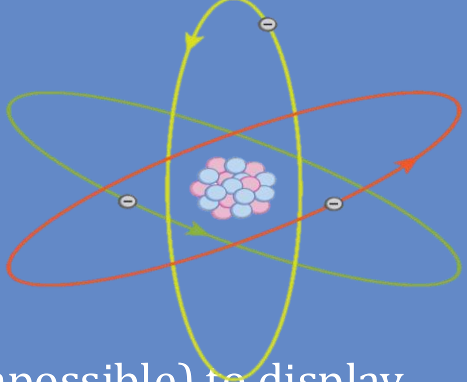
Applied Physics

Engr Ghulam Raza

Introduction

- Physics is the study of the rules (usually stated mathematically) by which the physical world operates.
- These rules describe "how" things happen. Laws of Nature
- These rules don't say "why" things happen. Physicists are most interested in being able to predict what will happen. Many physicists think that because they can say how things happen, they have answered the why.
- Why does gravity pull things together? Newton described the effects over 100 years before anyone asked why gravity happened. Einstein suggested that mass bends space-time, but that is just a model.
- Physics deals with "how". "Why" is philosophy.

Introduction



- Model, Theory, Law
  - Model
    - A representation of something that is often too difficult (or impossible) to display directly.
    - It is only accurate under limited situations.
  - Theory
    - an explanation for patterns in nature that is supported by scientific evidence and verified multiple times by various groups of researchers.
  - Law
    - Uses **concise language** to describe a **generalized pattern** in nature that is supported by scientific evidence and repeated experiments.
    - Often, a law can be expressed in the form of a single mathematical equation.

01-01 Introduction

- Scientific Method

- Can be used to solve many types of problems, not just science

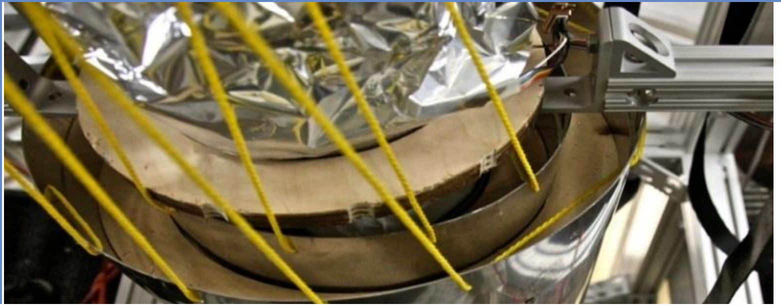
    - Usually begins with observation and question about the phenomenon to be studied
    - Next preliminary research is done and hypothesis is developed
    - Then experiments are performed to test the hypothesis
    - Finally the tests are analyzed and a conclusion is drawn

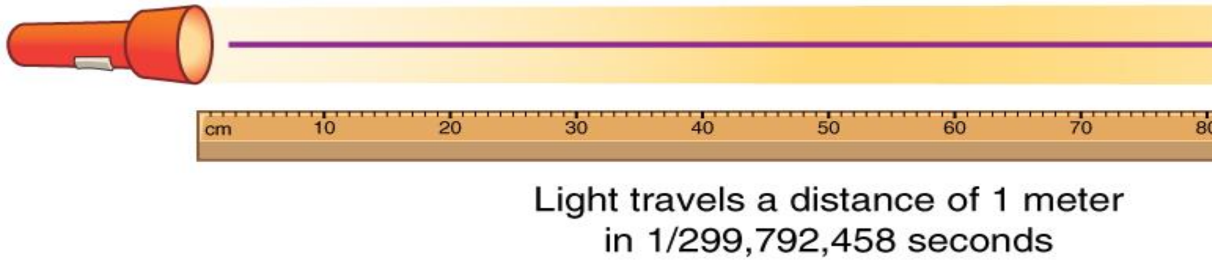
01-01 Units

- Units
  - USA uses English system as was used by the British Empire
  - Rest of world uses SI system (International System or Metric System)

- Fundamental Units - Can only be defined by procedure to measure them
  - Time = second (s)
  - Distance = meter (m)
  - Mass = kilogram (kg)
  - Electric Current = ampere (A)

- All other units are derived from these 4





01-01 Prefixes

- Metric Prefixes
  - SI system based on powers of tens

Prefix	Symbol	Value	Prefix	Symbol	Value
exa	E	10^{18}	deci	d	10^{-1}
peta	P	10^{15}	centi	c	10^{-2}
tera	T	10^{12}	milli	m	10^{-3}
giga	G	10^{9}	micro	µ	10^{-6}
mega	M	10^{6}	nano	n	10^{-9}
kilo	k	10^{3}	pico	p	10^{-12}
hecto	h	10^{2}	femto	f	10^{-15}
decka	da	10^{1}	atto	a	10^{-18}

01-01 Units

- Unit conversions
- Multiply by conversion factors so that the unwanted unit cancels out

- Convert 20 Gm to m
  - $\frac{20\ \cancel{Gm}}{} \cdot \left(\frac{1\times10^9\ m}{1\ \cancel{Gm}}\right)$
  - $2 \times 10^{10}\ m$

01-01 Units

- Convert 5 cg to kg
  - $\frac{5\ \cancel{cg}}{} \cdot \left(\frac{1\times10^{-2}\ \cancel{g}}{1\ \cancel{cg}}\right) \cdot \left(\frac{1\ kg}{1\times10^{3}\ \cancel{g}}\right)$
  - $\frac{5\times10^{-2}\ kg}{1\times10^{3}}$
  - $5 \times 10^{-5}\ kg$

01-01 Units

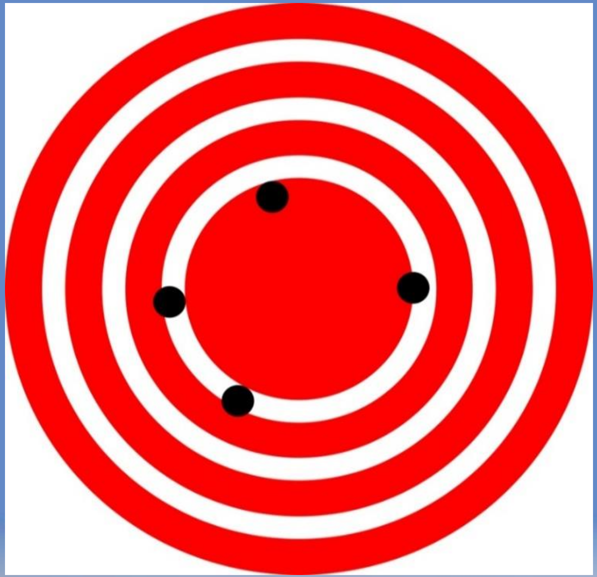
- Convert 25 km/h to m/s
  - $\frac{25\ \cancel{km}}{1\ \cancel{h}} \cdot \left(\frac{1\times10^3\ m}{1\ \cancel{km}}\right) \cdot \left(\frac{1\ \cancel{h}}{60\ \cancel{min}}\right) \cdot \left(\frac{1\ \cancel{min}}{60\ s}\right)$
  - $\frac{2.5\times10^4\ m}{3600\ s}$
  - $6.94\ m/s$

01- Accuracy and Precision

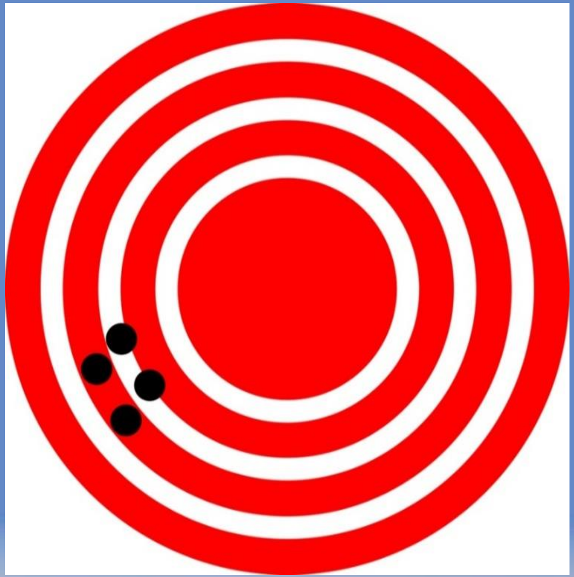
- Accuracy is how close a measurement is to the correct value for that measurement.
- Precision of a measurement system is refers to how close the agreement is between repeated measurements.

01-01 Accuracy and Precision

Accurate but not precise



Precise but not accurate



01-02 Displacement and Vectors

In this lesson you will…

- Define position, displacement, distance, and distance traveled.
- Explain the relationship between position and displacement.
- Distinguish between displacement and distance traveled.
- Calculate displacement and distance given initial position, final position, and the path between the two.
- Define and distinguish between scalar and vector quantities.
- Assign a coordinate system for a scenario involving one-dimensional motion.

01-02 Displacement and Vectors

- **Objectives**
  - Use a ruler to measure in cm.
- **Materials**
  - Metric Ruler
  - 3x5 Card
- **Background**
  - The last digit on a measurement is always an estimate. When measuring using a ruler or meter stick, you can estimate between the smallest marks.

1. What unit are the smallest marks on the metric side of the ruler/meter stick?
2. If you are measuring in cm, how many decimal places can you measure including the estimate between the smallest marks?
3. If the smallest marks on the ruler were cm, then what unit would you be estimating?
4. Measure the shortest side of a 3x5 card.
5. Measure the longest side of a 3x5 card.
6. Measure a diagonal of a 3x5 card.
7. Use the Pythagorean Theorem with the short and long sides to calculate the diagonal to the correct number of significant figures.
8. Calculate the percent error using

$$\%error = \frac{experimental - theoretical}{theoretical} \cdot 100\%$$

The percent error should be less than 5%.

01-02 Displacement and Vectors

- Kinematics studies motion without thinking about its cause
- Position
  - The location where something is relative to a coordinate system called a frame of reference
- Position is relative to a reference frame
  - Earth is the most common reference frame, but it could be something else
- Most common coordinate system is *x*-*y* coordinate system

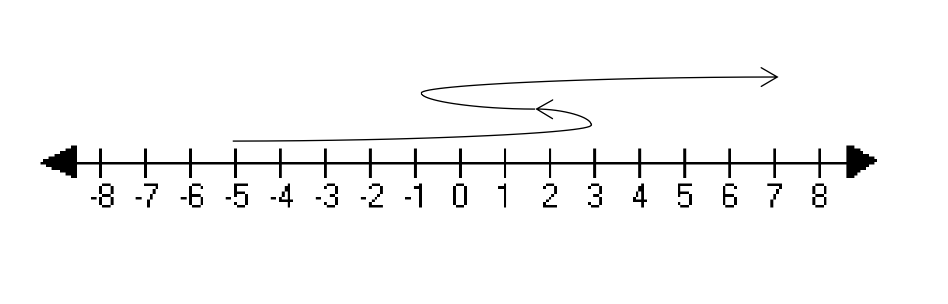
01-02 Displacement and Vectors

- Displacement
  - Change in position relative to a reference frame

  - $\Delta x = x_f - x_0$
  - Vector
    - Has direction and magnitude
  - Path does not matter
  - Only depends on final and initial position

01-02 Displacement and Vectors

- What is the displacement of the path in the diagram?

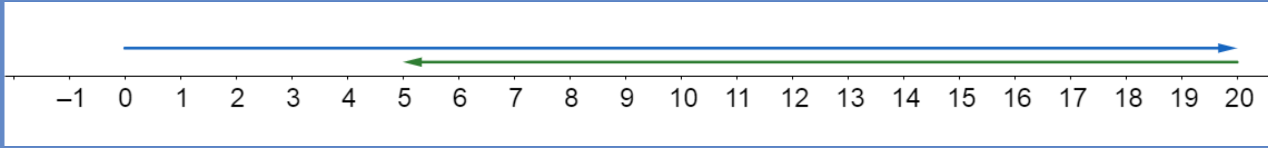


01-02 Displacement and Vectors

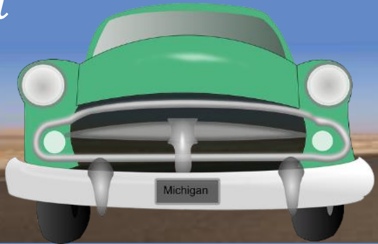
- Distance
  - Total length of the path taken
  - Scalar
    - Only has magnitude

01-02 Displacement and Vectors

- You drive 20 km east, then turn around and drive 15 km west. What is your displacement?
  - $\Delta x = x - x_0$
  - $\Delta x = 5\ km - 0\ km$
  - $5\ km$
  - 5 km east of your starting point



- What is your distance traveled?
  - $20\ km + 15\ km$
  - $35\ km$



01-03 Velocity and Graphs

In this lesson you will…

- Explain the relationships between instantaneous velocity, average velocity, instantaneous speed, average speed, displacement, and time.
- Calculate velocity and speed given initial position, initial time, final position, and final time.
- Derive a graph of velocity vs. time given a graph of position vs. time.
- Interpret a graph of velocity vs. time.
- Describe a straight-line graph in terms of its slope and *y*-intercept.
- Determine average velocity or instantaneous velocity from a graph of position vs. time.
- Derive a graph of velocity vs. time from a graph of position vs. time.

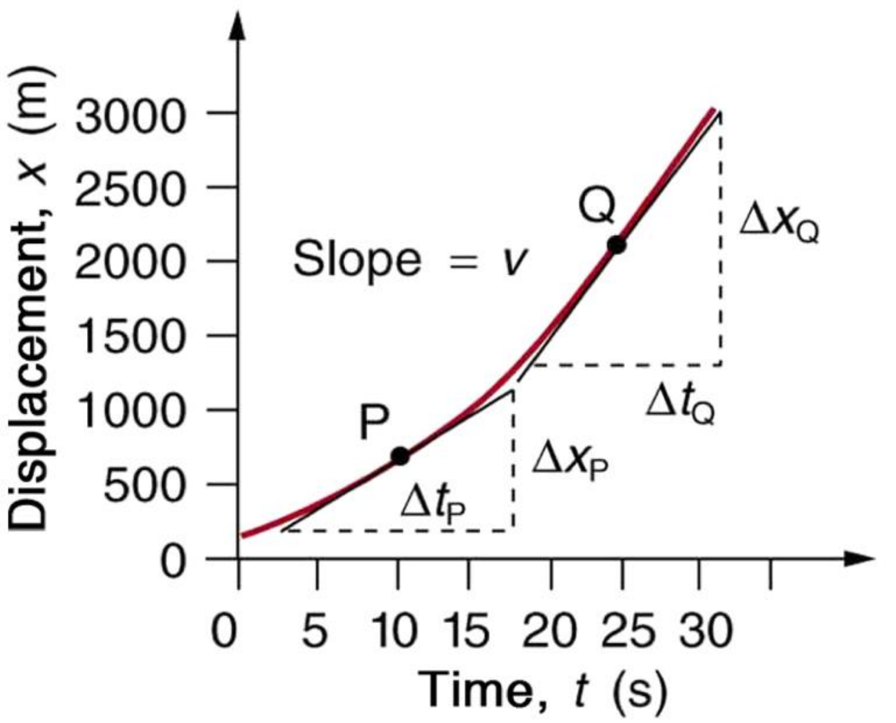
01-03 Velocity and Graphs

- The slope of a position vs time graph is the velocity
- Velocity is rate of change of position

$$\bar{v} = \frac{x - x_0}{t - t_0}$$

$$x = \bar{v}t + x_0$$

- If the graph is not a straight line, then use the slope of a tangent line drawn to that point.

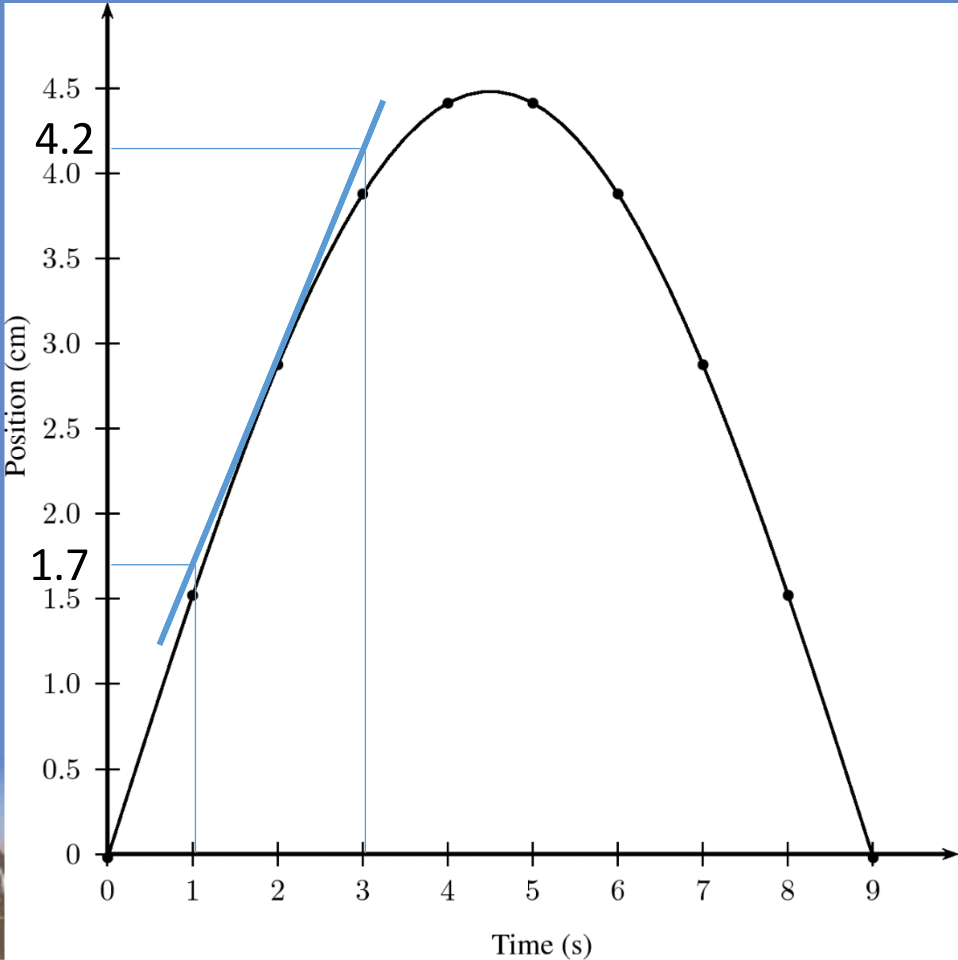


01-03 Velocity and Graphs

- Velocity is a vector (has direction) $v = \frac{displacement}{time}$
- Speed is a scalar (no direction) $v = \frac{distance}{time}$
- Units of both are m/s

01-03 Velocity and Graphs

- The graph at right shows the height of a ball thrown straight up vs time. Find the velocity of the ball at 2 seconds.
- $v = \frac{x - x_0}{t - t_0}$
- $v = \frac{4.2\ cm - 1.7\ cm}{3\ s - 1\ s}$
- $v = \frac{2.5\ cm}{2\ s} = 1.3\,\frac{cm}{s}$



01-03 Velocity and Graphs

- The spine-tailed swift is the fastest bird in powered flight. On one flight a particular bird flies 306 m east, then turns around and flies 406.5 m back west. This flight takes 15 s. What is the bird's average velocity?
  - $\overline{v} = \frac{\Delta x}{\Delta t} = \frac{306\ m - 406.5\ m}{15\ s} = -6.7\ m/s$
  - 6.7 m/s west
- Average speed?
  - $v = \frac{distance}{time}$
  - $v = \frac{(306\ m + 406.5\ m)}{15\ s} = 47.5\ \frac{m}{s}$
- Which of these would we use to say how fast the bird is?
  - Average speed

01-04 Acceleration and Graphs

In this lesson you will…

- Define and distinguish between instantaneous acceleration, average acceleration, and deceleration.
- Calculate acceleration given initial time, initial velocity, final time, and final velocity.
- Determine average or instantaneous acceleration from a graph of velocity vs. time.
- Derive a graph of acceleration vs. time from a graph of velocity vs. time.

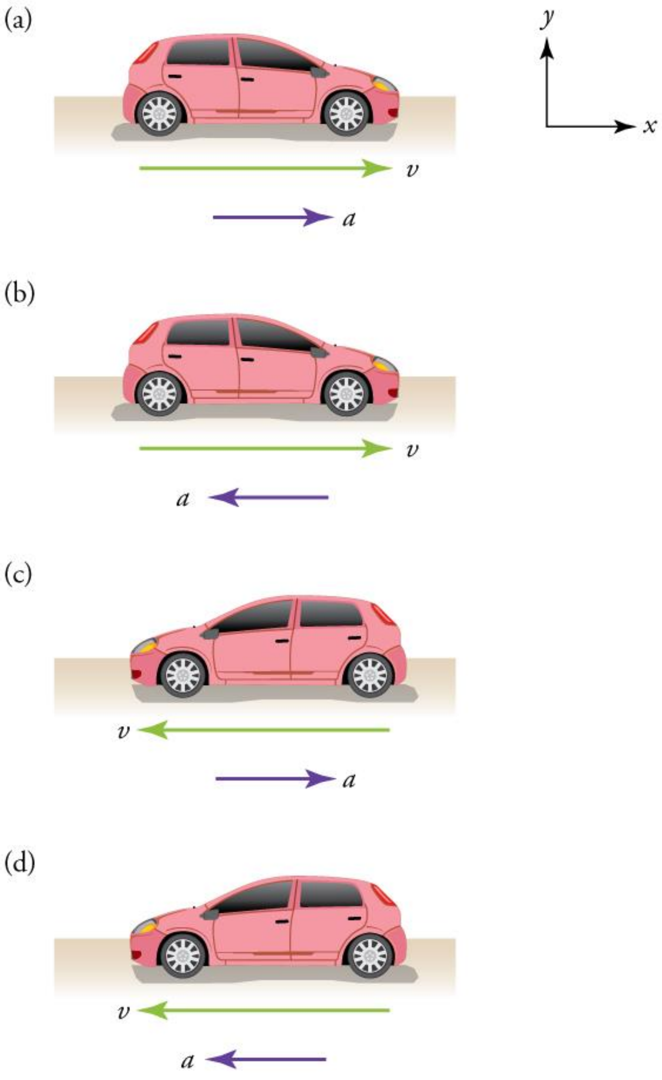
01-04 Acceleration and Graphs

- Acceleration
  - Rate of change of velocity

$$\bar{a} = \frac{\Delta v}{\Delta t} = \frac{v_f - v_0}{t_f - t_0}$$

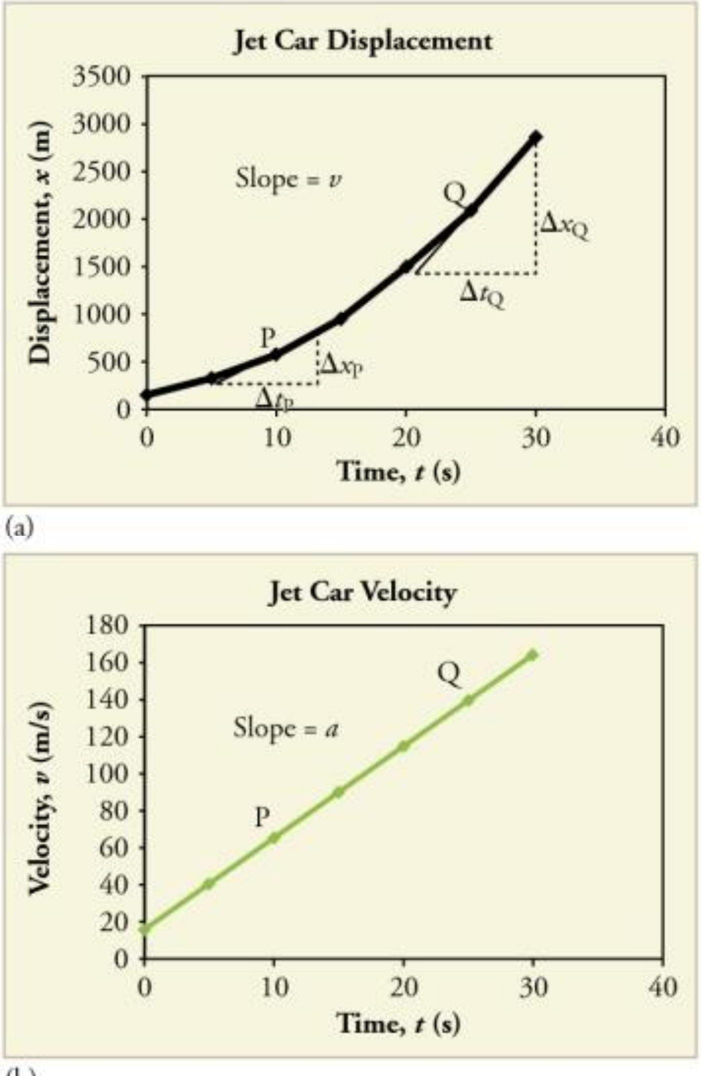
$$v = at + v_0$$

- Vector
- Unit: m/s^2
- If the acceleration is same direction as motion, then the object is increasing speed.
- If the acceleration is opposite direction as motion, then the object is decreasing speed.



01-04 Acceleration and Graphs

- Constant acceleration
  - The graph of position–time is parabolic
    - ($x = \frac{1}{2}at^2 + v_0t + x_0$ is quadratic)
  - The graph of velocity–time is linear
    - ($v = at + v_0$ is linear)



01-04 Acceleration and Graphs

- A dropped object near the earth will accelerate downward at 9.8 m/s^2. (Use -9.8 m/s^2.) If the initial velocity is 1 m/s downward, what will be it's velocity at the end of 3 s? Is it speeding up or slowing down?
- $a = \frac{v_f - v_0}{t_f - t_0}$
- $-9.8\frac{m}{s^2} = \frac{v_f - \left(-1\frac{m}{s}\right)}{3\ s}$
- $-29.4\frac{m}{s} = v_f + 1\frac{m}{s}$
- $-30.4\frac{m}{s} = v_f$
- 30.4 m/s downward

01-05 Equations for One-Dimensional Motion with Constant Acceleration

In this lesson you will…

- Calculate displacement of an object that is not accelerating, given initial position and velocity.
- Calculate final velocity of an accelerating object, given initial velocity, acceleration, and time.
- Calculate displacement and final position of an accelerating object, given initial position, initial velocity, time, and acceleration.
- Apply problem-solving steps and strategies to solve problems of one-dimensional kinematics.
- Apply strategies to determine whether or not the result of a problem is reasonable, and if not, determine the cause.

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- Assume $t_0 = 0$, so $\Delta t = t$ and acceleration is constant
- $\bar{v} = \frac{x - x_0}{t}$
- $x = \bar{v}t + x_0$ and $\bar{v} = \frac{v_0 + v}{2}$
- $\boxed{x = \frac{1}{2}(v_0 + v)t + x_0}$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- $a = \frac{v - v_0}{t}$

- $v - v_0 = at$

- $\boxed{v = at + v_0}$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- $v = at + v_0$
- $v_0 + v = at + 2v_0$
- $\frac{v_0 + v}{2} = \frac{1}{2}at + v_0$
- $\bar{v} = \frac{1}{2}at + v_0$
- $x = \bar{v}t + x_0$
- $x = \left(\frac{1}{2}at + v_0\right)t + x_0$
- $x = \frac{1}{2}at^2 + v_0t + x_0$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- $v = at + v_0$
- $t = \frac{v - v_0}{a}$
- $\bar{v} = \frac{v_0 + v}{2}$
- $x = \bar{v}t + x_0$
- $x = \left(\frac{v_0 + v}{2}\right)\left(\frac{v - v_0}{a}\right) + x_0$
- $x - x_0 = \left(\frac{v^2 - v_0^2}{2a}\right)$
- $2a(x - x_0) = v^2 - v_0^2$
- $v^2 = v_0^2 + 2a(x - x_0)$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

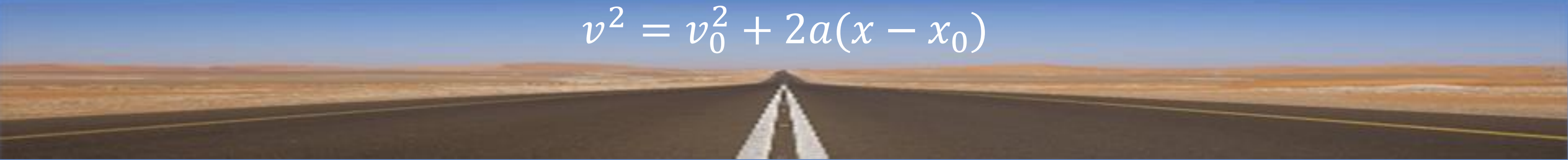
$$x = \bar{v}t + x_0$$

$$\bar{v} = \frac{v_0 + v}{2}$$

$$v = at + v_0$$

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

$$v^2 = v_0^2 + 2a(x - x_0)$$



01-05 Equations for One-Dimensional Motion with Constant Acceleration

- Examine the situation to determine which physical principles are involved.
  - Maybe draw a picture
- Make a list of what is given or can be inferred from the problem.
- Identify exactly what needs to be determined in the problem.
- Find an equation or set of equations that can help you solve the problem.
- Substitute the knowns along with their units into the appropriate equation, and Solve
- Check the answer to see if it is reasonable: Does it make sense?

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- A plane starting from rest accelerates to $40\ m/s$ in $10\ s$. How far did the plane travel during this time?
- $v = 40\ m/s,\ \ t = 10\ s, v_0 = 0, x_0 = 0, x = ?$
- $\overline{v} = \frac{v_0 + v}{2} \rightarrow \overline{v} = \frac{0 + 40\frac{m}{s}}{2} = 20\ m/s$
- $x = \overline{v}t + x_0$
- $x = \left(20\frac{m}{s}\right)(10\ s) + 0$
- $x = 200\ m$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- To avoid an accident, a car decelerates at $0.50\ m/s^2$ for $3.0\ s$ and covers $15\ m$ of road. What was the car's initial velocity?
- $a = -0.5\ m/s^2, t = 3\ s, x = 15\ m, x_0 = 0, v_0 = ?$
- $x = \frac{1}{2}at^2 + v_0 t + x_0$
- $15\ m = \frac{1}{2}\left(-0.5\frac{m}{s^2}\right)(3\ s)^2 + v_0(3\ s) + 0$
- $15\ m = -2.25\ m + v_0(3\ s)$
- $17.25\ m = v_0(3\ s)$
- $v_0 = 5.75\ m/s$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- A cheetah is walking at 1.0 m/s when it sees a zebra 25 m away. What acceleration would be required to reach 20.0 m/s in that distance?
- $v = 20.0\frac{m}{s}, v_0 = 1.0\frac{m}{s}, x = 25\,m, x_0 = 0, a = ?$
- $v^2 = v_0^2 + 2a(x - x_0)$
- $\left(20\frac{m}{s}\right)^2 = \left(1.0\frac{m}{s}\right)^2 + 2a(25\,m - 0)$
- $400\frac{m^2}{s^2} = 1\frac{m^2}{s^2} + (50\,m)a$
- $399\frac{m^2}{s^2} = (50\,m)a$
- $a = 7.98\,m/s^2$

01-05 Equations for One-Dimensional Motion with Constant Acceleration

- The left ventricle of the heart accelerates blood from rest to a velocity of +26 cm/s. (a) If the displacement of the blood during the acceleration is +2.0 cm, determine its acceleration (in cm/s²). (b) How much time does blood take to reach its final velocity?
- $v_0 = 0\frac{cm}{s}, v = 26\frac{cm}{s}, \Delta x = 2\ cm, a = ?$
- $v^2 = v_0^2 + 2a(x - x_0)$
- $a = 169\frac{cm}{s^2}$
- $v_0 = 0\frac{cm}{s}, v = 26\frac{cm}{s}, \Delta x = 2\ cm, t = ?$
- $x = \bar{v}t + x_0; \bar{v} = \frac{v_0+v}{2}$
- $t = 0.15\ s$

01-06 Falling Objects

In this lesson you will…

- Describe the effects of gravity on objects in motion.
- Describe the motion of objects that are in free fall.
- Calculate the position and velocity of objects in free fall.

01-06 Falling Objects

- Free fall is when an object is moving only under the influence of gravity
- In a vacuum all objects fall at same acceleration
- $g = 9.80 \frac{m}{s^2} down$
- Any object thrown up, down, or dropped has this acceleration

01-06 Falling Objects

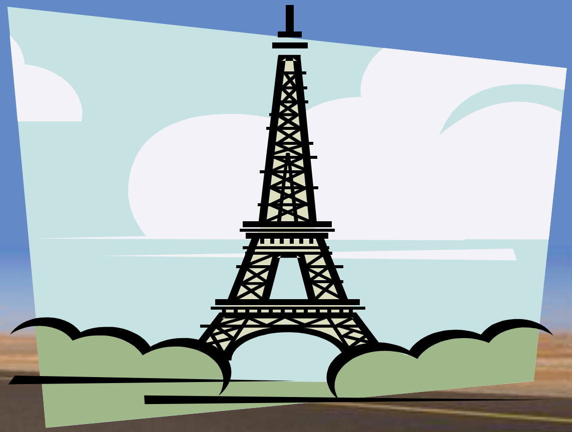
- Do feather falling demo

- Real life
  - Air resistance

- Use the one-dimensional equations of motion

01-06 Falling Objects

- You drop a coin from the top of a hundred story building (1000 m). If you ignore air resistance, how fast will it be falling right before it hits the ground?
- $v_0 = 0, v = ?, a = -9.80\frac{m}{s^2}, x_0 = 1000\ m, x = 0\ m$
- $v^2 = {v_0}^2 + 2a(x - x_0)$
- $v^2 = 0 + 2(-9.80\ m/s^2)(0 - 1000\ m)$
- $v^2 = 19600\ m^2/s^2$
- $v = -140\ m/s$



01-06 Falling Objects

- How long does it take to hit the ground?
- $x = \frac{1}{2}at^2 + v_0t + x_0$
- $0\ m = \frac{1}{2}\left(-9.80\,\frac{m}{s^2}\right)t^2 + 0(t) + 1000\ m$
- $-1000\ m = -4.90\,\frac{m}{s^2}\,t^2$
- $204.1\ s^2 = t^2$
- $14.3\ s = t$

01-06 Falling Objects

- A baseball is hit straight up into the air. If the initial velocity was 20 m/s, how high will the ball go?
- $v_0 = 20\frac{m}{s}, a = -9.80\frac{m}{s^2}, v\,(at\ top) = 0,\ x = ?\,, x_0 = 0$
- $v^2 = {v_0}^2 + 2a(x - x_0)$
- $0 = \left(20\frac{m}{s}\right)^2 + 2\left(-9.80\frac{m}{s^2}\right)(x - 0)$
- $-400\frac{m^2}{s^2} = -19.6\frac{m}{s^2}x$
- $x = 20.4\ m$

01-06 Falling Objects

- How long will it be until the catcher catches the ball at the same height it was hit?
- $v_0 = 20\frac{m}{s}, a = -9.80\frac{m}{s^2}, t = ?,\ x = 0, x_0 = 0$
- $x = \frac{1}{2}at^2 + v_0t + x_0$
- $0\ m = \frac{1}{2}\left(-9.80\frac{m}{s^2}\right)t^2 + \left(20\frac{m}{s}\right)t + 0\ m$
- $0 = t\left(-4.90\frac{m}{s^2}t + 20\frac{m}{s}\right)$
- $t = 0\ s$ or $-4.90\frac{m}{s^2}t + 20\frac{m}{s} = 0$
- $-4.90\frac{m}{s^2}t = -20\frac{m}{s}$
- $t = 4.08\ s$

01-06 Falling Objects

- How fast is it going when catcher catches it?
- $v_0 = 20\frac{m}{s}, a = -9.80\frac{m}{s^2}, t = ?,\ x = 0, x_0 = 0$
- $v^2 = v_0^2 + 2a(x - x_0)$
- $v^2 = \left(20\frac{m}{s}\right)^2 + 2\left(-9.80\frac{m}{s^2}\right)(0\,m\ - 0\,m)$
- $v^2 = \left(20\frac{m}{s}\right)^2$
- $v = \pm 20\,m/s$ so $\quad v = -20\,m/s$

01-07 Two-Dimensional Vectors

In this lesson you will…

• Observe that motion in two dimensions consists of horizontal and vertical components.

• Understand the independence of horizontal and vertical vectors in two-dimensional motion. • Understand the rules of vector addition, subtraction, and multiplication.

• Apply graphical methods of vector addition and subtraction to determine the displacement of moving objects. • Understand the rules of vector addition and subtraction using analytical methods.

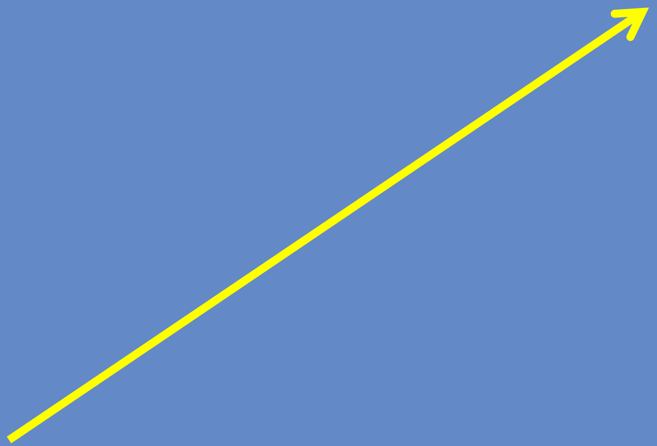
• Apply analytical methods to determine vertical and horizontal component vectors.

• Apply analytical methods to determine the magnitude and direction of a resultant vector.

01-07 Two-Dimensional Vectors

Vectors

- Vectors are measurements with magnitude and direction
  - They are represented by arrows
  - The length of the arrow is the magnitude
  - The direction of the arrow is the direction



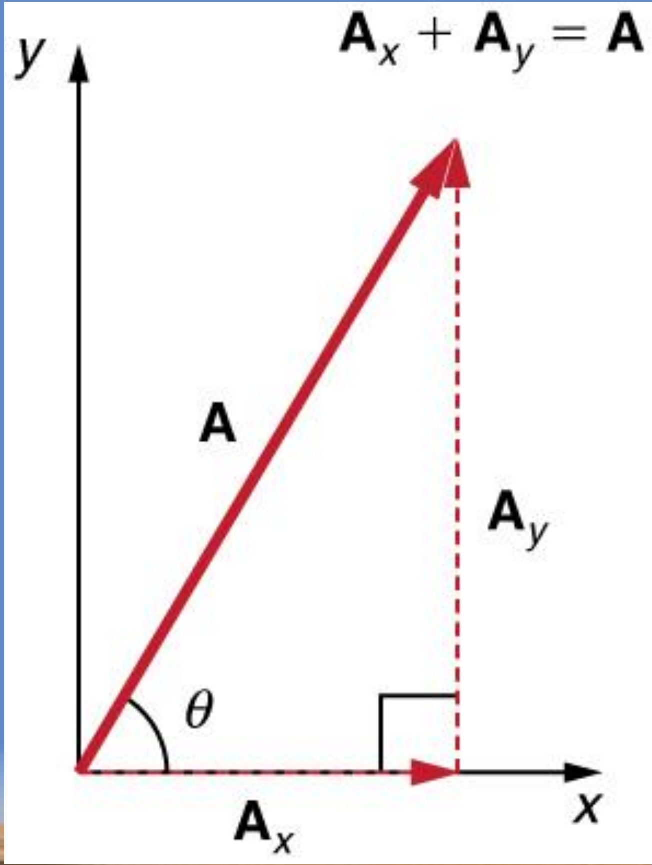
01-07 Two-Dimensional Vectors

- Vectors can be represented in component form
  - Make a right triangle using the vector as the hypotenuse
  - Use sine and cosine to find the horizontal (x) component and the vertical (y) component
  - Assign negative signs to any component going down or left

$$\sin(\theta) = \frac{opposite}{hypotenuse}$$

$$\cos(\theta) = \frac{adjacent}{hypotenuse}$$

$$\tan(\theta) = \frac{opposite}{adjacent}$$



01-07 Two-Dimensional Vectors

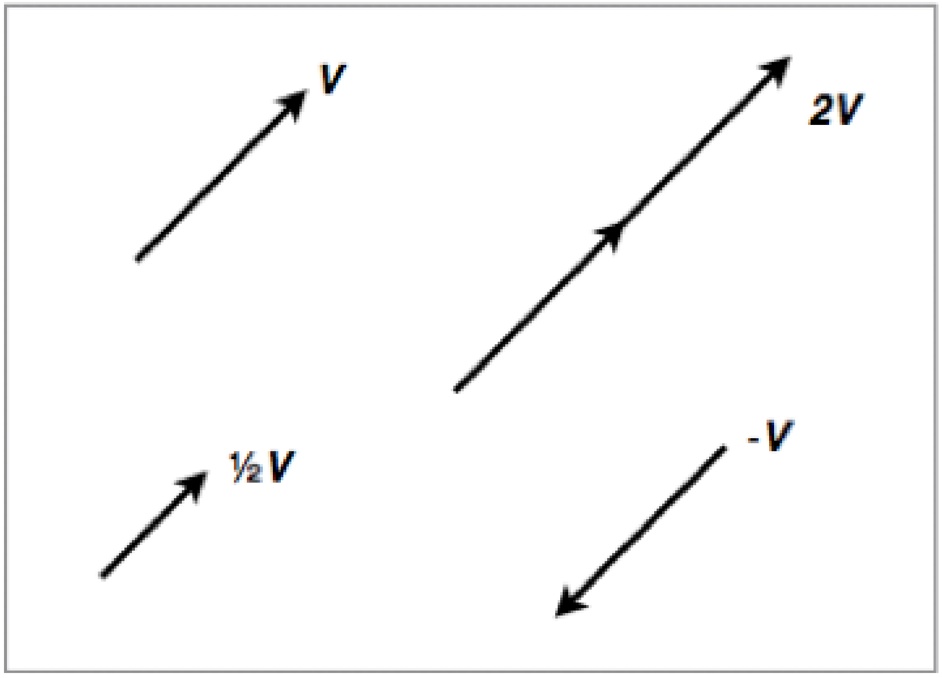
- A football player kicks a ball at 15 m/s at 30° above the ground. Find the horizontal and vertical components of this velocity.

- Horizontal: $v_x = 15\frac{m}{s}\ cos(30°) = 13.0\frac{m}{s}$
- Vertical: $v_y = 15\frac{m}{s}\ sin(30°) = 7.5\frac{m}{s}$

01-07 Two-Dimensional Vectors

Scalar Multiplication

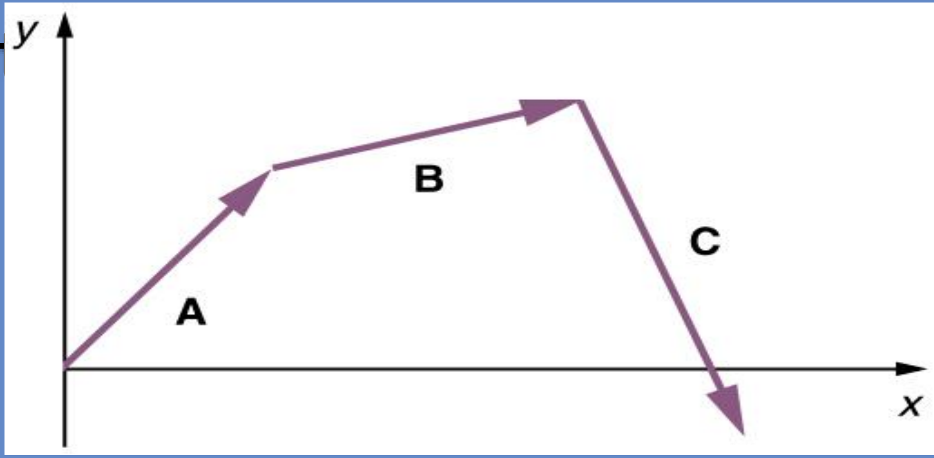
- Multiplying a vector by a single number
- Draw the vector that many times in a line
- Or multiply the components by that number
- A negative vector means multiply by -1, so it goes in the opposite direction

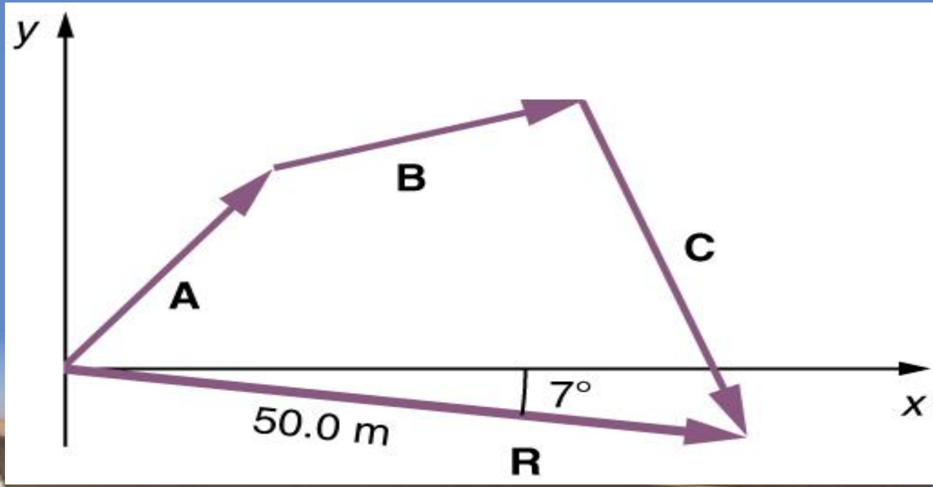


01-07 Two-Dimensional Vect

Vector Addition - Graphical Method

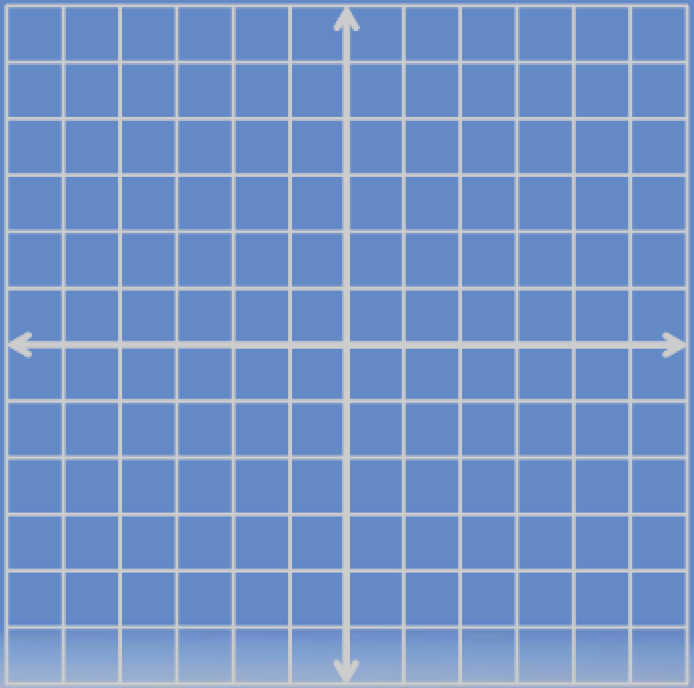
- Draw the first vector.
- Draw the second vector where the first one ends (tip-to-tail).
- Draw the resultant vector from where the first vector begins to where the second vector ends.
- Measure the resultant's length and direction.





01-07 Two-Dimensional Vectors

- Add the following vectors graphically. $\boldsymbol{A} = 2\sqrt{2}$ at 45° N of E, $\boldsymbol{B} = 2\sqrt{2}$ at 45° W of N.



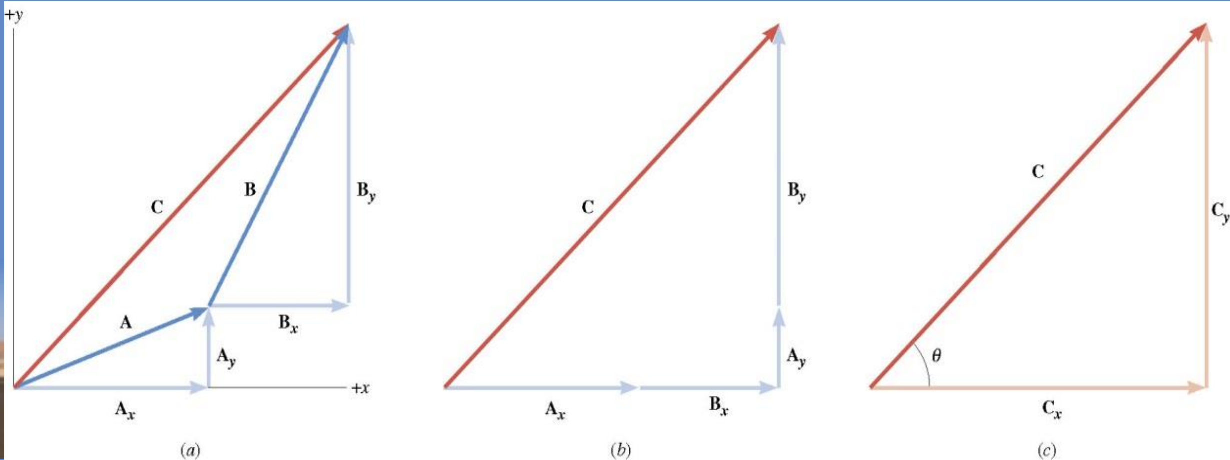
01-07 Two-Dimensional Vectors

Vector Addition – Component Method

- Vectors can be described by its components to show how far it goes in the x and y directions.
- To add vectors, you simply add the x-component and y-components to get total (resultant) x and y components.

1. Find the components for all the vectors to be added
2. Add all the x-components
3. Add all the y-components
4. Use the Pythagorean Theorem to find the magnitude of the resultant
5. Use $\tan^{-1}$ to find the direction (the direction is always found at the tail-end of the resultant)

- *Note: Drawing pictures and triangles helps immensely.*



01-07 Two-Dimensional Vectors

Add the follow vectors.

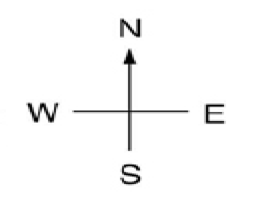
$\boldsymbol{C} = 15\ m$ at 25° N of E;

$\boldsymbol{D} = 20\ m$ at 60° S of E

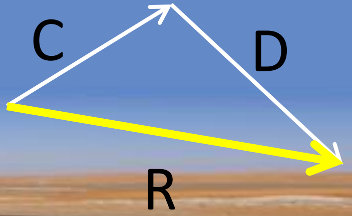
	x	y
C	$15\ m\cos 25° = \mathbf{13.6}\boldsymbol{m}$	$15\ m\sin 25° = \mathbf{6.34}\ \boldsymbol{m}$
D	$20\ m\cos 60° = \mathbf{10}\ \boldsymbol{m}$	$-20\ m\sin 60° = \mathbf{-17.32}\boldsymbol{m}$
R	$\mathbf{23.6}\ \boldsymbol{m}$	$\mathbf{-10.98}\ \boldsymbol{m}$

$$R = \sqrt{(23.6\ m)^2 + (-10.98\ m)^2} = 26.0\ m$$

$$\theta = \tan^{-1}\frac{10.98\ m}{23.6\ m} = 2$$



E



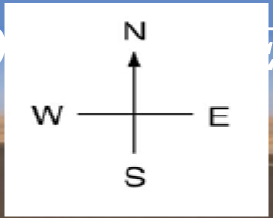
01-07 Two-Dimensional Vectors

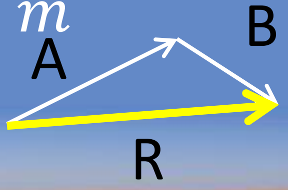
A jogger runs 145 m in a direction 20.0° east of north and then 105 m in a direction 35.0° south of east. Determine the magnitude and direction of jogger's position from her starting point.

	x	y
A	$145\,m\,sin\,20° = \mathbf{49.6\,m}$	$145\,m\cos 20° = \mathbf{136.3\,m}$
B	$105\,m\cos 35° = \mathbf{86.0\,m}$	$-105\,m\sin 35° = \mathbf{-60.2\,m}$
R	$\mathbf{135.6\,m}$	$\mathbf{76.1\,m}$

$$R = \sqrt{(135.6\,m)^2 + (76.1m)^2} = 155.5\,m$$

$$\theta = \tan^{-1}\frac{76.1\,m}{135.6\,m} = 29$$





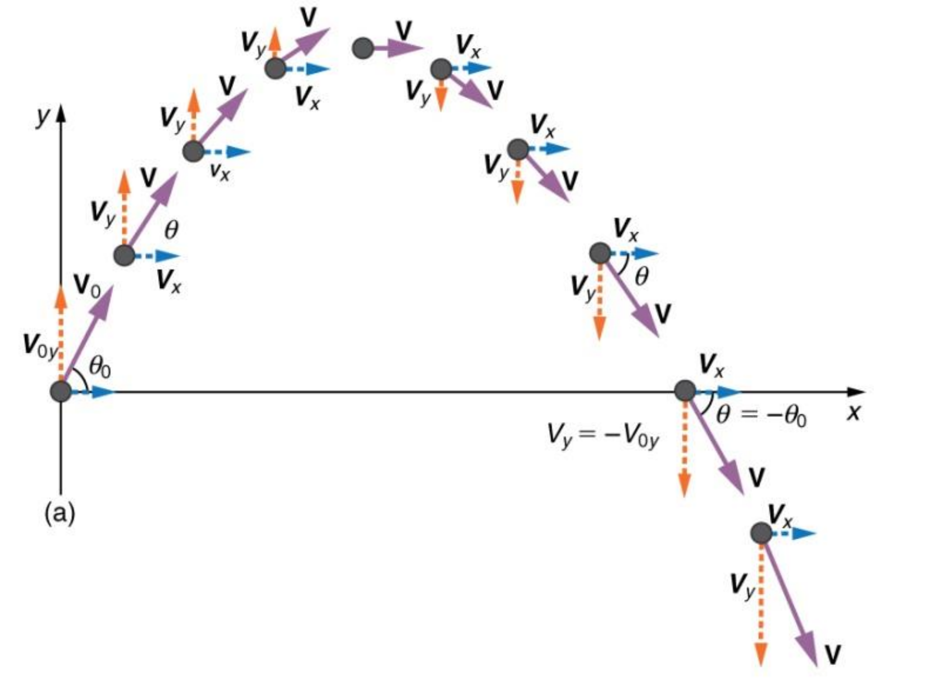
01-08 Projectile Motion

In this lesson you will…

- Identify and explain the properties of a projectile, such as acceleration due to gravity, range, maximum height, and trajectory.
- Determine the location and velocity of a projectile at different points in its trajectory.
- Apply the principle of independence of motion to solve projectile motion problems.

01-08 Projectile Motion

- Objects in flight only under influence of gravity
- x and y components are independent
  - Time is only quantity that is the same in both dimensions
- x-component velocity constant since nothing pulling it sideways
  - Use $x = v_0 t$
- y-component changes because gravity pulling it down
  - Use equations of kinematics



01-08 Projectile Motion

- If the starting and ending heights are the same, the distance the object goes can be found with the range equation

$$r = \frac{v_0^2 \sin 2\theta}{g}$$

01-08 Projectile Motion

- A meatball with v = 5.0 m/s rolls off a 1.0 m high table. How long does it take to hit the floor?
- y-motion only
- $v_{0y} = 0\frac{m}{s}, y_0 = 1.0\ m,$

  $y = 0\ m, a_y = -9.8\frac{m}{s^2}, t = ?$
- $y = \frac{1}{2}a_y t^2 + v_{0y}t + y_0$
- $0\ m = \frac{1}{2}\left(-9.8\frac{m}{s^2}\right)t^2 + 0\frac{m}{s}t + 1.0\ m$
- $-1.0\ m = -4.9\frac{m}{s^2}t^2$
- $0.20\ s^2 = t^2$
- $0.45\ s = t$

01-08 Projectile Motion

- What was the velocity when it hit?
- Both x and y motion
- x: $v_{0x} = 5.0\frac{m}{s}, t = 0.45\ s$
- y: $v_{0y} = 0\frac{m}{s}, y_0 = 1.0\ m,$

  $y = 0\ m, a_y = -9.8\frac{m}{s^2},$

  $t = 0.45\ s$

- x-direction
- $v_x = 5.0\frac{m}{s}$
- y-direction
- $v_y = a_y t + v_{0y}$
- $v_y = -9.8\frac{m}{s^2}(0.45\ s) + 0\frac{m}{s}$
- $v_y = -4.4\frac{m}{s}$

$$v_R = \sqrt{\left(5.0\frac{m}{s}\right)^2 + \left(-4.4\frac{m}{s}\right)^2} = 6.7\frac{m}{s}$$

$$6.7\frac{m}{s}\ at\ 42°\ below\ \ horizontal$$

$$-4.4\frac{m}{s}$$

01-08 Projectile Motion

- A truck (v = 11.2 m/s) turned a corner too sharp and lost part of the load. A falling box will break if it hits the ground with a velocity greater than 15 m/s. The height of the truck bed is 1.5 m. Will the box break?
- x: $v_{0x} = 11.2\frac{m}{s}, v_x = 11.2\frac{m}{s}$
- y:$v_{0y} = 0\frac{m}{s}, y_0 = 1.5\ m, y = 0\ m, a_y = -9.8\frac{m}{s^2}, v_y = ?$
- y-direction:
- $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$
- $v_y^2 = \left(0\frac{m}{s}\right)^2 + 2\left(-9.8\frac{m}{s^2}\right)(0 - 1.5\ m)$
- $v_y^2 = 29.4\frac{m^2}{s^2}$
- $v_y = -5.42\ m/s$
- $v_R = \sqrt{\left(11.2\frac{m}{s}\right)^2 + \left(-5.42\frac{m}{s}\right)^2}$
- $v_R = 12.4\ m/s$ The box doesn't break

01-08 Projectile Motion

- While driving down a road a bad guy shoots a bullet straight up into the air. If there was no air resistance where would the bullet land – in front, behind, or on him?

- If air resistance present, bullet slows and lands behind.
- No air resistance the v_x doesn't change and bullet lands on him.

01-08 Projectile Motion

- If a gun were fired horizontally and a bullet were dropped from the same height at the same time, which would hit the ground first?

01-08 Projectile Motion

- A batter hits a ball at 35° with a velocity of 32 m/s. How high did the ball go?
- x: $v_{0x} = 32\frac{m}{s}\cos 35° = 26.2\frac{m}{s}$
- y: $y_{0y} = 32\frac{m}{s}\sin 35° = 18.4\frac{m}{s}$, $a_y = -9.8\frac{m}{s^2}, y_0 = 0\,m, y = ?,$ $v_y = 0\frac{m}{s}$

- y-direction:
- $v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$
- $0^2 = \left(18.4\frac{m}{s}\right)^2 + 2\left(-9.8\frac{m}{s^2}\right)(y - 0)$
- $0 = 338.9\frac{m^s}{s^2} - 19.6\frac{m}{s^2}y$
- $y = 17\,m$

01-08 Projectile Motion

- How long was the ball in the air?
- x: $v_{0x} = 32\frac{m}{s}\cos 35° = 26.2\frac{m}{s}$
- y: $v_{0y} = 32\frac{m}{s}\sin 35° = 18.4\frac{m}{s}$, $a_y = -9.8\frac{m}{s^2}, y_0 = 0\ m, y = 0\ m,$ $t = ?$

- y-direction:
- $y = \frac{1}{2}a_y t^2 + v_{0y}t + y_0$
- $0 = \frac{1}{2}\left(-9.8\frac{m}{s^2}\right)t^2 + \left(18.4\frac{m}{s}\right)t + 0$
- $0 = t\left(-4.9\frac{m}{s^2}t + 18.4\frac{m}{s}\right)$
- $t = 0\ or\ t = 3.8\ s$

01-08 Projectile Motion

- How far did the ball go?
- x: $v_{0x} = 32\frac{m}{s}\cos 35° = 26.2\frac{m}{s}$, $t = 3.8\ s, x = ?$

- x-direction:
- $x = x_0 + v_{0x}t$
- $x = 0\ m + 26.2\frac{m}{s}(3.8\ s)$
- $x = 98\ m$

Or use the range equation

$$R = \frac{v_0^2 \sin 2\theta}{g}$$

Where g is positive, θ is the launch angle, and $y = y_0$