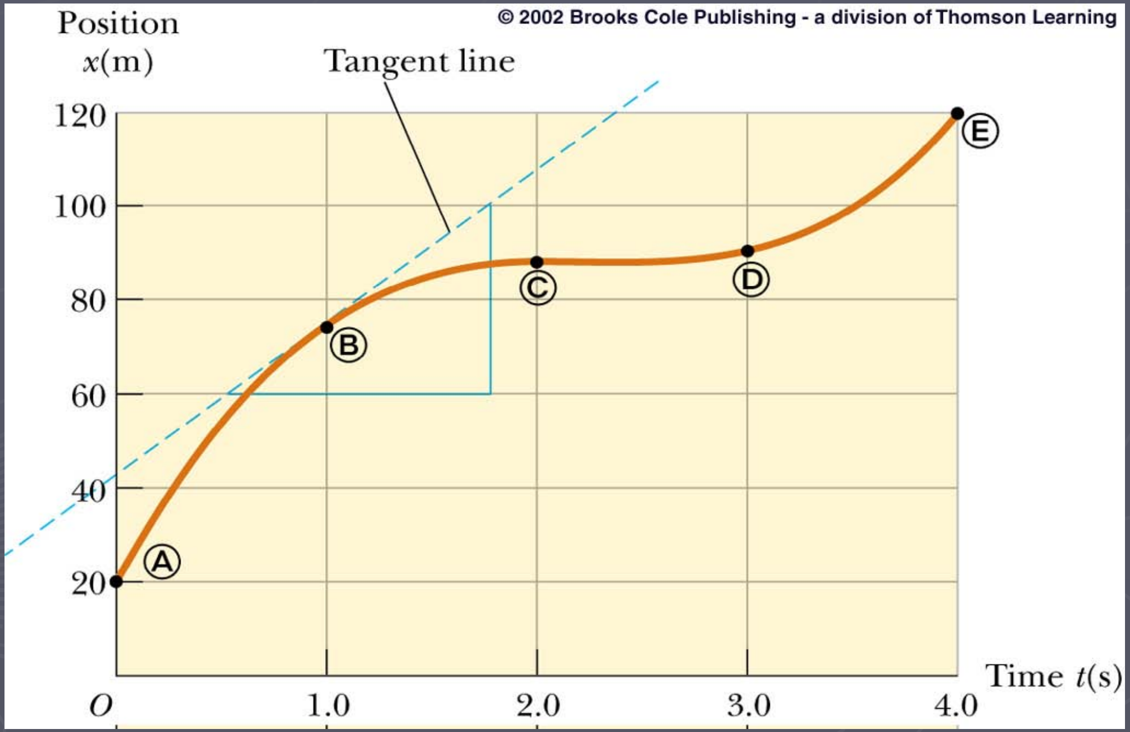
- The instantaneous velocity indicates what is happening at every point of time

Uniform Velocity

- Uniform velocity is constant velocity
- The instantaneous velocities are always the same
  - All the instantaneous velocities will also equal the average velocity

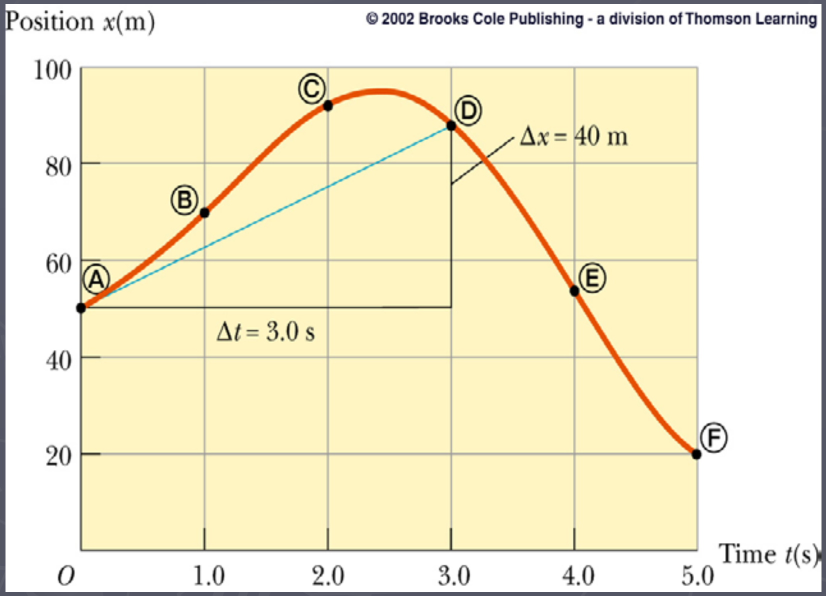
Graphical Interpretation of Instantaneous Velocity

- Instantaneous velocity is the slope of the tangent to the curve at the time of interest

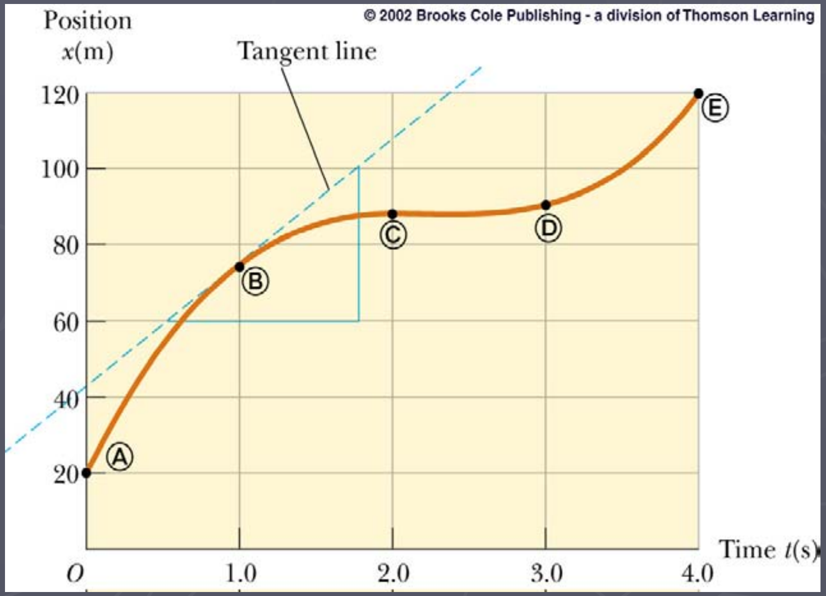


- The instantaneous speed is the magnitude of the instantaneous velocity

Average vs Instantaneous Velocity



Average velocity

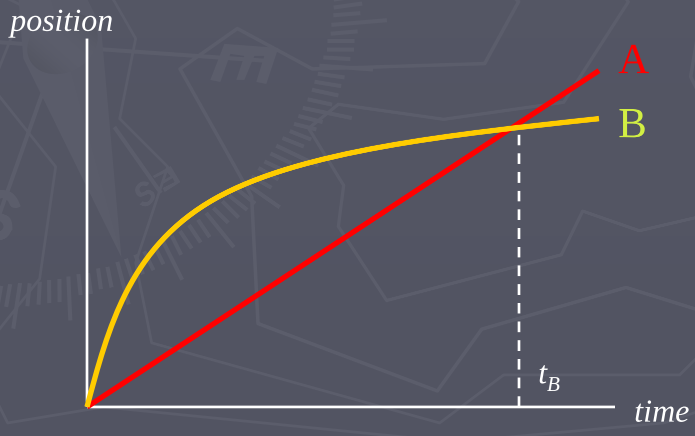


Instantaneous velocity

ConcepTest 2

The graph shows position as a function of time for two trains running on parallel tracks. Which of the following is true:

1. at time t_B both trains have the same velocity
2. both trains speed up all the time
3. both trains have the same velocity at some time before t_B
4. train A is longer than train B
5. all of the above statements are true

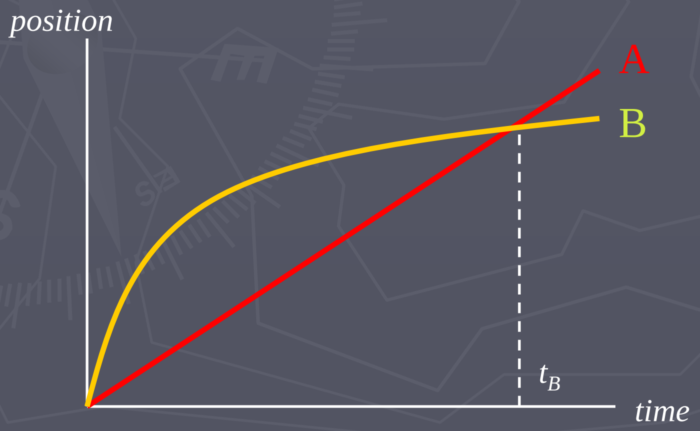


Please fill your answer as question 3 of General Purpose Answer Sheet

ConcepTest 2

The graph shows position as a function of time for two trains running on parallel tracks. Which of the following is true:

1. at time t_B both trains have the same velocity
2. both trains speed up all the time
3. both trains have the same velocity at some time before t_B
4. train A is longer than train B
5. all of the above statements are true

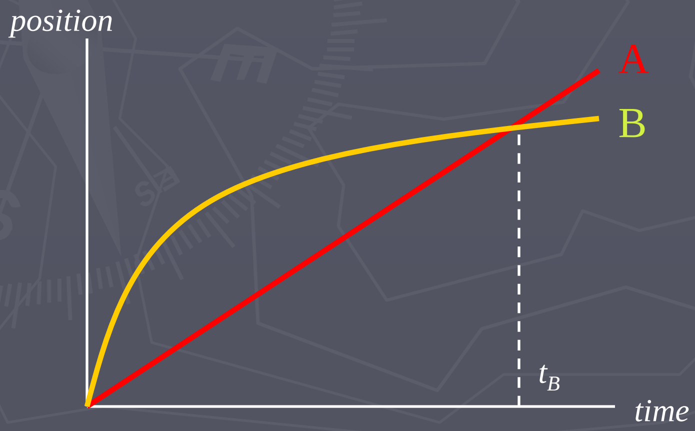


Please fill your answer as **question 4** of General Purpose Answer Sheet

ConcepTest 2 (answer)

The graph shows position as a function of time for two trains running on parallel tracks. Which of the following is true:

1. at time t_B both trains have the same velocity
2. both trains speed up all the time
3. both trains have the same velocity at some time before t_B
4. train A is longer than train B
5. all of the above statements are true



Note: the slope of curve B is parallel to line A at some point $t < t_B$

Average Acceleration

- Changing velocity (non-uniform) means an acceleration is present
- Average acceleration is the rate of change of the velocity

$$\vec{a}_{average} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

- Average acceleration is a vector quantity

Average Acceleration

- When the sign of the velocity and the acceleration are the same (either positive or negative), then the speed is increasing
- When the sign of the velocity and the acceleration are opposite, the speed is decreasing

Units	
SI	Meters per second squared (m/s^2)
CGS	Centimeters per second squared (cm/s^2)
US Customary	Feet per second squared (ft/s^2)

Instantaneous and Uniform Acceleration

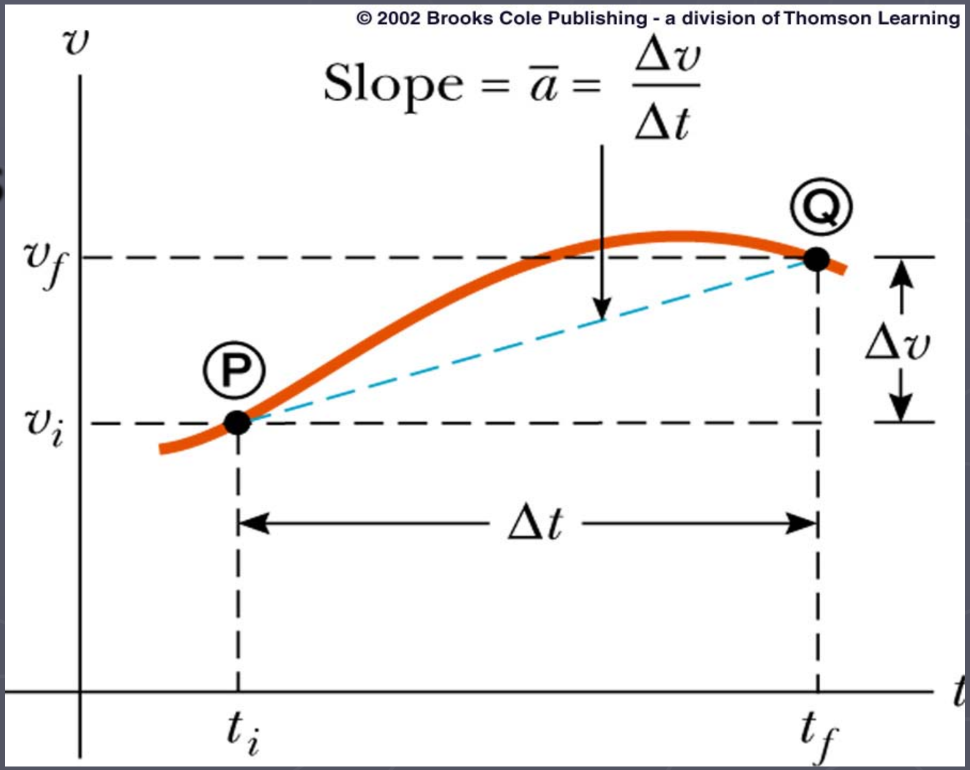
- Instantaneous acceleration is the limit of the average acceleration as the time interval goes to zero

$$\vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} = \lim_{\Delta t \to 0} \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

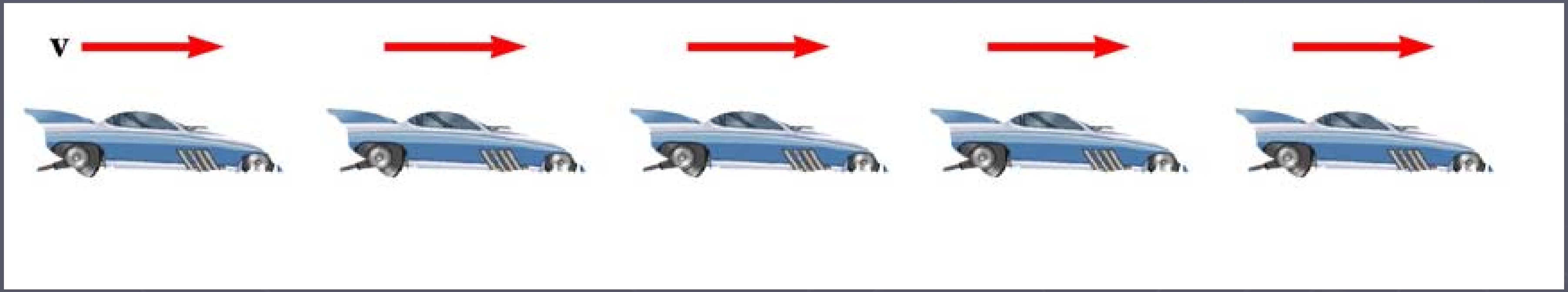
- When the instantaneous accelerations are always the same, the acceleration will be uniform
  - The instantaneous accelerations will all be equal to the average acceleration

Graphical Interpretation of Acceleration

- Average acceleration is the slope of the line connecting the initial and final velocities on a velocity-time graph
- Instantaneous acceleration is the slope of the tangent to the curve of the velocity-time graph

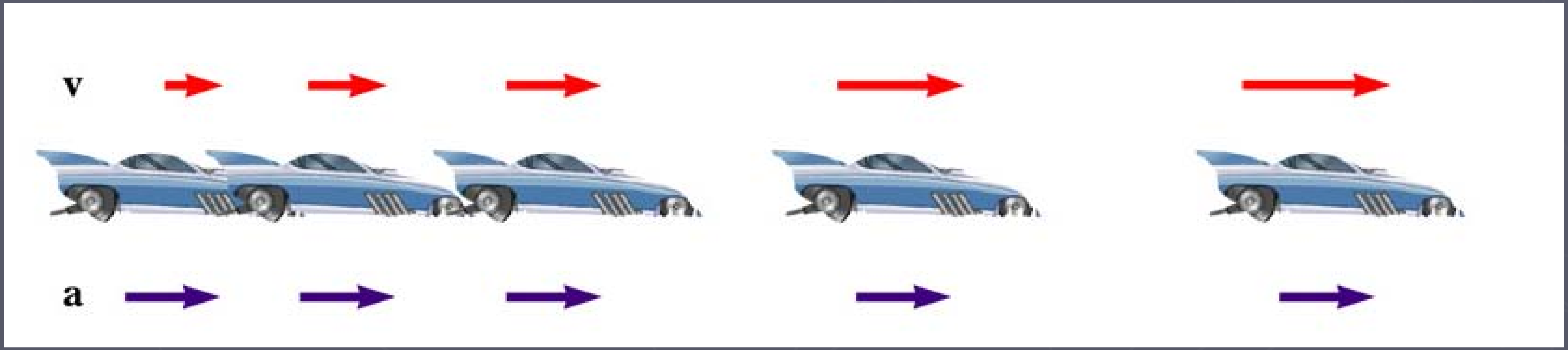


Example 1: Motion Diagrams



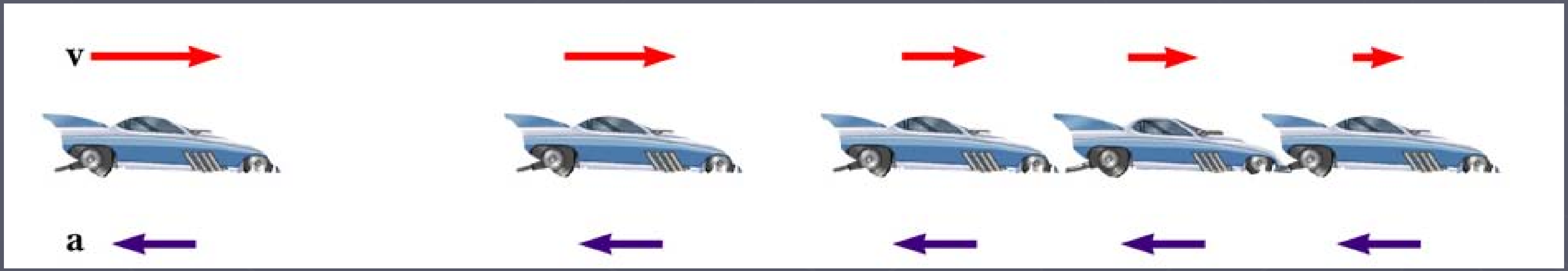
- Uniform velocity (shown by red arrows maintaining the same size)
- Acceleration equals zero

Example 2:



- Velocity and acceleration are in the same direction
- Acceleration is uniform (blue arrows maintain the same length)
- Velocity is increasing (red arrows are getting longer)

Example 3:



- Acceleration and velocity are in opposite directions
- Acceleration is uniform (blue arrows maintain the same length)
- Velocity is decreasing (red arrows are getting shorter)