

# physics

FOR SCIENTISTS AND ENGINEERS

a strategic approach

FOURTH EDITION

randall d. knight

# Brief Introduction to Physics

What is Physics?

“Physics is the **process** by which we attempt to understand the Universe around us.”

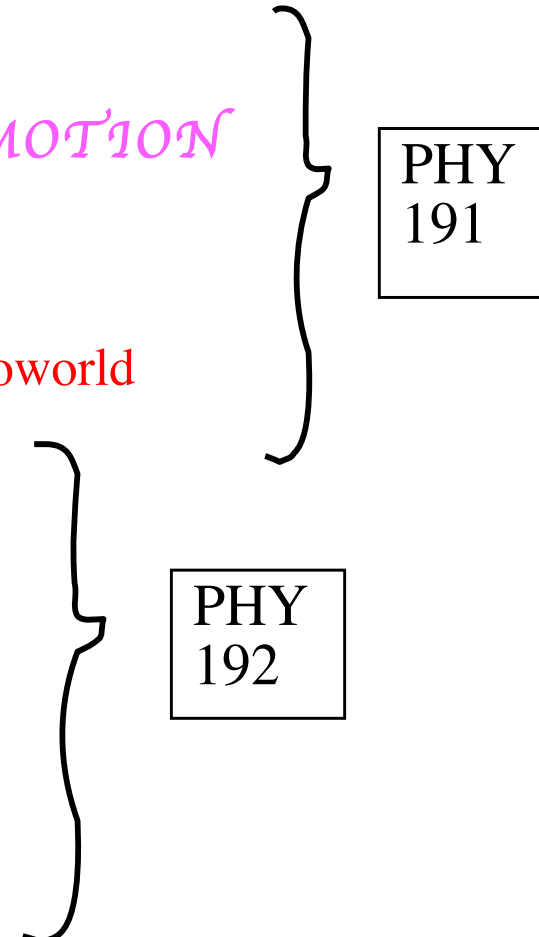
*Note: this is a process or a way of thinking – Physics is much more than a body of knowledge.*

# Our Motivation

## UNDERSTAND MOTHER NATURE...

...look around us harder...look deeper...

- *What we see...*
  - Newton's laws of *MOTION*
  - Waves
- *What we cannot see...*
  - The Quantum Microworld
- *All we need to see...*
  - Statistical physics
- *How we see...*
  - Electromagnetism
- *Do you see what I see...*
  - Relativity



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# Where do we Begin our Study of Physics?

- Imagine for a minute that we are totally ignorant about the Universe.
- What single observation of our surroundings would be most revealing about the Universe?
- Everything Moves\*. (*if nothing moved, there would be no need for physics because nothing would change!*)
  - \*Don't be deceived by your senses. Objects that appear to be motionless, have internal motion.*

So, our first goal in physics is to describe motion:

How do things move? **Kinematics** (position, velocity, acceleration)

Why do things move? **Dynamics** (force, momentum, energy)

# Chapter 1 Concepts of Motion



## **Buckeye Bullet Sets Electric Vehicle Land-Speed Record**

Topping 307 mph is an amazing feat in any vehicle. It's even more so when the vehicle in question is a student-built electric vehicle. The Venturi Buckeye Bullet built by students at Ohio State University achieved an average speed of 307.7 mph during a two-run pass at the Bonneville Salt Flats on Tuesday.

**Chapter Goal:** To introduce the fundamental concepts of motion.



**Linear motion**



**Circular motion**



**Projectile motion**



**Rotational motion**

# Four basic types of motion

# Chapter 1 Preview

First step toward **understanding** anything:

**DRAW IT!**

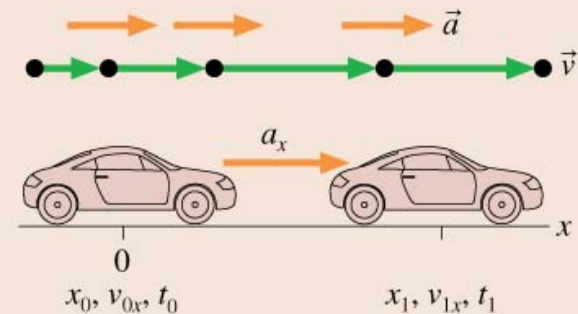
## Describing Motion

Before solving problems about motion, we first must learn to describe motion. In this chapter, you'll learn to describe motion with

- Motion diagrams
- Graphs
- Pictures

In Chapter 2, these tools will become the basis of a powerful problem-solving strategy.

Motion concepts that we'll introduce in this chapter include **position, velocity, and acceleration.**



Known

$$x_0 = v_{0x} = t_0 = 0$$

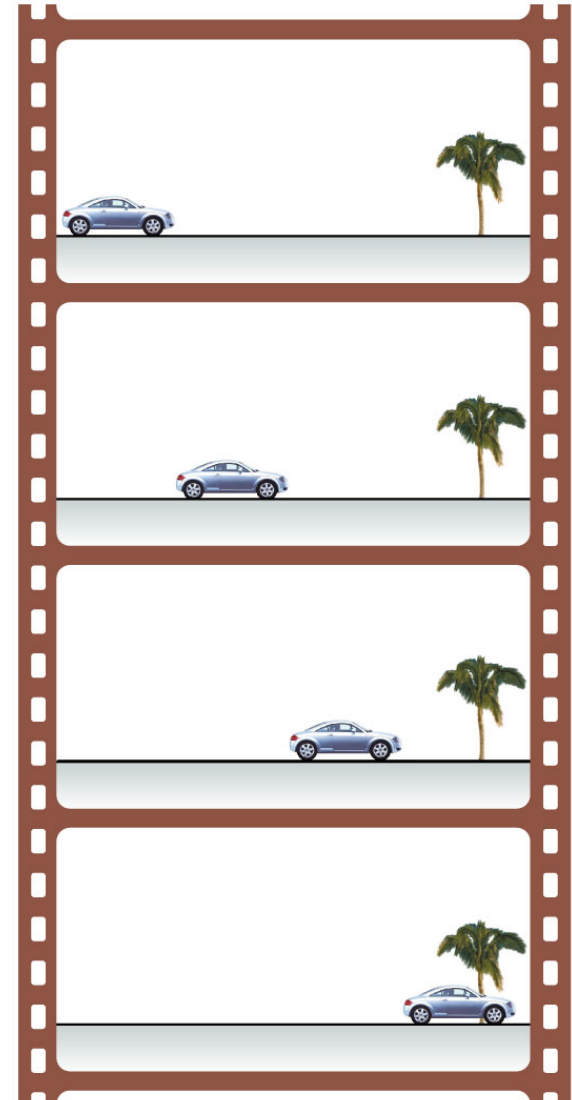
$$a_x = 2.0 \text{ m/s}^2 \quad t_1 = 2.0 \text{ s}$$

Find

$$x_1$$

# Making a Motion Diagram – Sec 1.1

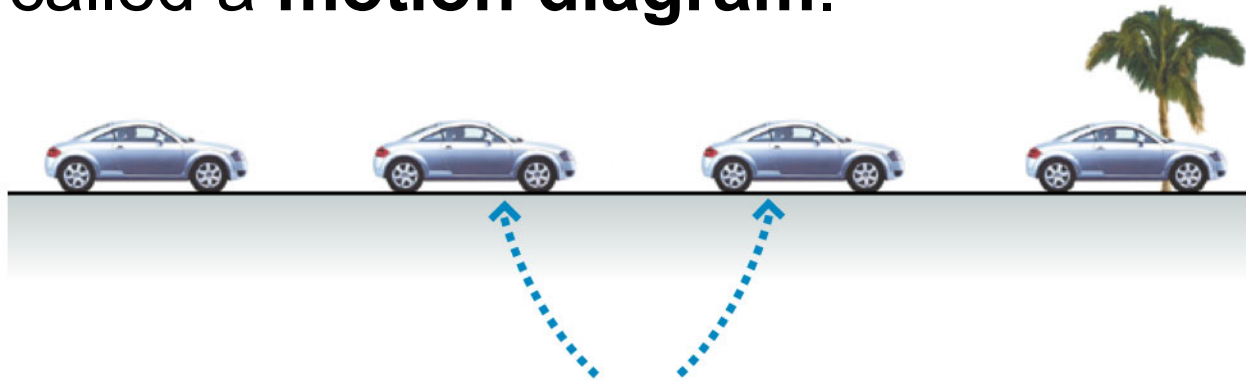
- Consider a movie of a moving object.
- A movie camera takes photographs at a fixed rate (i.e., 30 photographs every second).
- Each separate photo is called a *frame*.
- The car is in a different position in each frame.
- Shown are four frames in a *filmstrip*.





# Making a Motion Diagram – Sec 1.1

- Cut individual frames of the filmstrip apart.
- Stack them on top of each other.
- This composite photo shows an object's position at several *equally spaced instants of time*.
- This is called a **motion diagram**.



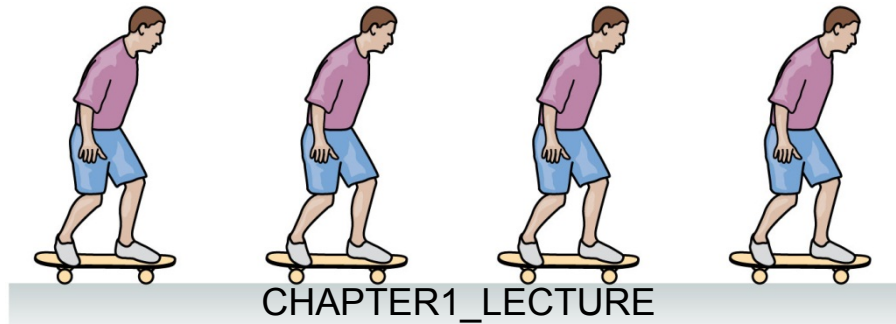
The same amount of time elapses between each image and the next.

# Examples of Motion Diagrams – Sec 1.1

- An object that has a *single position* in a motion diagram is *at rest*.
- Example: **A stationary ball on the ground.**

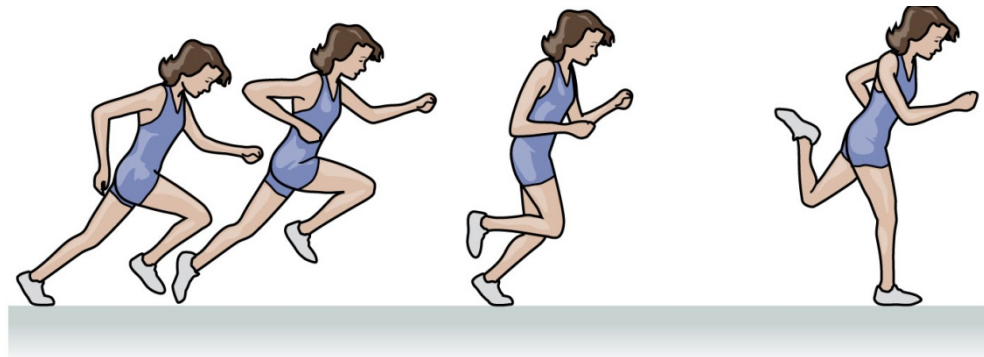


- An object with images that are *equally spaced* is moving with *constant speed*.
- Example: **A skateboarder rolling down the sidewalk.**



# Examples of Motion Diagrams – Sec 1.1

- An object with images that have *increasing distance* between them is *speeding up*.
- Example: **A sprinter starting the 100 meter dash.**



- An object with images that have *decreasing distance* between them is *slowing down*.
- Example: **A car stopping for a red light.**



# Examples of Motion Diagrams – Sec 1.1

- A motion diagram can show more complex motion in two dimensions.
- Example: **A jump shot from center court.**
- In this case the ball is slowing down as it rises, and speeding up as it falls.



# Stop to Think 1.1 in book



Car A



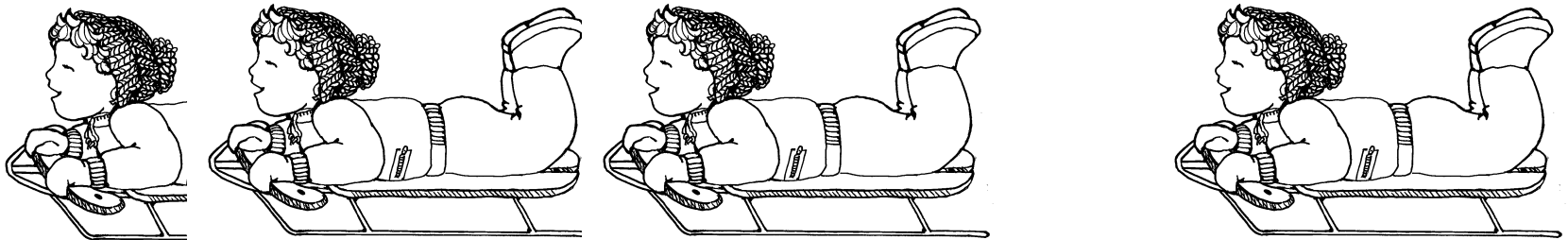
Car B

Motion diagrams are made of two cars. Both have the same time interval between photos. Which car, A or B, is going slower?

# Whiteboard Problem 1.1

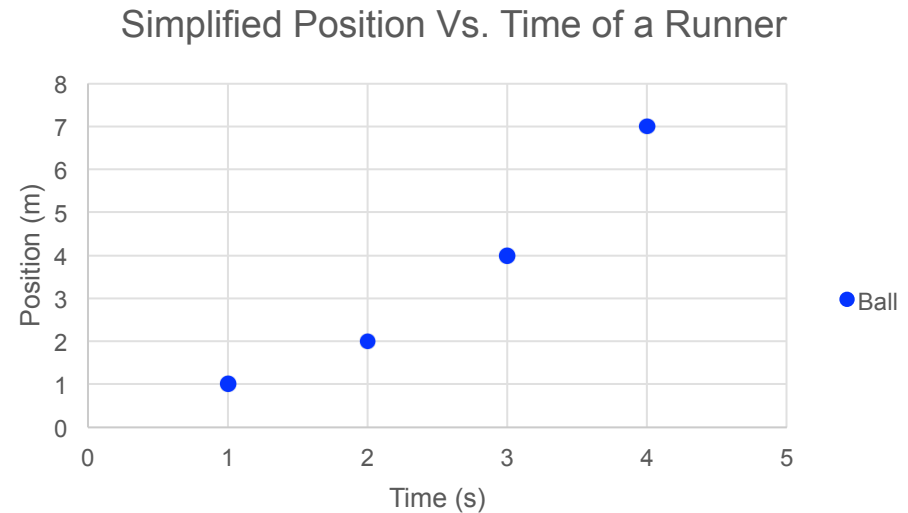
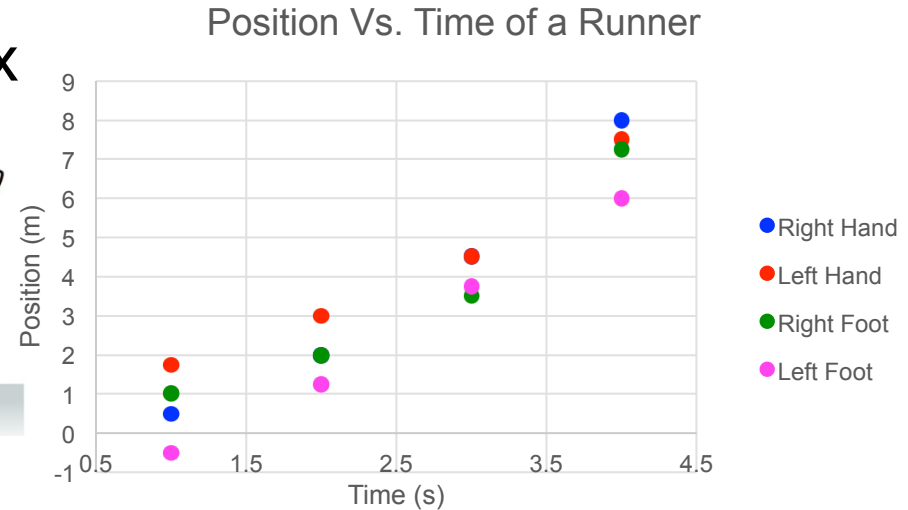
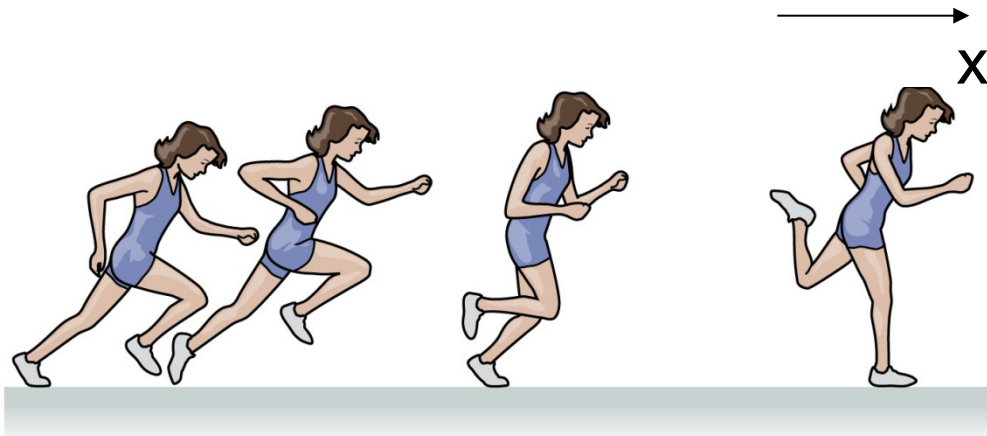
A child is sledding on a smooth, level patch of snow. She encounters a slushy patch and slows to a stop. Draw a complete motion diagram of the child and sled.

# Whiteboard Problem 1.1



Slush!

# Particle Model – Sec 1.2



We only want to describe the motion of the particle, the shape and internal processes are not important



# Reading Question – Sec 1.2

What is a “particle?”

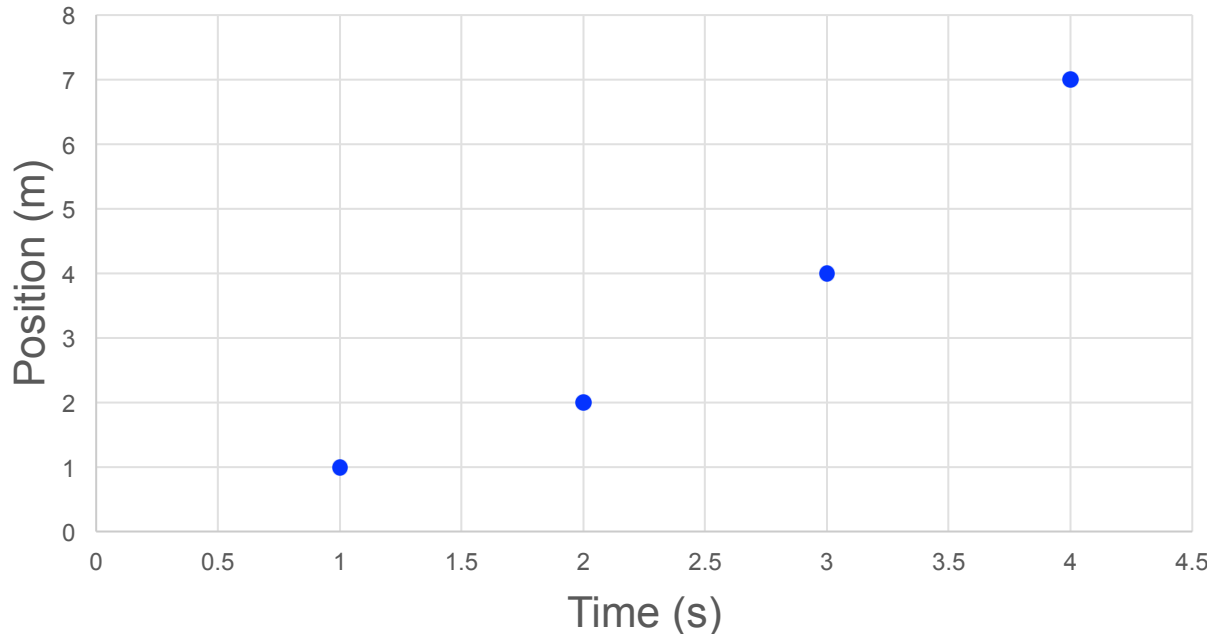
- A. Any part of an atom.
- B. An object that can be represented as a mass at a single point in space.
- C. A part of a whole.
- D. An object that can be represented as a single point in time.
- E. An object that has no top or bottom, no front or back.

# Origin for space-time plot – Sec 1.2

We can choose any point in space and time to be 0.

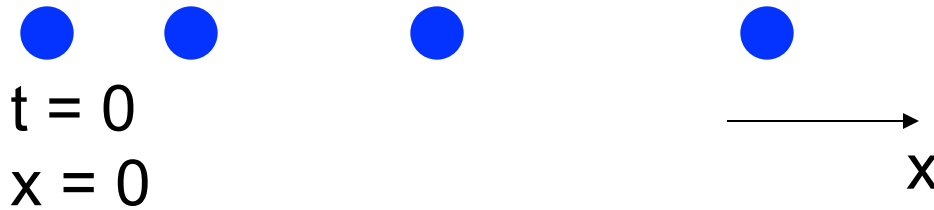


As long as you are consistent with that choice throughout the problem

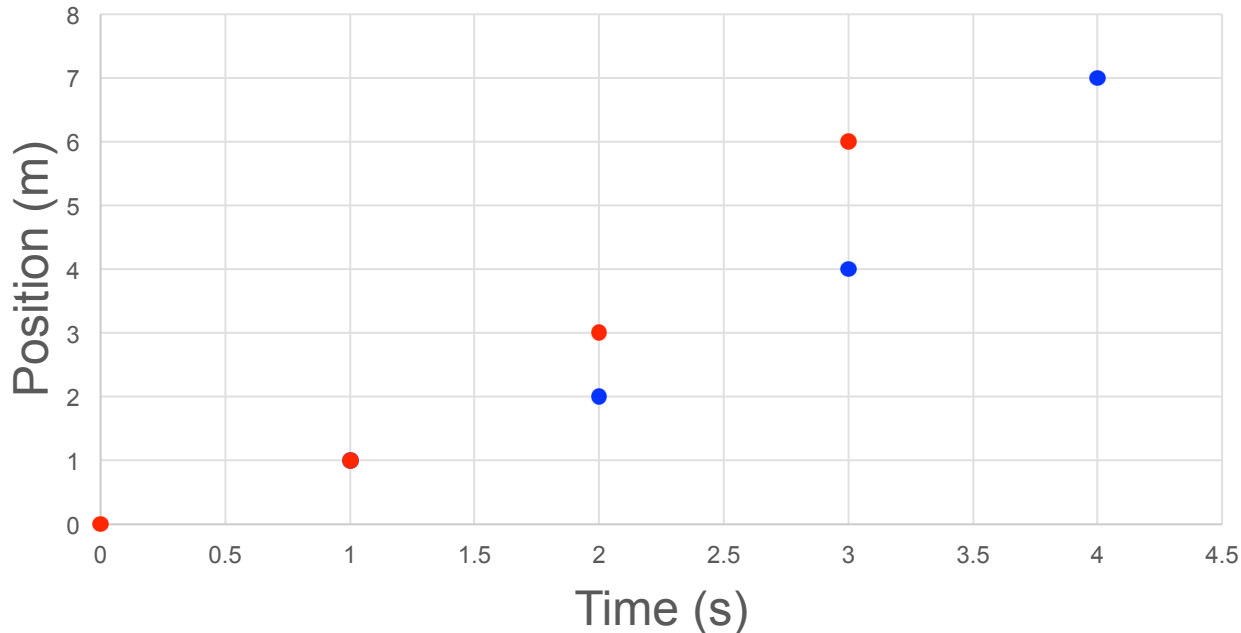


# Origin for space-time plot – Sec 1.2

We can choose any point in space and time to be 0.



Simplified Position Vs. Time of a Runner



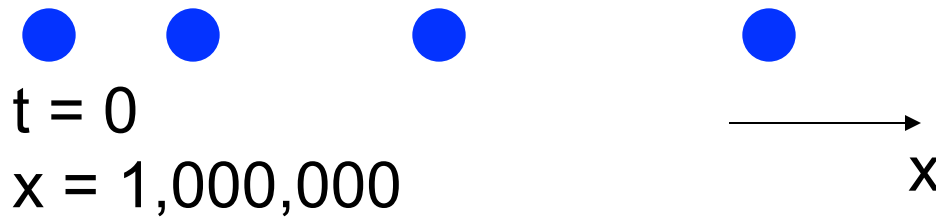
●  $t=1, x=1$

●  $t=0, x=0$

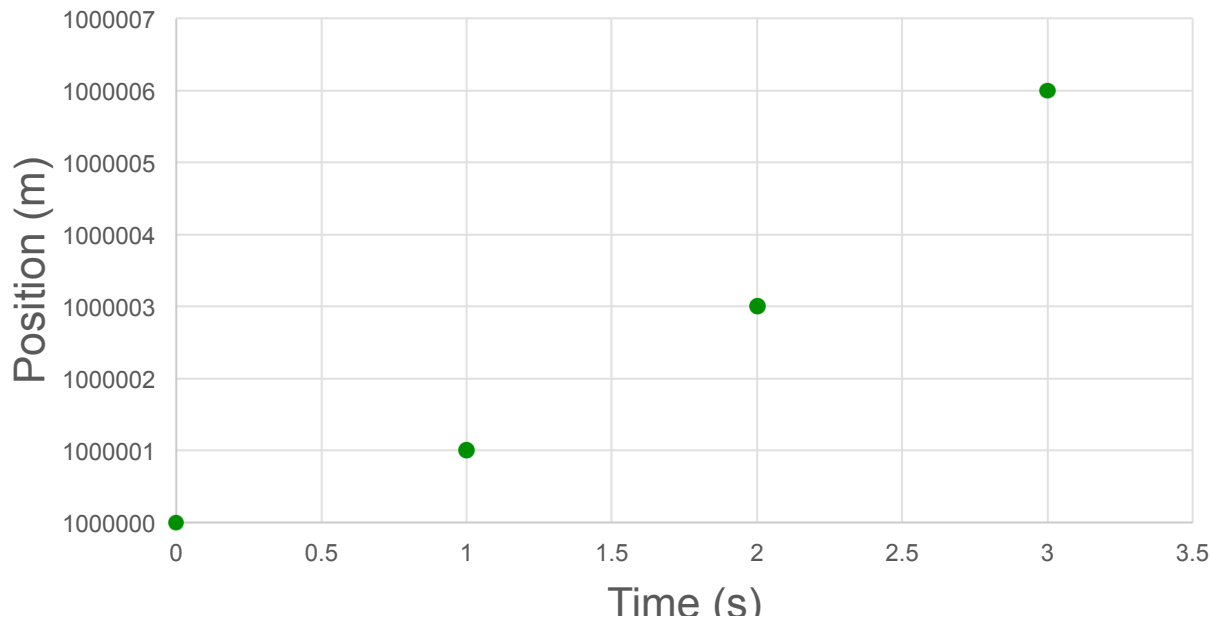


# Origin for space-time plot – Sec 1.2

We can choose any point in space and time to be 1,000,000.



Simplified Position Vs. Time of a Runner



# Limitations to Particle Model – Sec. 1.2

- “Happy” and “Sad” Ball demonstration (also recall demo with liquid nitrogen from 1<sup>st</sup> lecture)
  - Recap: Both balls appear to be identical. When released from the same height:
    - One bounces to almost the same height it was dropped
    - Other does not rebound at all
    - <https://www.youtube.com/watch?v=seoPklidAio> [first 25 seconds, the remainder is something we will discuss in a few weeks]
    - Takeaway: **particle model can miss important physics!**

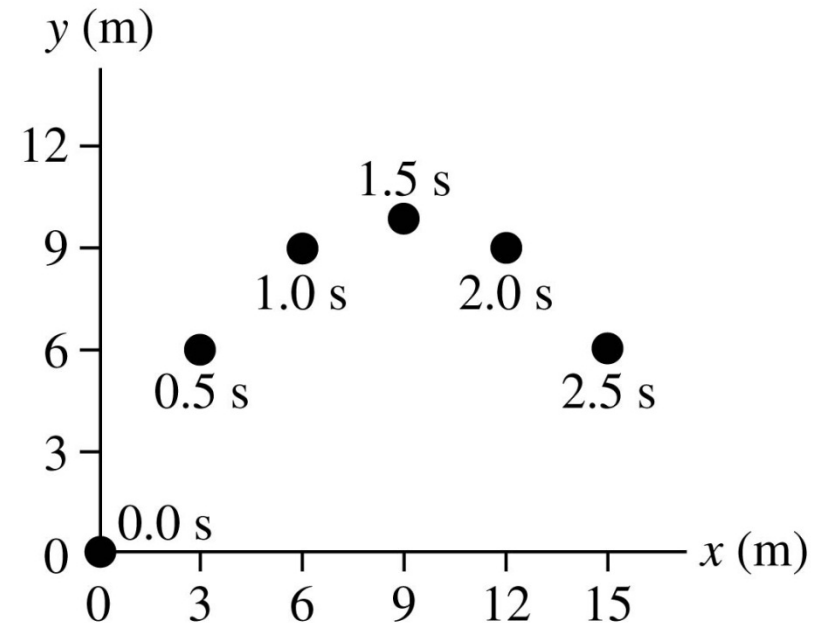
# Stop to Think 1.2 in book

Three motion diagrams are shown. Which is a dust particle settling to the floor at constant speed, which is a ball dropped from the roof of a building, and which is a descending rocket slowing to make a soft landing on Mars?

- |   |         |         |         |
|---|---------|---------|---------|
|   | (a) 0 ● | (b) 0 ● | (c) 0 ● |
|   | 1 ●     |         |         |
| A. (a) is dust, (b) is ball, (c) is rocket. | 2 ●     | 1 ●     |         |
| B. (a) is ball, (b) is dust, (c) is rocket. | 3 ●     | 2 ●     | 1 ●     |
| C. (a) is rocket, (b) is dust, (c) is ball. |         | 3 ●     | 2 ●     |
| D. (a) is rocket, (b) is ball, (c) is dust. | 4 ●     | 4 ●     | 3 ●     |
| E. (a) is ball, (b) is rocket, (c) is dust. |         |         | 4 ●     |
|   | 5 ●     | 5 ●     | 5 ●     |

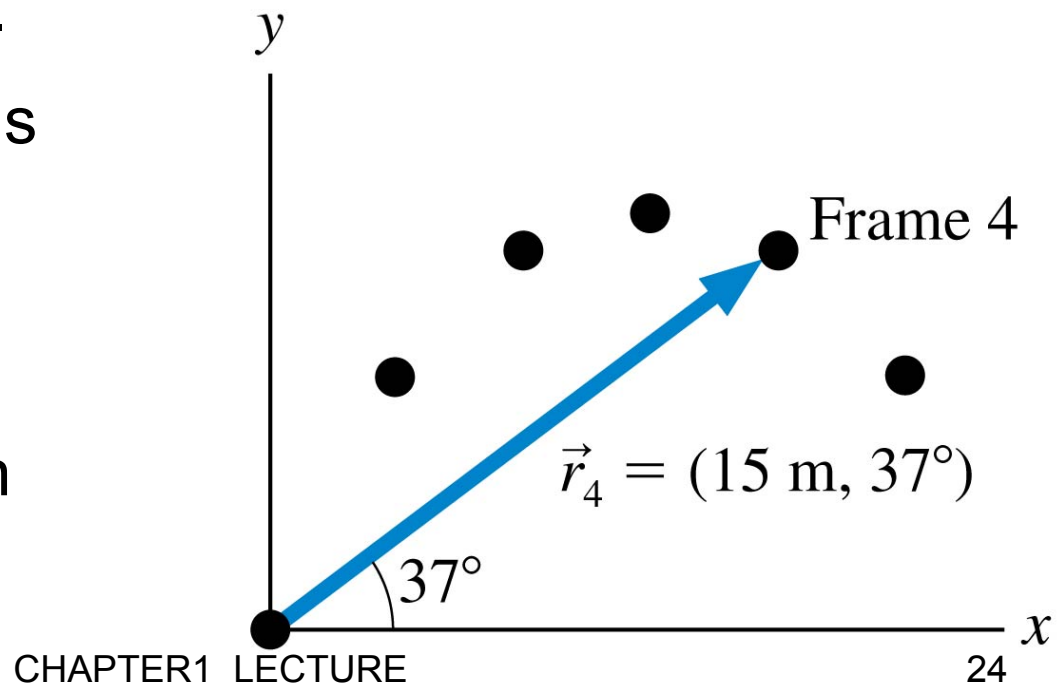
# Position and Time – Sec 1.3

- In a motion diagram it is useful to add numbers to specify *where* the object is and *when* the object was at that position.
- Shown is the motion diagram of a basketball, with 0.5 s intervals between frames.
- A coordinate system has been added to show  $(x, y)$ .
- The frame at  $t = 0$  is frame 0, when the ball is at the origin.
- The ball's position in frame 4 can be specified with coordinates  $(x_4, y_4) = (12 \text{ m}, 9 \text{ m})$  at time  $t_4 = 2.0 \text{ s}$ .



# Position as a Vector – Sec 1.3

- Another way to locate the ball is to draw an arrow from the origin to the point representing the ball.
- You can then specify the length and direction of the arrow.
- This arrow is called the **position vector**  $\vec{r}$  of the object.
- The position vector  $\vec{r}$  is an alternative form of specifying position.
- It does not tell us anything different than the coordinates  $(x, y)$ .





# Time Interval – Sec 1.3



A stopwatch is used to measure a time interval.

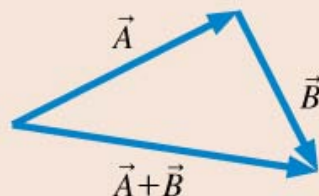
- It's useful to consider a *change* in time.
- An object may move from an **initial position**  $\vec{r}_i$  at time  $t_i$  to a **final position**  $\vec{r}_f$  at time  $t_f$ .

- Different observers may choose different coordinate systems and different clocks, however, all observers find the same values for the **displacement**  $\vec{r}$  and the **time interval**  $t$ .

## Vectors

Numbers alone aren't always enough; sometimes the direction of a quantity is also important. We use **vectors** to represent quantities, such as velocity, that have both a size and a direction.

You will learn to use a graphical technique to add and subtract vectors. Chapter 3 will explore vectors in more detail.



There are FOUR ways to combine vectors, each of great importance in science.

## Units and Significant Figures

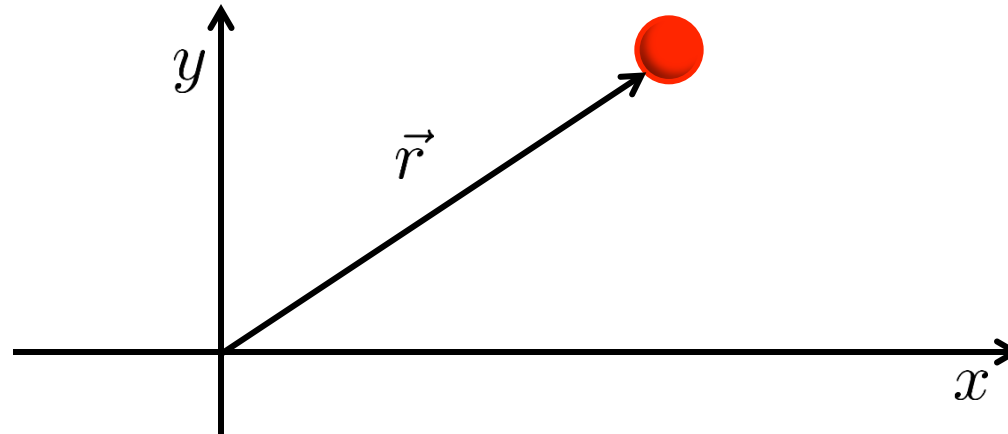
Calculations in physics are most commonly done using **SI units**—known more informally as the metric system. The basic units needed in the study of motion are the meter (m), the second (s), and the kilogram (kg).



The kilogram.

A **significant figure** is a digit that is reliably known. You will learn the rules for using significant figures correctly.

# Recap: Position, shown as a Vector – Sec 1.3



$\vec{r}$  = position vector\* of the object relative to the origin of some arbitrary coordinates

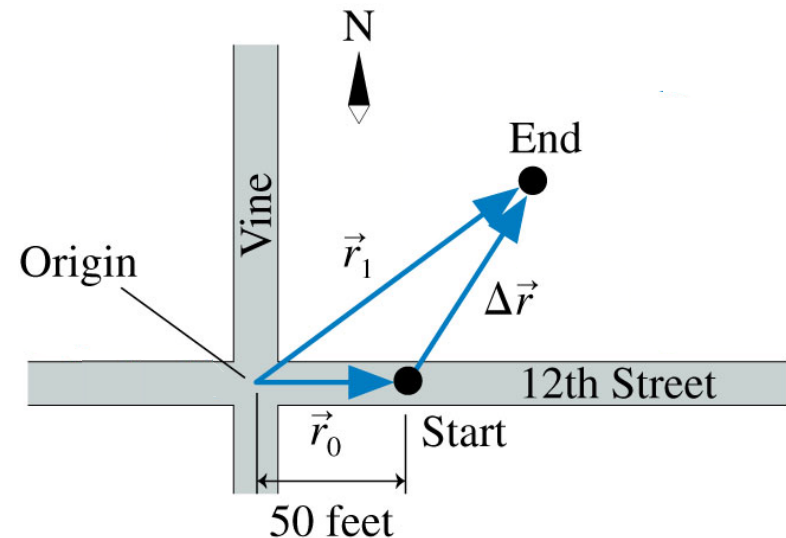
\*Vector is a quantity that has both magnitude and direction. We'll cover the details in Chapter 3. **For now, all we need to know is that we add and subtract vectors using arrows.**

# Displacement (use vector addition / subtraction) – Sec 1.3

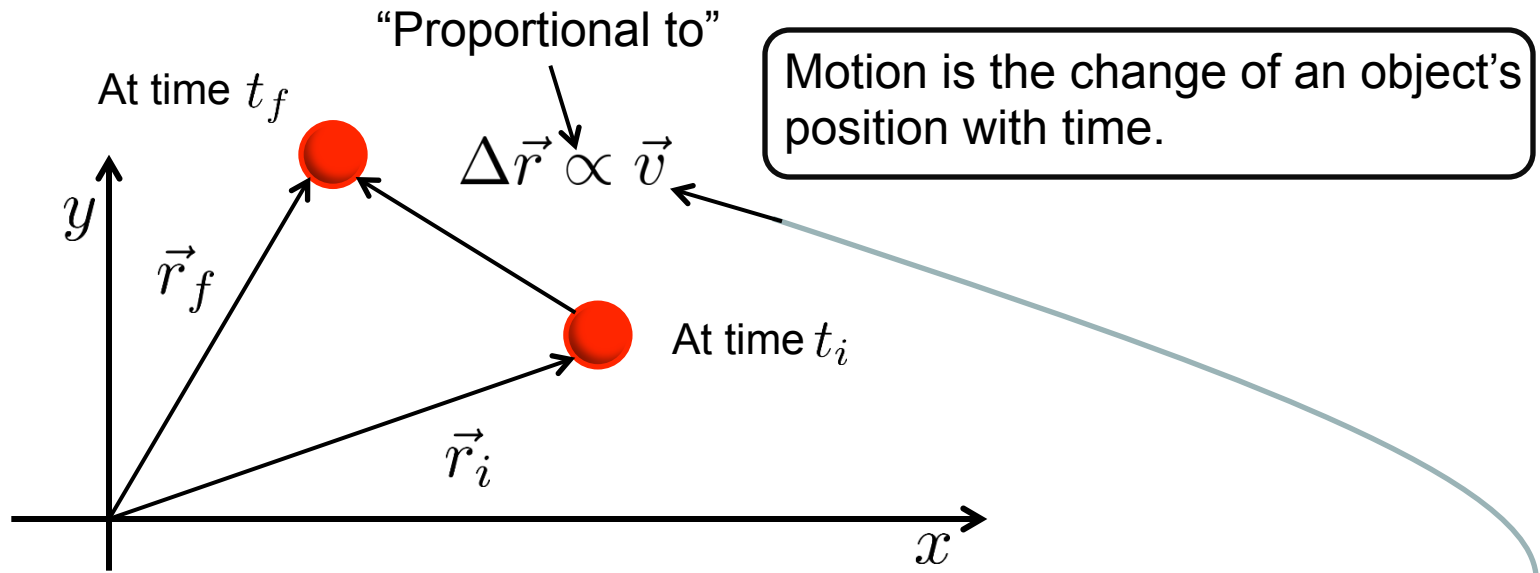
Sam is standing 50 ft east of the corner of 12<sup>th</sup> Street and Vine. He then walks northeast for 100 ft to a second point. What is Sam's change of position?

- Sam's initial position is the vector  $\vec{r}_0$ .
- Vector  $\vec{r}_1$  is his position after he finishes walking.
- Sam has *changed* position, and a change in position is called a **displacement**.
- His displacement is the vector labeled  $\Delta\vec{r}$ .

$$\vec{r}_1 = \vec{r}_0 + \Delta\vec{r}$$

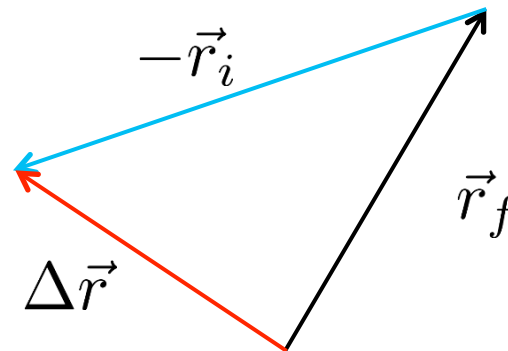


# Velocity (again, use vector addition & subtraction) – Sec 1.4



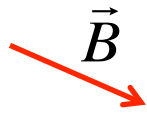
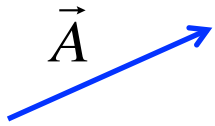
Average Velocity,  $\vec{v}_{avg} = \frac{\Delta \vec{r}}{\Delta t} = \frac{\vec{r}_f - \vec{r}_i}{t_f - t_i}$  (call it just  $\vec{v}$  for now)

$$\Delta \vec{r} = \vec{r}_f - \vec{r}_i$$



# Combining Vectors

There are four ways to combine vectors, each of which is greatly important in science.



KEY PROPERTY OF VECTORS: *We can translate them anywhere.* B/c a vector essentially represents a direction!

1) Vector **Addition**: *Join tail-to-tip*

$$\vec{A} + \vec{B} = \text{[blue arrow]} + \text{[red arrow]} = \text{[green arrow labeled } \vec{A} + \vec{B}]$$

Example – Net displacement of a professor who moves along  $\vec{A}$ , followed by motion along  $\vec{B}$ .

2) Vector **Subtraction**: *Join tail-to-tip*

$$\vec{A} - \vec{B} = \text{[blue arrow]} - \text{[red arrow]} = \text{[blue arrow]} + \text{[red arrow pointing left]} = \text{[pink arrow labeled } \vec{A} - \vec{B}]$$

Example – Definitions of velocity and acceleration, and so on.

## VECTOR MULTIPLICATION (*Join tail-to-tail*)

3) Vector **Multiplication – I** :

Scalar Product or Dot Product

$\vec{A} \cdot \vec{B}$  = a scalar quantity

Example:  $\vec{Force} \cdot \vec{Displacement} = \text{Work}$

4) Vector **Multiplication – II** :

Vector Product or Cross Product

$\vec{A} \times \vec{B}$  = a new vector

Example:  $\vec{Position} \times \vec{Force} = \text{Torque}$

# Definition of Displacement – Sec 1.3

- The displacement  $\Delta\vec{r}$  of an object as it moves from an initial position  $\vec{r}_i$  to a final position  $\vec{r}_f$  is

$$\Delta\vec{r} = \vec{r}_f - \vec{r}_i$$

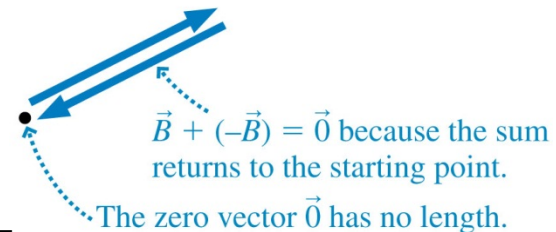
- The definition of  $\Delta\vec{r}$  involves *vector subtraction*.
- With numbers, subtraction is the same as the addition of a negative number.
- Similarly, with vectors

$$\vec{A} - \vec{B} = \vec{A} + (-\vec{B})$$

The negative of a vector.

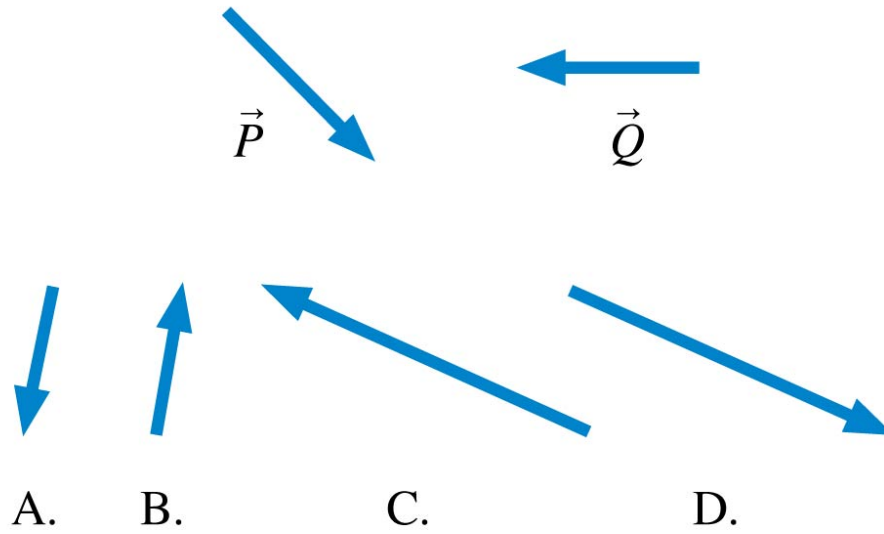


Vector  $-\vec{B}$  has the same length as  $\vec{B}$  but points in the opposite direction.



# Vector Addition

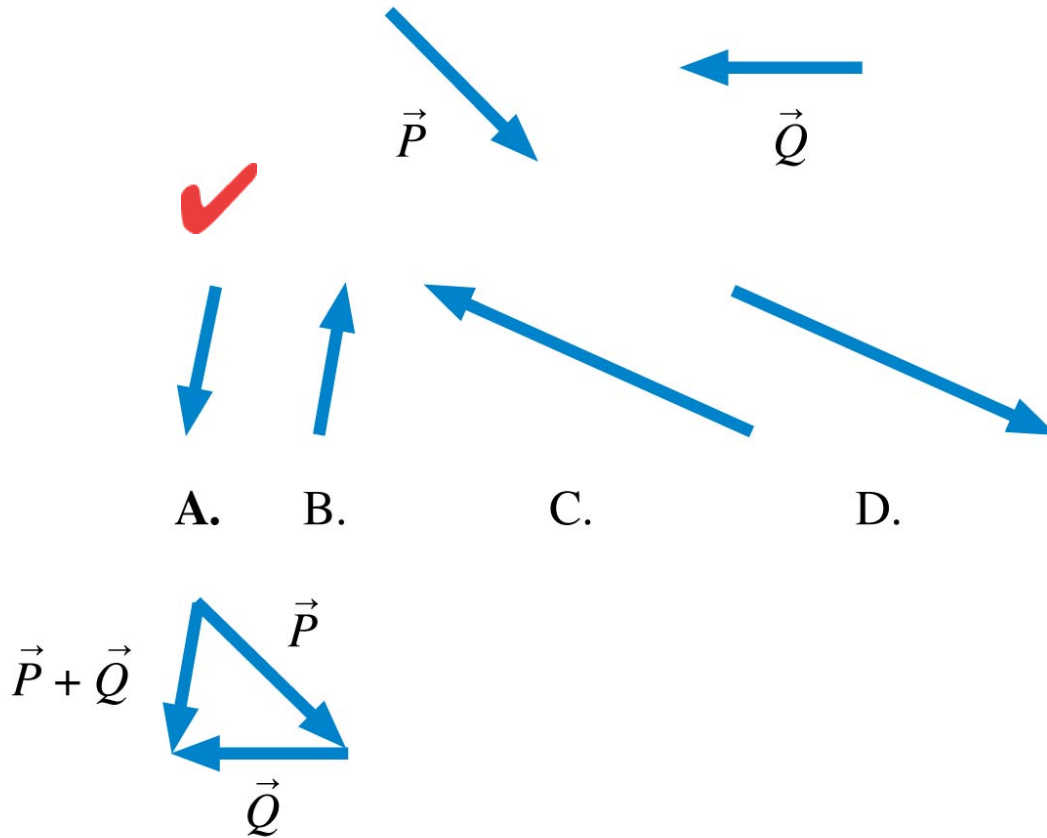
Given vectors  $\vec{P}$  and  $\vec{Q}$ , what is  $\vec{P} + \vec{Q}$ ?





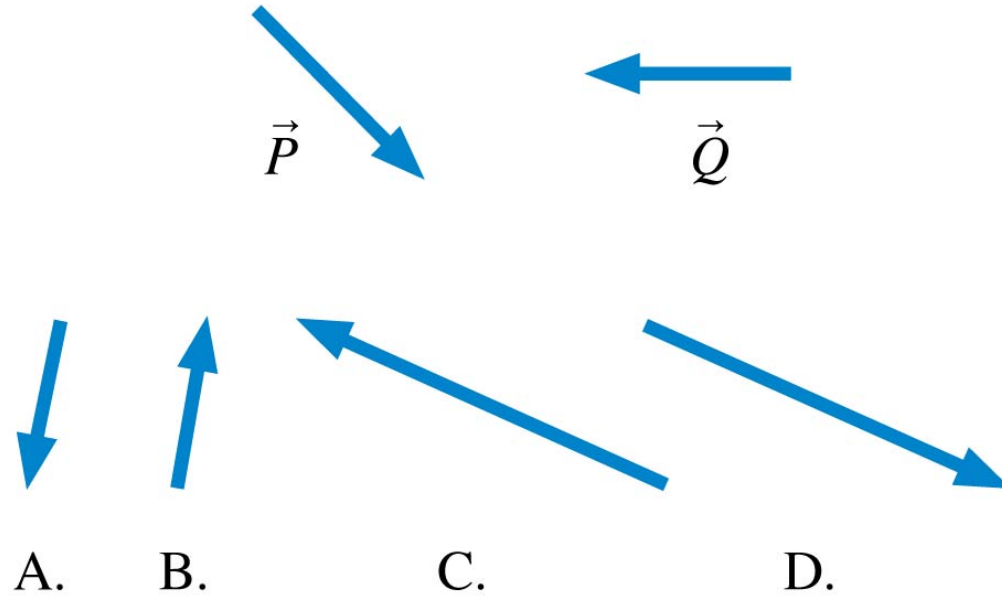
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Given vectors  $\vec{P}$  and  $\vec{Q}$ , what is  $\vec{P} + \vec{Q}$ ?



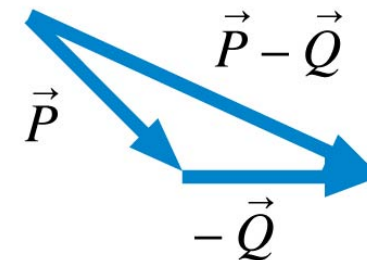
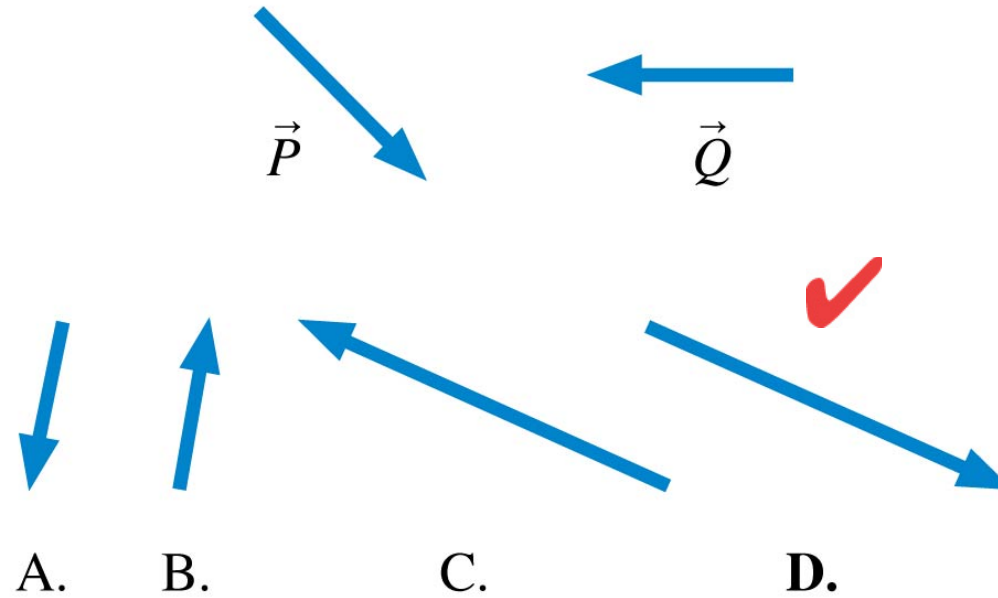
# Vector Subtraction

Given vectors  $\vec{P}$  and  $\vec{Q}$ , what is  $\vec{P} - \vec{Q}$ ?



# Vector Subtraction

Given vectors  $\vec{P}$  and  $\vec{Q}$ , what is  $\vec{P} - \vec{Q}$ ?



# Average Speed versus Average Velocity: Different!! (Sec 1.4)



The victory goes to the runner with the highest average speed.

To quantify an object's fastness or slowness, we define a ratio:

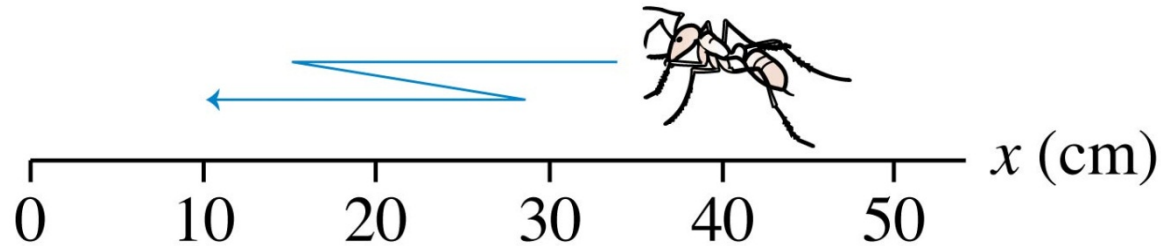
$$\text{average speed} = \frac{\text{distance traveled}}{\text{time interval spent traveling}} = \frac{d}{\Delta t}$$

- Average speed does not include information about *direction* of motion.
- The **average velocity** of an object during a time interval  $t$ , in which the object undergoes a displacement  $\vec{r}$ , is the vector:

$$\vec{v}_{\text{avg}} = \frac{\Delta \vec{r}}{\Delta t}$$

# Average speed vs Average Velocity, Distance vs Displacement

An ant zig-zags back and forth on a picnic table as shown.

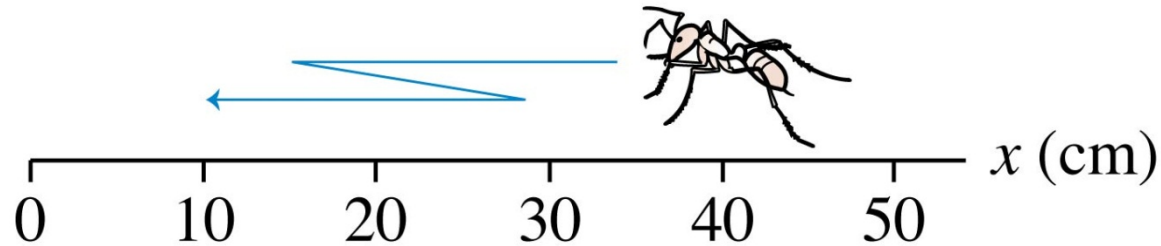


The ant's **distance traveled** and **displacement** are

- A. 50 cm and 50 cm.
- B. 30 cm and 50 cm.
- C. 50 cm and 30 cm.
- D. 50 cm and  $-50$  cm.
- E. 50 cm and  $-30$  cm.

# Average speed vs Average Velocity, Distance vs Displacement

An ant zig-zags back and forth on a picnic table as shown.



The ant's **distance traveled** and **displacement** are

- A. 50 cm and 50 cm.
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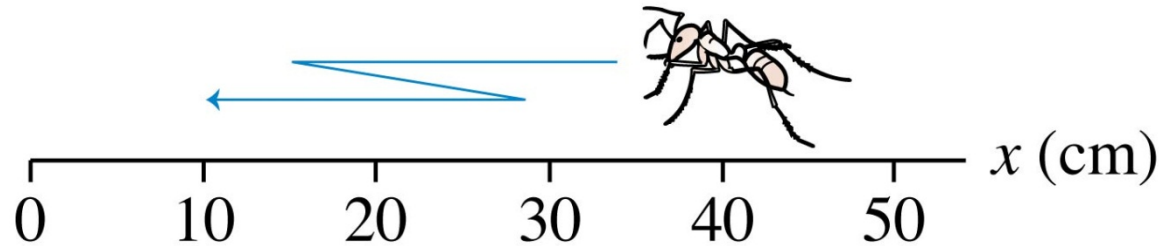
Suppose  $\Delta t = 2$  sec

Av. speed = \_\_\_\_\_

Av. velocity = \_\_\_\_\_

# Average speed vs Average Velocity, Distance vs Displacement

An ant zig-zags back and forth on a picnic table as shown.



The ant's **distance traveled** and **displacement** are

- A. 50 cm and 50 cm.
- B. 30 cm and 50 cm.
- C. 50 cm and 30 cm.
- D. 50 cm and  $-50$  cm.
- E. 50 cm and  $-30$  cm.

Suppose  $\Delta t = 2$  sec

Av. speed = \_\_\_\_\_

Av. velocity = \_\_\_\_\_

Not just direction, even magnitudes are different!

Later, we will learn about the **instantaneous** speed and velocity...

In physics, what is the difference between “speed” and “velocity”?

- A. Velocity is represented by an exact number, while speed is only an approximate number.
- B. Speed can be positive or negative, while velocity is always positive.
- C. Speed is a scalar, which is the magnitude of the velocity, which is a vector.
- D. Velocity is a scalar and speed is a vector.
- E. Speed and velocity mean the same thing.



## Instantaneous Speed vs Instantaneous Velocity (Sec. 2.2)

In physics, what is the difference between “speed” and “velocity”?

- A. Velocity is represented by an exact number, while speed is only an approximate number.
- B. Speed can be positive or negative, while velocity is always positive.
- C. Speed is a scalar, which is the magnitude of the velocity, which is a vector.
- D. Velocity is a scalar and speed is a vector.
- E. Speed and velocity mean the same thing.

# Maximum Speeds (Sec 1.4)

[Source: Natural History Magazine, March 1974]

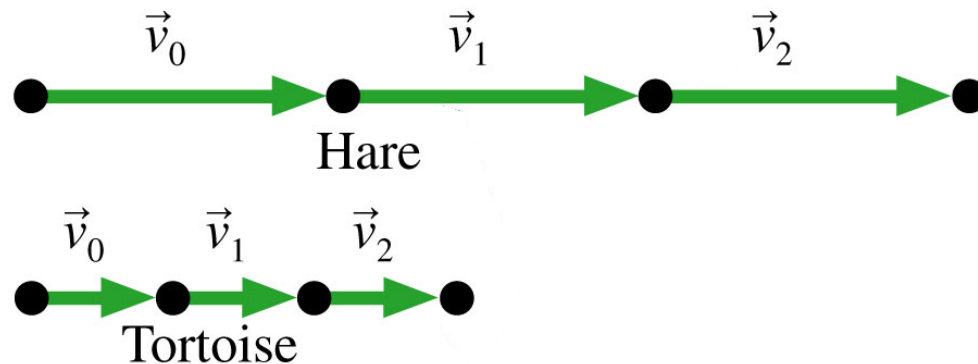
	mph	m/s
Peregrine Falcon	200+	90+
Cheetah	70	31*
Horse	50	22
Domestic Cat	30	13
Grizzly Bear	30	13
Human	28	12**
Giant Tortoise	0.2	0.09

\* measured over 100 yards

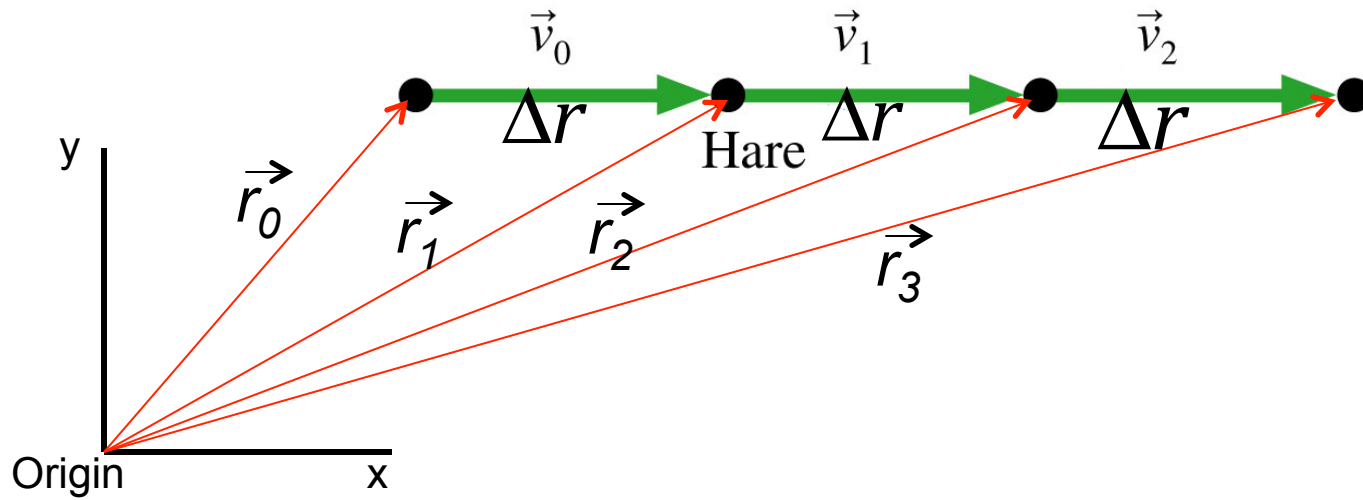
\*\* measured over 15 yard segment of a 100 yard run!  
Usain did 10.3 m/s at the World Championships.  
You are not Usain.

# Motion Diagrams with Velocity Vectors – Sec 1.4

- The velocity vector is in the same direction as the displacement  $\vec{r}$ .
- Below is a motion diagram for a tortoise racing a hare.
- The arrows are average velocity vectors.
- The length of each arrow represents the average speed.



# Motion Diagrams with Velocity Vectors – Sec 1.4



**Velocity in same direction as Displacement!**

From now on, while drawing a motion diagram replace the displacement vectors with velocity vectors.

# Acceleration: final ingredient for Motion Diagrams (Sec 1.5)

- Acceleration describes a *change* in velocity.
- Consider an object whose velocity changes from  $\vec{v}_1$  to  $\vec{v}_2$  during the time interval  $\Delta t$ .
- The quantity  $\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$  is the change in velocity.
- The *rate of change of velocity* is called the **average acceleration**:

$$a_{\text{avg}} = \frac{\Delta\vec{v}}{\Delta t}$$



The Audi TT accelerates from 0 to 60 mph in 6 s.

# Maximum accelerations – Sec 1.5

- Free fall downward  $9.8 \text{ m/s}^2 = g$
- Space shuttle lift-off  $3g$
- Pollen from dogwood flower\*  $2,400g!!$
- Exploding spores from sphagnum moss\*  $10,000g!!$

\*Fastest Accelerating Living Things: We tend to think of plants as stationary, yet some move with spectacular speed as they propel their reproductive particles - seeds and spores and pollen - as far as they can.

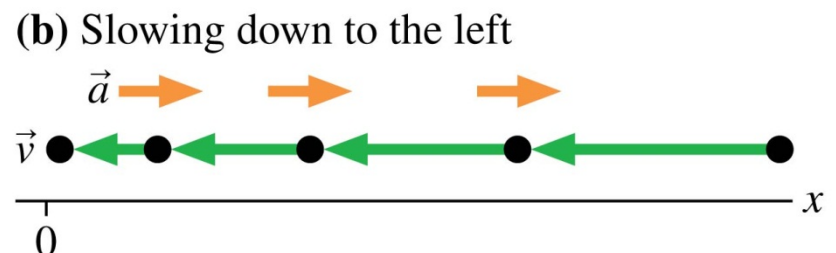
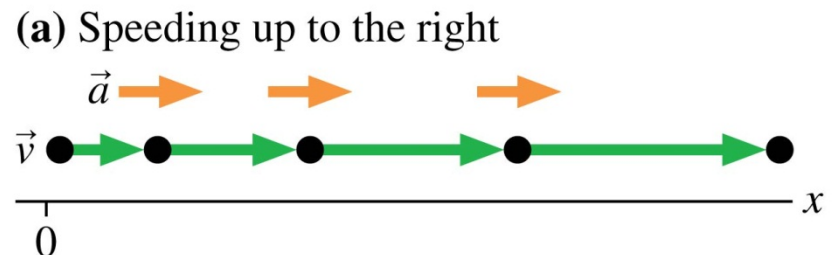
<http://www.newscientist.com/article/mg20827920.200-botanical-ballistics-natures-fastest-plants.html>

<https://www.youtube.com/watch?v=aFR17bX0noI>

# Speeding Up or Slowing Down? (Sec 1.6)

- When an object is speeding up, the acceleration and velocity vectors point in the *same direction*.
- When an object is slowing down, the acceleration and velocity vectors point in *opposite directions*.
- One object is speeding up, other is slowing down, but they both have acceleration vectors toward the right.

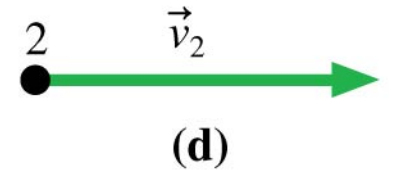
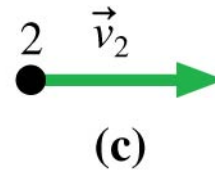
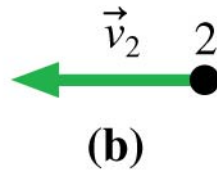
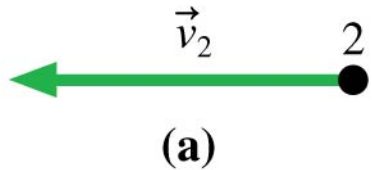
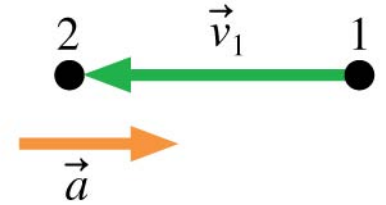
**NOTE!** A complete motion diagram shows both velocity and acceleration vectors.



# Stop to Think 1.4 in book

A particle has velocity  $\vec{v}_1$  as it accelerates from 1 to 2.

What is its velocity vector  $\vec{v}_2$  as the particle leaves point 2?



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# Whiteboard Problem 1.2

One table will be collected for grading!

Draw a complete motion diagram for a ball tossed straight up in the air. The ball reaches a highest point before falling back down to its starting position. Be sure to indicate the velocity and acceleration vectors at the highest point!

(For clarity, you may draw the upward and downward trajectories separately)

# Whiteboard Problem 1.3

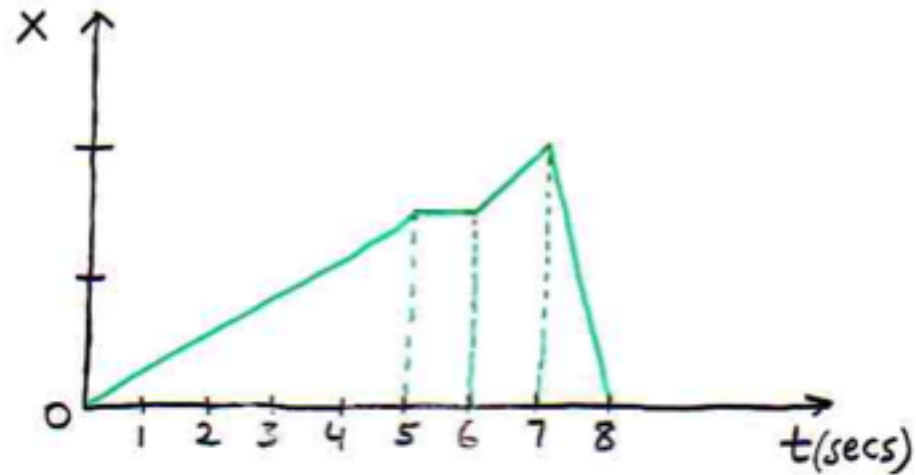
One table will be collected for grading!

Your roommate drops a tennis ball from a third-story balcony. It hits the sidewalk and bounces as high as the second story. Draw a complete motion diagram of the tennis ball from the time it is released until it reaches the maximum height on its bounce. Be sure to determine and show the acceleration at the lowest point!

## Position-Time Graphs (Sec 1.6)

# What is a "Position vs Time graph"? (Sec 1.6)

- The Walking Student

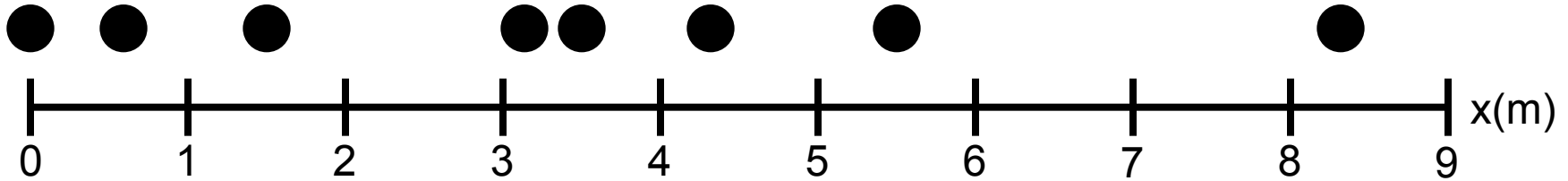


# Whiteboard Problem 1.4 (position vs time graphs – Sec 1.6)

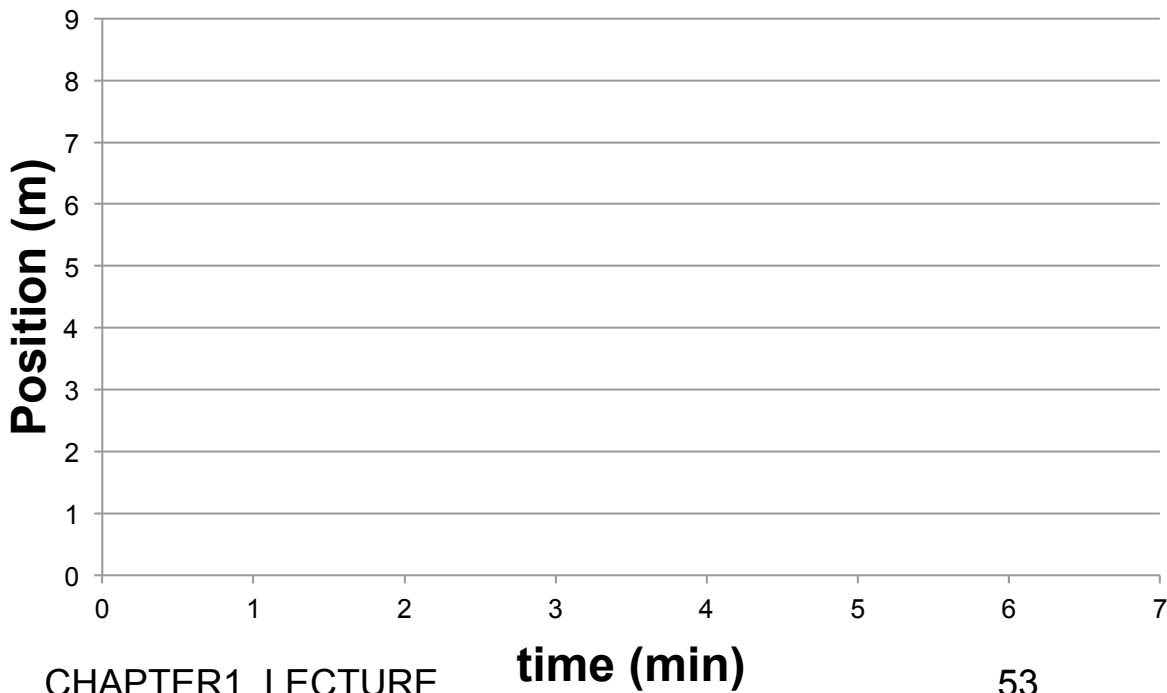
Using the particle model draw a position versus time graph for the following situation:

The line graph below represents the 1D path of a tortoise transporting a child. Each dot represents the tortoise's position at each minute.

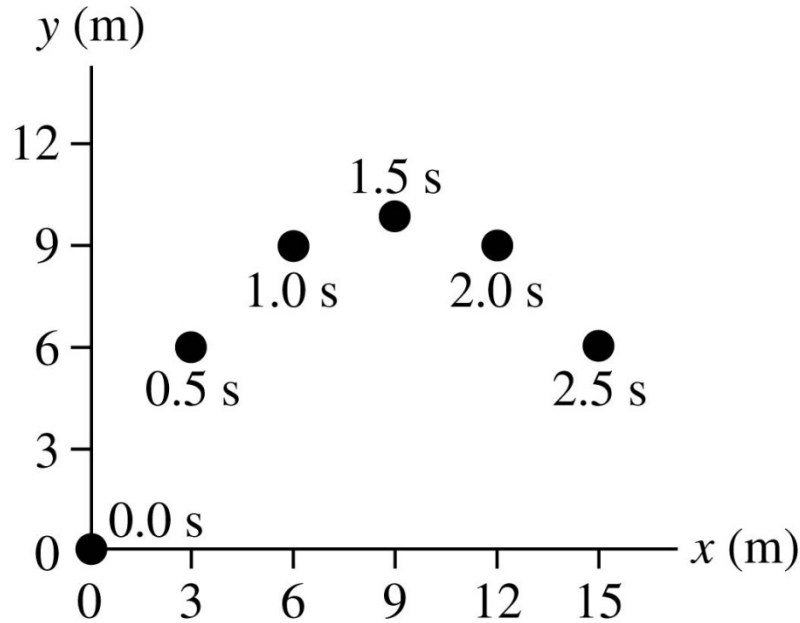
$t = 0$  min



One table will be collected for grading!



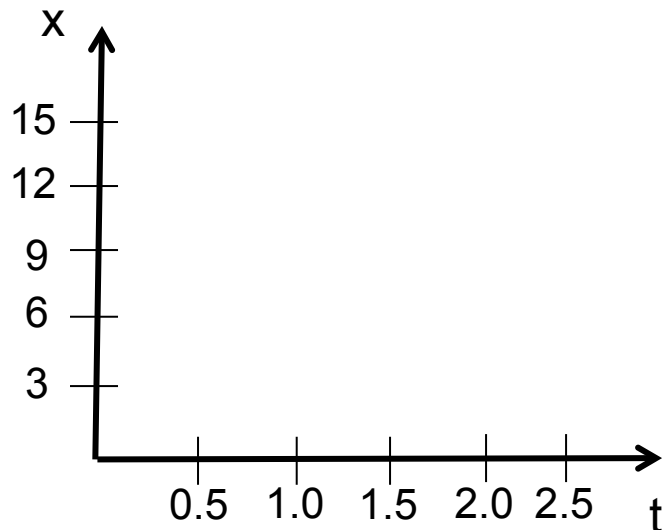
# Whiteboard Problem 1.5: Position vs. Time Graphs (Sec 1.6)



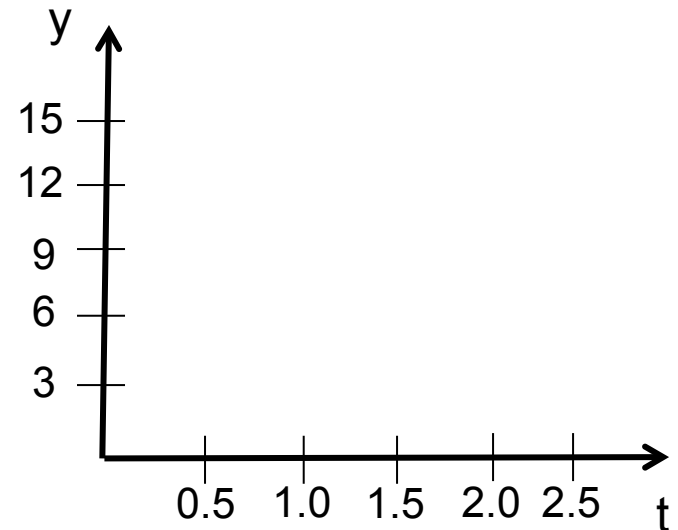
Shown is the motion diagram of a basketball, with 0.5 s intervals between frames.

One table will be collected for grading!

x-motion vs. t



y-motion vs. t



# Significant Figures (Sec 1.8)

- More precise measurement gives more significant figures.
- For example, if you report a length as 6.2 m, you imply that the actual value is between 6.15 m and 6.25 m and has been rounded to 6.2.
- The number 6.2 has *two* significant figures.
- Calculations follow the “weakest link” rule: The input value with the smallest number of significant figures determines the number of significant figures to use in reporting the output value.

# Significant Figures (Sec 1.8)

Rules:

- When using the following mathematical operators :

Operators	$\div \times \sqrt{\quad}$	$+ -$
# of significant figures	Lowest # of significant figures	Smallest # of decimal places
Example	$4.3/1.456 = 3.0$	$1.2 + 5.96 = 7.2$



# Significant figures (Sec 1.8)

Determining significant figures.

Leading zeros locate the decimal point.  
They are not significant.

$$0.00620 = 6.20 \times 10^{-3}$$

A trailing zero after the decimal place is reliably known. It is significant.

The number of significant figures is the number of digits when written in scientific notation.

- The number of significant figures  $\neq$  the number of decimal places.
- In whole numbers, trailing zeros are not significant. 320 is  $3.2 \times 10^2$  and has 2 significant figures, not 3.
- Changing units shifts the decimal point but does not change the number of significant figures.

# Stop to Think 1.5

Rank in order, from the most to the least, the number of significant figures in the following numbers. For example, if b has more than c, c has the same number as a, and a has more than d, you would give your answer as  $b > c = a > d$ .

a. 82

b. 0.0052

c. 0.430

d.  $4.321 \times 10^{-10}$

A.  $d > c > b = a$

B.  $a = b = d > c$

C.  $b = d > c > a$

D.  $d > c > a > b$

E.  $a = d > c > b$

# Whiteboard Problem 1.6 (Sec 1.8)

One table will be collected for grading!

Compute the following numbers using the significant figures rules:

A)  $33.3 * 25.40 =$

B)  $33.34 - 25.4 =$

C)  $\sqrt{33.3} =$

D)  $333.3/25.4 =$

Operators	$\div \times \sqrt{\quad}$	$+ -$
# of significant figures	Lowest # of significant figures	Smallest # of decimal places
Example	$4.3/1.456 = 3.0$	$1.2 + 5.96 = 7.2$

# Tactics: Using Significant Figures

## TACTICS BOX 1.6 Using significant figures



- 1 When multiplying or dividing several numbers, or taking roots, the number of significant figures in the answer should match the number of significant figures of the *least* precisely known number used in the calculation.
- 2 When adding or subtracting several numbers, the number of decimal places in the answer should match the *smallest* number of decimal places of any number used in the calculation.
- 3 It is acceptable to keep one or two extra digits during intermediate steps of a calculation, as long as the final answer is reported with the proper number of significant figures. The goal is to minimize round-off errors in the calculation. But only one or two extra digits, not the seven or eight shown in your calculator display.

Exercises 38–39



# EXAMPLE 1.10 Using significant figures

## EXAMPLE 1.10 Using significant figures

An object consists of two pieces. The mass of one piece has been measured to be 6.47 kg. The volume of the second piece, which is made of aluminum, has been measured to be  $4.44 \times 10^{-4} \text{ m}^3$ . A handbook lists the density of aluminum as  $2.7 \times 10^3 \text{ kg/m}^3$ . What is the total mass of the object?

**SOLVE** First, calculate the mass of the second piece:

$$\begin{aligned} m &= (4.44 \times 10^{-4} \text{ m}^3)(2.7 \times 10^3 \text{ kg/m}^3) \\ &= 1.199 \text{ kg} = 1.2 \text{ kg} \end{aligned}$$

The number of significant figures of a product must match that of the *least* precisely known number, which is the two-significant-figure density of aluminum. Now add the two masses:

$$\begin{array}{r} 6.47 \text{ kg} \\ + 1.2 \text{ kg} \\ \hline 7.7 \text{ kg} \end{array}$$

The sum is 7.67 kg, but the hundredths place is not reliable because the second mass has no reliable information about this digit. Thus we must round to the one decimal place of the 1.2 kg. The best we can say, with reliability, is that the total mass is 7.7 kg.

# Units (Sec 1.8)

- Standard of units
  - Important for comparison
- Le Système Internationale d'Unités (SI units)
  - Time: second (s)
  - Length: meter (m)
  - Mass: kilogram (kg)
- Author is fond of giving non-standard quantities in problems, particularly prefixes (e.g.)
  - See front flap of text  $\text{cm} \Leftrightarrow 10^{-2} \text{ m}$
  - $\text{nm} \Leftrightarrow 10^{-9} \text{ m}$
- If the conversion is not obvious, write it out

Useful Prefixes:  
micro:  $10^{-6}$   
kilo:  $10^3$   
milli-  $10^{-3}$   
centi-  $10^{-2}$

$$\text{Atmospheric pressure} = 14.7 \frac{\cancel{\text{lb}}}{\cancel{\text{in}^2}} \left( \frac{4.448 \text{ N}}{1 \cancel{\text{lb}}} \right) \left( \frac{39.37 \cancel{\text{in}}}{1 \text{ m}} \right)^2 = 1.013 \times 10^5 \frac{\text{N}}{\text{m}^2}$$

# Whiteboard Problem 1.7 (Sec 1.8)

One table will be collected  
for grading!

Convert the following to SI units:

A)  $8 \text{ in} =$

B)  $66 \text{ ft/s} =$

C)  $60 \text{ mph} =$

D)  $14 \text{ in}^2 =$

# Assessment (Sec 1.8)

- When problem solving, it is important to decide whether or not your final answer “makes sense.”
- For example, if you are working a problem about automobile speeds and reach an answer of 35 m/s, is this a realistic speed?
- The table shows some approximate conversion factors that can be used to assess answers.
- Using  $1 \text{ m/s} \approx 2 \text{ mph}$ , you find that 35 m/s is roughly 20 mph, a reasonable speed for a car.
- If you reached an answer of 350 m/s, this would correspond to an unreasonable 700 mph, indicating that perhaps you made a calculation error.

---

$$1 \text{ cm} \approx \frac{1}{2} \text{ in}$$

$$10 \text{ cm} \approx 4 \text{ in}$$

$$1 \text{ m} \approx 1 \text{ yard}$$

$$1 \text{ m} \approx 3 \text{ feet}$$

$$1 \text{ km} \approx 0.6 \text{ mile}$$

$$1 \text{ m/s} \approx 2 \text{ mph}$$

---



# Order of Magnitude (Sec 1.8)

General training as a scientist – estimation is very powerful

1 order of magnitude is  $10^1$

Distance:

My arm is ~1m long  
Width of the classroom is ~10m

Mass:

Textbook ~ 1 kg  
Apple ~ 0.1 kg

Velocity:

Car on highway ~30 m/s  
Human walking ~ 1 m/s