Introduction and 1-D Kinematics

OpenStax High School Physics

Unit 1

NAD 2023 Standards: Motion M1, M2, M3

Credits

- This Slideshow was developed to accompany the textbook
  - *OpenStax High School Physics*
    - *Available for free at https://openstax.org/details/books/physics*
    - *By Paul Peter Urone and Roger Hinrichs*
    - *2020 edition*
- Some examples and diagrams are taken from the *OpenStax College Physics, Physics,* and *Cutnell & Johnson Physics* 6th ed.

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1-01 Introduction, Units, and Uncertainty

In this lesson you will…

- Explain the difference between a model and a theory.
- Perform unit conversions both in the SI and English units.
- Explain the most common prefixes in the SI units and be able to write them in scientific notation.
- Determine the appropriate number of significant figures in both addition and subtraction, as well as multiplication and division calculations.

OpenStax High School Physics 1.1-1.3
OpenStax College Physics 2e 1.1-1.4

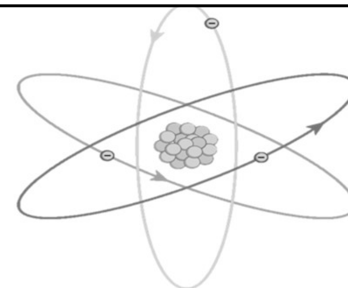
1-01 Introduction, Units, and Uncertainty

- 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.

1-01 Introduction, Units, and Uncertainty

- I believe God created the laws of physics.
- Since He made the laws, He can stop the effects of those laws when He chooses. This is called a miracle.
- Many scientists think that because they can describe nature so well without using God that it proves God does not exist.
- I believe being able to describe these intricate, interrelated laws shows the wisdom and might of God. It allows for miracles.
- God's laws of nature don't change, neither do His other laws like, "Treat other how you would like to be treated" or the 10 Commandments. Following His laws makes everything work better.

1-01 Introduction, Units, and Uncertainty



- Physics studies anything that can be sensed with our five senses.
- 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.

The models, theories, and laws we devise sometimes *imply the existence of objects or phenomena as yet unobserved.*
However, if *experiment* does not verify our predictions, then the theory or law is wrong, no matter how elegant or convenient it is.

1-01 Introduction, Units, and Uncertainty

- Scientific Method

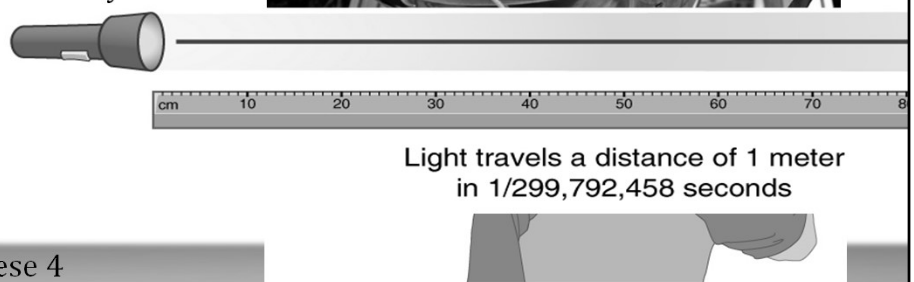
- Can be used to solve many types of problems, not just science

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

1-01 Introduction, Units, and Uncertainty

- 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

Meter based on distance light travels in a vacuum in 1/299,792,458 of a second
Second based on time it takes for 9,192,631,770 vibrations of Cesium atoms
Mass based on mass of a platinum-iridium cylinder kept with the old meter standard at the International Bureau of Weights and Measures near Paris

1-01 Introduction, Units, and Uncertainty

- Metric Prefixes
  - SI system based on powers of ten
  - Memorize from T to p

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}

1-01 Introduction, Units, and Uncertainty

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

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

1-01 Introduction, Units, and Uncertainty

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

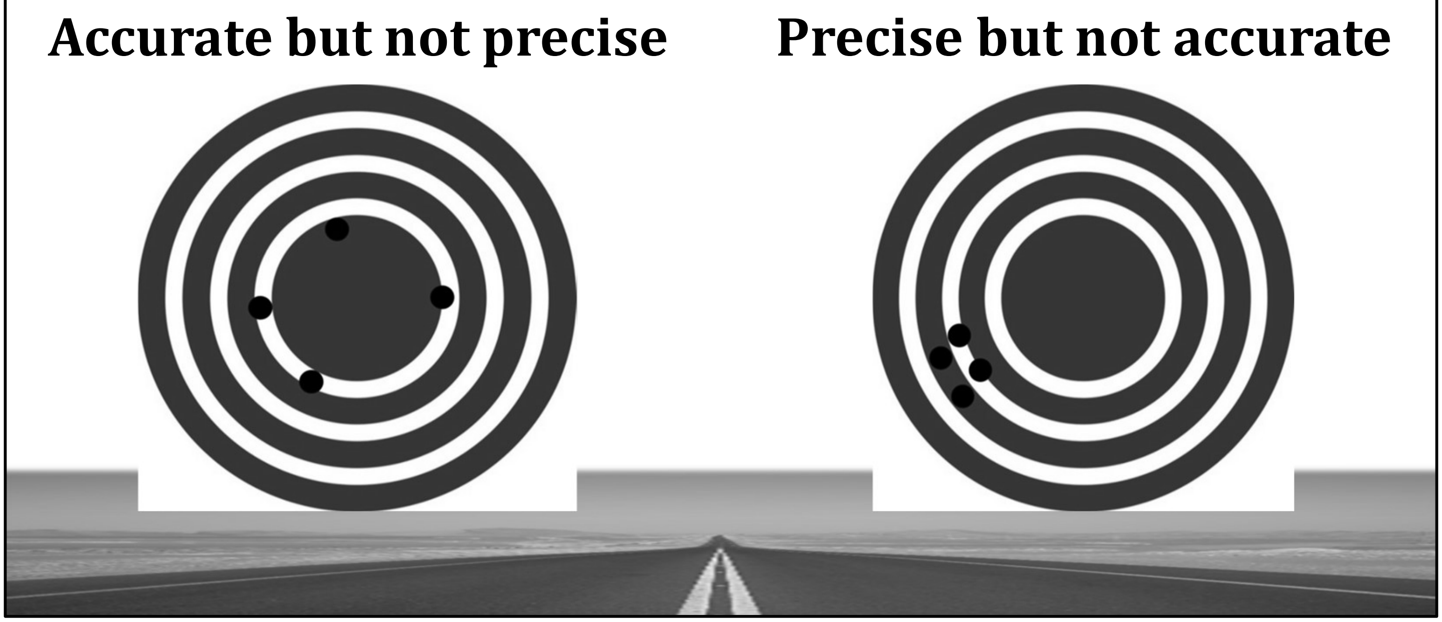
1-01 Introduction, Units, and Uncertainty

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

1-01 Introduction, Units, and Uncertainty

- 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.

1-01 Introduction, Units, and Uncertainty



1-01 Introduction, Units, and Uncertainty

- The accuracy and precision of a measuring system leads to uncertainty.
- A device can repeated get the same measurement (precise), but always be wrong (not accurate).

1-01 Introduction, Units, and Uncertainty

- Measurement lab

1-02 Relative Motion, Distance, and Displacement

In this lesson you will…

- Describe motion in different reference frames
- Define distance and displacement, and distinguish between the two
- Solve problems involving distance and displacement

Standards

- M1: Use vector analysis to characterize change in position and motion

NAD Standards
M1

- Define displacement, relative motion, scalar, vector
- Compare vector and scalar quantities
- Use vectors to describe relative motion
- Use vector analysis to characterize change in position and motion

OpenStax High School Physics 2.1
OpenStax College Physics 2e 2.1-2.2

1-02 Relative Motion, Distance, and Displacement

- 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

1-02 Relative Motion, Distance, and Displacement

- Relative motion is how to describe the motion of an object based on different reference frames.
- Think of sitting in your car next to a big tractor-trailer truck.
- The truck starts to move, but you stay still.
- What to you feel?

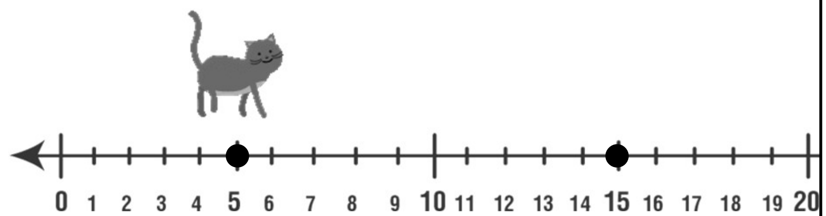
The background moves relative to the screen making it look like the dog is moving. The dog is moving relative to the background, but not moving relative to the screen.

At the end, the background stops moving and the dog moves relative to the screen. The dog is moving relative to the background, but is also moving relative to the screen.

[redacted]

1-02 Relative Motion, Distance, and Displacement

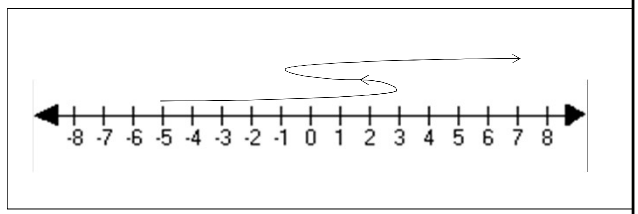
- Displacement
  - Change in position relative to a reference frame
  - $\Delta d = d_f - d_0$
  - Vector
    - Has direction and magnitude
  - Path does not matter
  - Only depends on final and initial position



$$\Delta d = d_f - d_0$$
$$\Delta d = 15 - 5 = 10 \text{ units}$$

1-02 Relative Motion, Distance, and Displacement

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



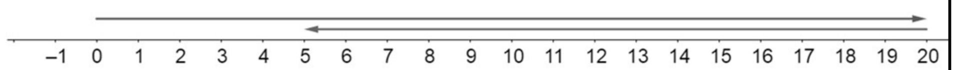
$$\Delta d = d_f - d_0$$
$$\Delta d = 7 - (-5) = 12$$

1-02 Relative Motion, Distance, and Displacement

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

1-02 Relative Motion, Distance, and Displacement

- You drive 20 km east, then turn around and drive 15 km west. What is your displacement?



- What is your distance traveled?

$$\Delta d = d_f - d_0$$
$$\Delta d = 5\ km - 0\ km$$
$$5\ km$$

5 km east of your starting point

$$20\ km + 15\ km$$
$$35\ km$$

1-03 Speed and Velocity and Graphs

In this lesson you will…

- Calculate the average speed of an object
- Relate displacement and average velocity
- Explain the meaning of slope in position vs. time graphs
- Solve problems using position vs. time graphs

Standards

- M1: Use vector analysis to characterize change in position and motion
- M2: Use graphs to characterize change in position and motion

NAD Standards

M1

- Define velocity
- Compare vector and scalar quantities

M2

- Define position-time graph
- Interpret graphs from change in position and motion
- Create graphs for change in position and motion
- Use graphs to interpret slope and area form motion
- Use graphs to characterize change in position and motion

OpenStax High School Physics 2.2-2.3

OpenStax College Physics 2e 2.3

1-03 Speed and Velocity and Graphs

- Motion graphs lab

1-03 Speed and Velocity and Graphs

- Speed
  - Rate of change of distance
  - $v_{ave} = \frac{distance}{time}$
  - $v_{ave} = \frac{dist}{\Delta t}$
  - Scalar (no direction)

- Velocity
  - Rate of change of displacement
  - $v_{ave} = \frac{displacement}{time}$
  - $v_{ave} = \frac{\Delta d}{\Delta t} = \frac{d_f - d_0}{t_f - t_0}$
  - Vector

1-03 Speed and Velocity and Graphs

- Instantaneous velocity
  - Exact velocity at a given moment

1-03 Speed and Velocity and Graphs

- A coyote walks east 2 km, then turns around and walks back west 3 km. If this trip takes 1.5 hours, what is the coyote's average speed?

$$v_{ave} = \frac{distance}{time}$$

$$v_{ave} = \frac{2\ km + 3\ km}{1.5\ h} = 3.33\frac{km}{h}$$

1-03 Speed and Velocity and Graphs

- A coyote walks east 2 km, then turns around and walks back west 3 km. If this trip takes 1.5 hours, what is the coyote's average velocity?

$$v_{ave} = \frac{\Delta d}{\Delta t}$$

$$v_{ave} = \frac{-1\ km}{1.5\ h} = -0.667\frac{km}{h} = 0.667\frac{km}{h}\ west$$

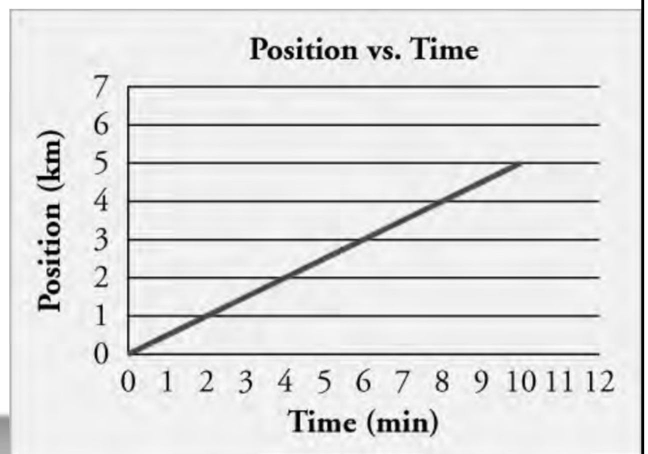
1-03 Speed and Velocity and Graphs

- A black bear at top speed can run about 13.5 m/s. If its friend is 50.0 m away, how much time does it have to prepare for a bear hug before the it gets there?

$$v_{age} = \frac{\Delta d}{\Delta t}$$
$$13.5\frac{m}{s} = \frac{50\ m}{\Delta t}$$
$$13.5\frac{m}{s}\Delta t = 50\ m$$
$$\Delta t = 3.70\text{ s}$$

1-03 Speed and Velocity and Graphs

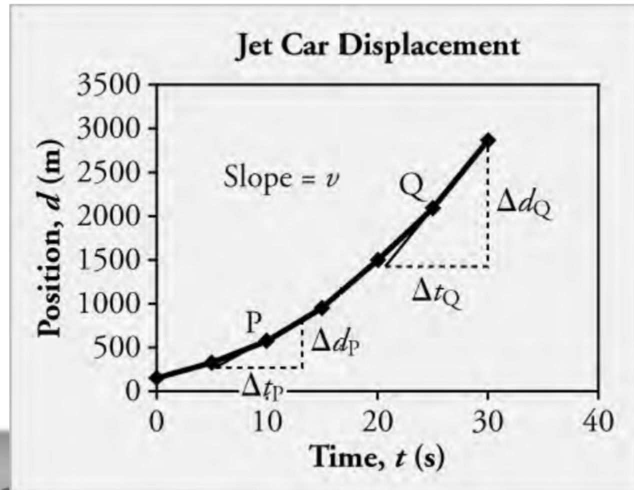
- Position vs. Time graph
  - $slope = \frac{rise}{run}$
  - $= \frac{\Delta d}{\Delta t} = v$
  - Slope of d vs. t is velocity



As the dog moves, his position increases as time increases

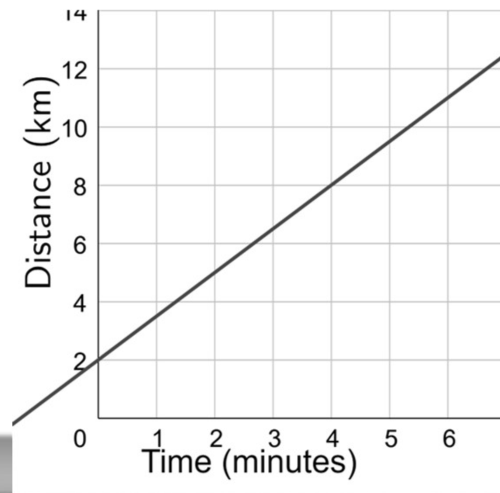
1-03 Speed and Velocity and Graphs

- If the graph is curved, use the slope of the tangent line at the given time



1-03 Speed and Velocity and Graphs

- The graph shows the distance a car is from its house. What is the velocity of the car at 5 minutes? (Give the answer in m/s.)



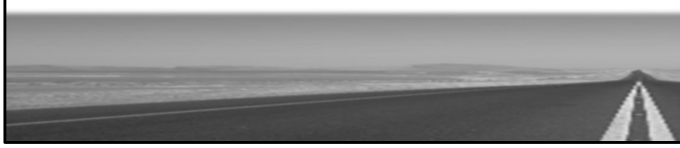
Find slope

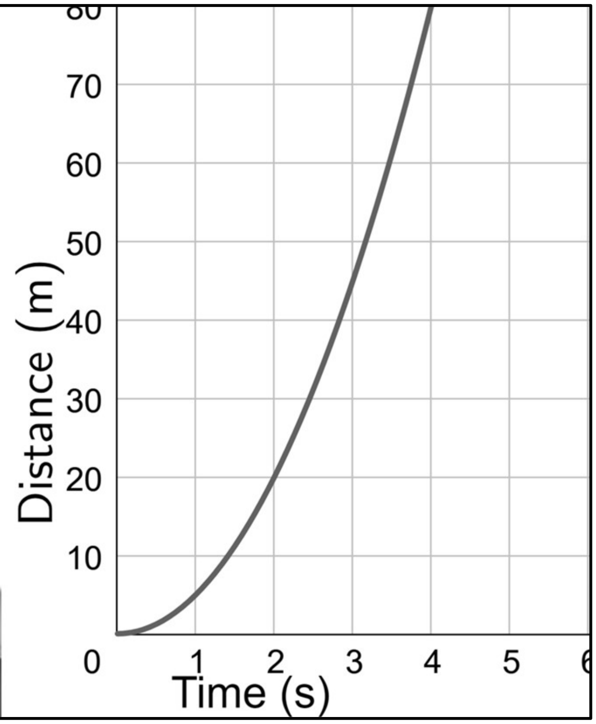
$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

$$m = \frac{8\ km - 2\ km}{4\ \text{min} - 0\ \text{min}} = \frac{6\ km}{4\ \text{min}} = 1.5\ km/min$$

1-03 Speed and Velocity and

- The graph shows the distance a car is from the starting point of a race. What is the velocity of the car at 3 seconds?





Draw tangent line at t=3 s.
Find slope of the tangent line.
30 m/s

1-04 Velocity vs Time graphs

In this lesson you will…

- Find displacement from a velocity-time graph
- Find average velocity from a velocity-time graph
- Find acceleration from a velocity-time graph

Standards

- M2: Use graphs to characterize change in position and motion

NAD Standards
M2

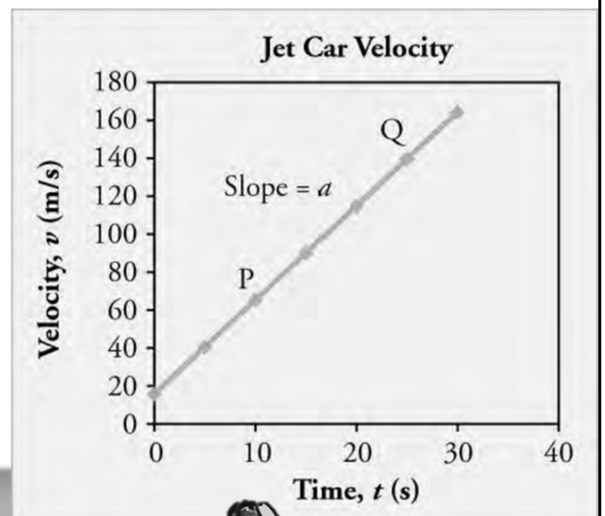
- Define velocity-time graph
- Interpret graphs for change in position and motion
- Create graphs for change in position and motion
- Use graphs to interpret the slope and area for motion
- Use kinematics to characterize change in position and motion

OpenStax High School Physics 2.4
OpenStax College Physics 2e 2.3, 2.8

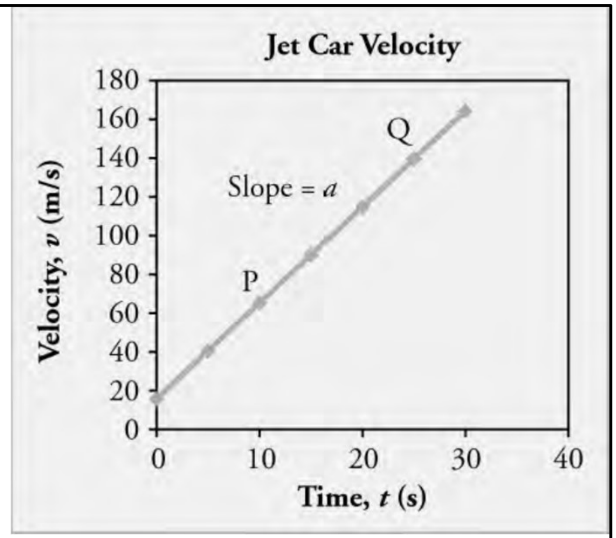
1-04 Velocity vs Time graphs

- Acceleration
  - Rate of change of velocity
  - Slope of velocity vs. time graph

- Displacement
  - Area between graph and *t*-axis of a velocity vs. time graph



1-04 Velocity vs Time graphs



- Calculate

a. Displacement over the 30s.

b. Acceleration over the 30s.

c. Instantaneous velocity at 20s.

d. Average velocity over the 30s.

a. area: two parts upper triangle and lower rectangle.
   Triangle: $A = \frac{1}{2}bh = \frac{1}{2}(30\ s)\left(165\frac{m}{s} - 15\frac{m}{s}\right) = 2250\ m$
   Rectangle: $A = bh = (30\ s)\left(15\frac{m}{s}\right) = 450\ m$
   Add together: $2250\ m + 450\ m = 2700\ m$
b. Slope: $m = \frac{y_2 - y_1}{x_2 - x_1}$

$$a = \frac{165\frac{m}{s} - 15\frac{m}{s}}{30\ s\ - 0\ s} = 5\frac{m}{s^2}$$

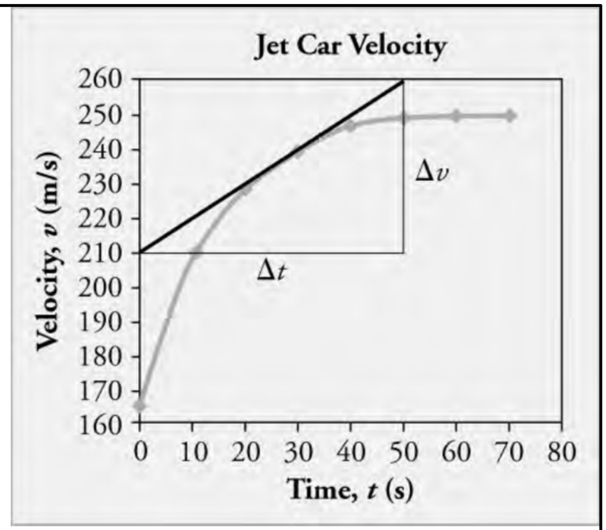
c. Read from graph. 120 m/s
d. Find mean: $\overline{v} = \frac{165\frac{m}{s} + 15\frac{m}{s}}{2} = 90\frac{m}{s}$

1-04 Velocity vs Time graphs

- Calculate

a. Displacement over the first 20s.

b. Instantaneous acceleration at 30s.



a. Area: estimate with 2 triangles (from 0 to 10s and 10-20s) and 2 rectangles

Triangle (0-10s): $A = \frac{1}{2}bh = \frac{1}{2}(10\ s)\left(210\frac{m}{s} - 165\frac{m}{s}\right) = 225\ m$

Triangle (10-20s): $A = \frac{1}{2}bh = \frac{1}{2}(10\ s)\left(230\frac{m}{s} - 210\frac{m}{s}\right) = 100\ m$

Rectangle (0-10s): $A = bh = (10\ s)\left(165\frac{m}{s}\right) = 1650\ m$

Rectangle(10-20s): $A = bh = (10\ s)\left(210\frac{m}{s} - 0\frac{m}{s}\right) = 2100\ m$

Total: 225 m + 100 m + 1650 m + 2100 m = 4075 m

b. Use slope of tangent line (already drawn)

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

$$a = \frac{260\frac{m}{s} - 210\frac{m}{s}}{50\ s - 0s} = 1\ m/s^2$$

1-05 Acceleration

In this lesson you will…

- Understand the meaning of positive and negative acceleration
- Solve problems involving acceleration
- Recognize graphs with constant acceleration

Standards

- M1: Use vector analysis to characterize change in position and motion
- M2: Use graphs to characterize change in position and motion
- M3: Use kinematics equations to characterize change in position and motion

NAD Standards

M1

- Define acceleration
- Use vectors to describe relative motion
- Use vector analysis to characterize change in position and motion

M2

- Use graphs to characterize change in position and motion

M3

- Define acceleration-time graph
- Use kinematics equations to solve for missing 1D variables

OpenStax High School Physics 3.1

OpenStax College Physics 2e 2.4, 2.8

1-05 Acceleration

- Acceleration graphs lab

1-05 Acceleration

- Acceleration
  - Rate of change of velocity

$$\overline{a} = \frac{\Delta v}{\Delta t}$$

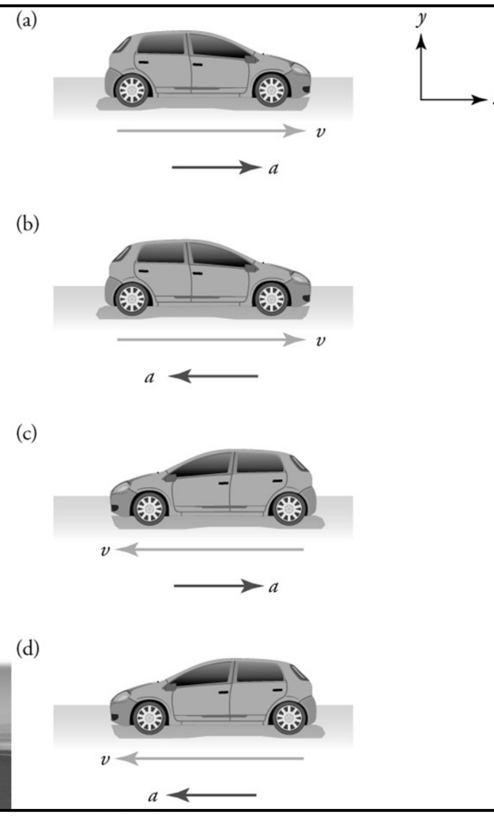
$$\overline{a} = \frac{v_f - v_0}{t_f - t_0}$$

$$v = at + v_0$$

- Vector
- Unit: m/s^2

(a) Speeding up
(b) Slowing
(c) Slowing
(d) Speeding up

1-05 Acceleration



- 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.

(a) Speeding up
(b) Slowing
(c) Slowing
(d) Speeding up

1-05 Acceleration

- A horse starts running. If it goes from 0 to 55 km/h in 3.5 s, what is the horse's acceleration?

$$v = \frac{55\ km}{h}\left(\frac{10^3\ m}{km}\right)\left(\frac{h}{3600\ s}\right) = 15.278\,\frac{m}{s}$$

$$\overline{a} = \frac{v_f - v_0}{t_f - t_0}$$

$$\overline{a} = \frac{15.278\,\frac{m}{s} - 0\,\frac{m}{s}}{3.5\ s\ - 0\ s} = 4.37\ m/s^2$$

1-05 Acceleration

- A car slows from 15 m/s to 10 m/s by an acceleration of 4 m/s². How much time did it take to slow down?

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

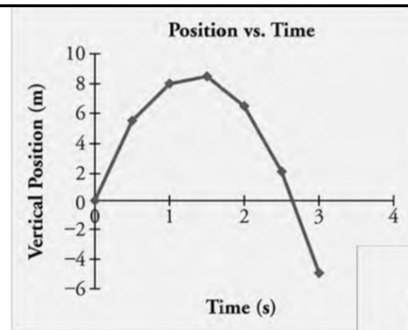
$$-4\frac{m}{s^2} = \frac{10\frac{m}{s} - 15\frac{m}{s}}{\Delta t}$$

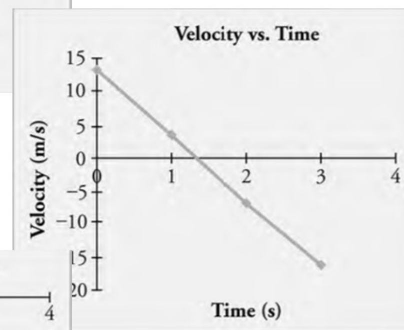
$$\left(-4\frac{m}{s^2}\right)\Delta \mathrm{t} = -5\frac{\mathrm{m}}{\mathrm{s}}$$

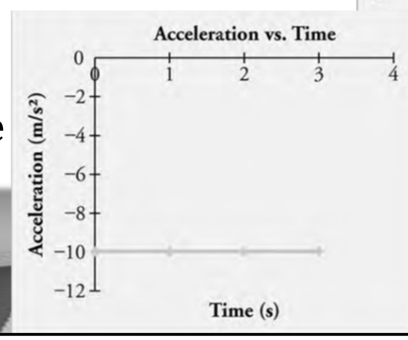
$$\Delta t = 1.25\ s$$

1-05 Acceleration

- Constant acceleration
  - The graph of position–time is parabolic
    - ($d = d_0 + v_0 t + \frac{1}{2} a t^2$ is quadratic)
  - The graph of velocity–time is linear
    - ($v = at + v_0$ is linear)
  - The graph of acceleration-time is constant
    - ($a = a$)







1-06 Representing Acceleration with Equations Part 1

In this lesson you will…

Use kinematics equations to solve for missing 1D motion variables

Use kinematics equations to characterize change in position and motion

Standards

- M3: Use kinematics equations to characterize change in position and motion

NAD Standards
M3

- Use kinematics equations to solve for missing 1D motion variables
- Use kinematics equations to characterize change in position and motion

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OpenStax College Physics 2e 2.5-2.6

1-06 Representing Acceleration with Equations Part 1

- Assume $t_0 = 0$, so $\Delta t = t$ and acceleration is constant
- $\overline{v} = \frac{d - d_0}{t}$
- $d = \overline{v}t + d_0$ and $\overline{v} = \frac{v_0 + v}{2}$
- $\boxed{d = \frac{1}{2}(v_0 + v)t + d_0}$

1-06 Representing Acceleration with Equations Part 1

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

- $v - v_0 = at$

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

1-06 Representing Acceleration with Equations Part 1

- $v = at + v_0$
- $v_0 + v = at + 2v_0$
- $\frac{v_0 + v}{2} = \frac{1}{2}at + v_0$
- $\overline{v} = \frac{1}{2}at + v_0$
- $d = \overline{v}t + d_0$
- $d = \left(\frac{1}{2}at + v_0\right)t + d_0$
- $\boxed{d = \frac{1}{2}at^2 + v_0 t + d_0}$

1-06 Representing Acceleration with Equations Part 1

- $v = at + v_0$
- $t = \frac{v - v_0}{a}$
- $\bar{v} = \frac{v_0 + v}{2}$
- $d = \bar{v}t + d_0$
- $d = \left(\frac{v_0 + v}{2}\right)\left(\frac{v - v_0}{a}\right) + d_0$
- $d - d_0 = \left(\frac{v^2 - v_0^2}{2a}\right)$
- $2a(d - d_0) = v^2 - v_0^2$
- $v^2 = v_0^2 + 2a(d - d_0)$

1-06 Representing Acceleration with Equations Part 1

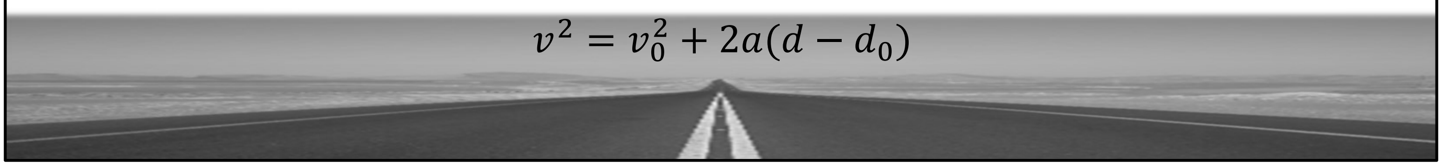
$$d = \overline{v}t + d_0$$

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

$$v = at + v_0$$

$$d = \frac{1}{2}at^2 + v_0 t + d_0$$

$$v^2 = v_0^2 + 2a(d - d_0)$$



1-06 Representing Acceleration with Equations Part 1

- Examine the situation to determine which physical principles are involved.
  - Maybe draw a picture
- List the knowns.
- Identify the unknowns.
- 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?

1-06 Representing Acceleration with Equations Part 1

- A plane starting from rest accelerates to 40 m/s in 10 s. How far did the plane travel during this time?

$$v = 40\ m/s, t = 10\ s, v_0 = 0, d_0 = 0, d = ?$$

$$\bar{v} = \frac{v_0 + v}{2} \rightarrow \bar{v} = \frac{0 + 40\frac{m}{s}}{2} = 20\ m/s$$

$$d = \bar{v}t + d_0$$

$$d = \left(20\frac{m}{s}\right)(10\ s) + 0$$

$$d = 200\ m$$

1-06 Representing Acceleration with Equations Part 1

- 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?

$$a = -0.5\frac{m}{s^2}, t = 3\ s, d = 15\ m, d_0 = 0, v_0 = ?$$

$$d = \frac{1}{2}at^2 + v_0 t + d_0$$

$$15\ m = \frac{1}{2}\left(-0.5\frac{m}{s^2}\right)(3\ s)^2 + v_0(3\ s) + 0$$

$$15\ m = -2.25\ m + v_0(3\ s)$$

$$17.25\ m = v_0(3\ s)$$

$$v_0 = 5.75\ m/s$$

1-06 Representing Acceleration with Equations Part 1

- 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?

$$v = 20.0\frac{m}{s}, v_0 = 1.0\frac{m}{s}, d = 25\ m, d_0 = 0, a = ?$$

$$v^2 = v_0^2 + 2a(d - d_0)$$

$$\left(20\frac{m}{s}\right)^2 = \left(1.0\frac{m}{s}\right)^2 + 2a(25\ m - 0)$$

$$400\frac{m^2}{s^2} = 1\frac{m^2}{s^2} + (50\ m)a$$

$$399\frac{m^2}{s^2} = (50\ m)a$$

$$a = 7.98\ m/s^2$$

1-06 Representing Acceleration with Equations Part 1

- 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/s^2). (b) How much time does blood take to reach its final velocity?

a) $v^2 = v_0^2 + 2a(d - d_0)$

$$\left(26\frac{cm}{s}\right)^2 = \left(0\frac{m}{s}\right)^2 + 2a(2\ cm)$$

$$676\frac{cm^2}{s^2} = 4a\ cm$$

$$a = 169\frac{cm}{s^2}$$

b) $d = \overline{v}t + d_0; \overline{v} = \frac{v+v_0}{2}$

$$\overline{v} = \frac{0\frac{cm}{s} + 26\frac{cm}{s}}{2} = 13\frac{cm}{s}$$

$$d = \overline{v}t + d_0$$

$$2\ cm = \left(13\frac{cm}{s}\right)t$$

$$t = 0.15\ s$$

1-07 Representing Acceleration with Equations Part 2

In this lesson you will…

- Define freefall
- Use kinematics equations to solve free-fall motion
- Use kinematics equations to characterize change in position and motion

Standards

- M3: Use kinematics equations to characterize change in position and motion

NAD Standards
M3

- Define freefall
- Use kinematics equations to solve free-fall motion
- Use kinematics equations to characterize change in position and motion

OpenStax High School Physics 3.2
OpenStax College Physics 2e 2.7

1-07 Representing Acceleration with Equations Part 2

- 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

1-07 Representing Acceleration with Equations Part 2

- Do feather falling demo

- Real life
  - Air resistance

- Use the one-dimensional equations of motion

1-07 Representing Acceleration with Equations Part 2

- 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?

When solving and taking square root, then use $\pm$ sign. Took negative here because it was going down.

$$v_0 = 0, v = ?, a = -9.80\frac{m}{s^2}, d_0 = 1000\,m, d = 0\,m$$

$$v^2 = {v_0}^2 + 2a(d - d_0)$$

$$v^2 = 0 + 2(-9.80\,m/s^2)(0 - 1000\,m)$$

$$v^2 = 19600\,m^2/s^2$$

$$v = -140\,m/s$$

1-07 Representing Acceleration with Equations Part 2

- How long does it take to hit the ground?

$$d = \frac{1}{2}at^2 + v_0 t + d_0$$

$$0\ m = \frac{1}{2}\left(-9.80\frac{m}{s^2}\right)t^2 + 0(t) + 1000\ m$$

$$-1000\ m = -4.90\frac{m}{s^2}t^2$$

$$204.1\ s^2 = t^2$$

$$14.3\ s = t$$

1-07 Representing Acceleration with Equations Part 2

- A baseball is hit straight up into the air. If the initial velocity was 20 m/s, how high will the ball go?

$$v_0 = 20\frac{m}{s}, a = -9.80\frac{m}{s^2}, v\ (at\ top) = 0, d = ?, d_0 = 0$$
$$v^2 = {v_0}^2 + 2a(d - d_0)$$
$$0 = \left(20\frac{m}{s}\right)^2 + 2\left(-9.80\frac{m}{s^2}\right)(d - 0)$$
$$-400\frac{m^2}{s^2} = -19.6\frac{m}{s^2}d$$
$$d = 20.4\ m$$

1-07 Representing Acceleration with Equations Part 2

- How long will it be until the catcher catches the ball at the same height it was hit?

$$v_0 = 20\frac{m}{s}, a = -9.80\frac{m}{s^2}, t = ?, d = 0, d_0 = 0$$

$$d = \frac{1}{2}at^2 + v_0t + d_0$$

$$0\ m = \frac{1}{2}\left(-9.80\frac{m}{s^2}\right)t^2 + \left(20\frac{m}{s}\right)t + 0\ m$$

$$0 = t\left(20\frac{m}{s} - 4.90\frac{m}{s^2}t\right)$$

$$t = 0\ s\ or 20\frac{m}{s} - 4.90\frac{m}{s^2}t = 0$$

$$-4.90\frac{m}{s^2}t = -20\frac{m}{s}$$

$$t = 4.08\ s$$

1-07 Representing Acceleration with Equations Part 2

- How fast is it going when catcher catches it?

It's going down.

$$v_0 = 20\frac{m}{s}, a = -9.80\frac{m}{s^2}, t = ?, d = 0, d_0 = 0$$

$$v^2 = v_0^2 + 2a(d - d_0)$$

$$v^2 = \left(20\frac{m}{s}\right)^2 + 2\left(-9.80\frac{m}{s^2}\right)(0\,m\; - 0\,m)$$

$$v^2 = \left(20\frac{m}{s}\right)^2$$

$$v = \pm 20\frac{m}{s}\;\; so\;\; v = -20\,m/s$$

1-07 Representing Acceleration with Equations Part 2

- Acceleration of gravity lab

1-08 Vector Addition

In this lesson you will…

- Define resultant
- Add vectors graphically
- Add vectors algebraically

Standards

- M1: Use vector analysis to characterize change in position and motion

NAD Standards

M1

- Define resultant
- Add vectors algebraically

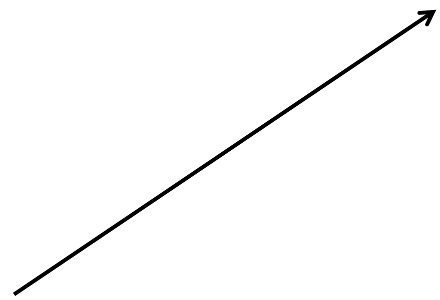
OpenStax High School Physics 5.1-5.2

OpenStax College Physics 2e 3.1-3.3

1-08 Vector Addition

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



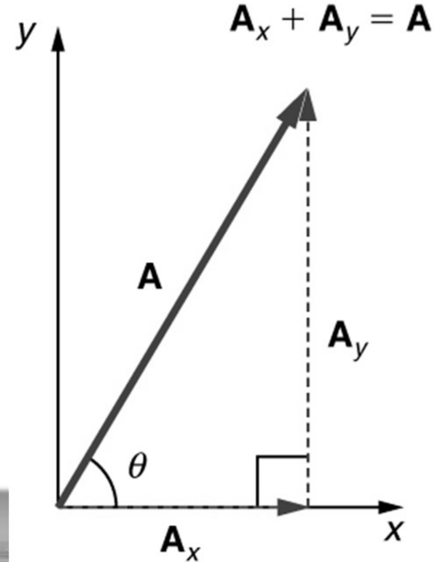
1-08 Vector Addition

- 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

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

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

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



1-08 Vector Addition

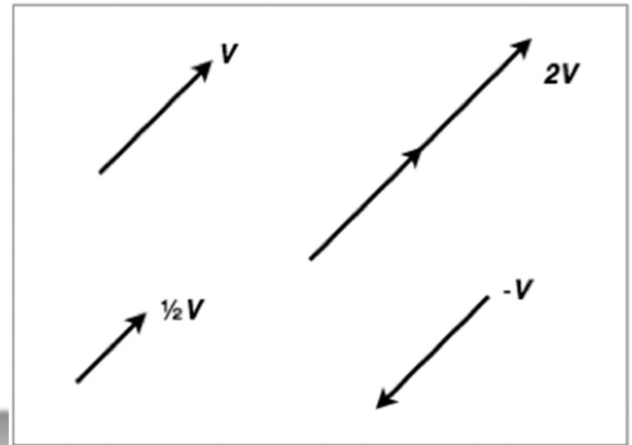
- A football player kicks a ball at 15 m/s at 30° above the ground. Find the horizontal and vertical components of this velocity.

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

1-08 Vector Addition

Scalar Multiplication

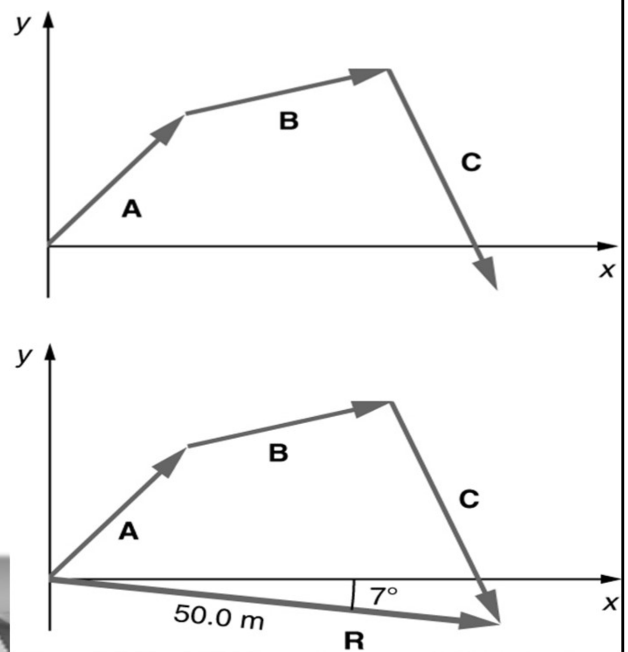
- Multiplying a vector by a single number
- Draw the vector that many times in a line
- Or multiply the components by that number
- A negative vector means multiply by −1, so it goes in the opposite direction



1-08 Vector Addition

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.



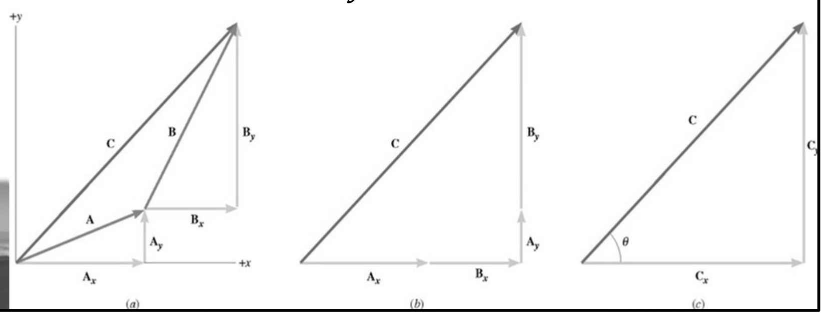
1-08 Vector Addition

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.*



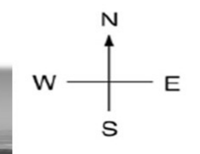
1-08 Vector Addition

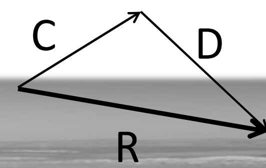
Add the follow vectors.
$\boldsymbol{C} = 15\ m$ at 25° N of E;
$\boldsymbol{D} = 20\ m$ at 60° S of E

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

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

$$\theta = \tan^{-1}\frac{10.98\ m}{23.6\ m} = 25.0°\ S\ of\ E$$





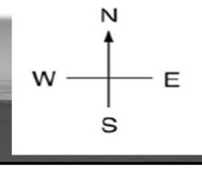
1-08 Vector Addition

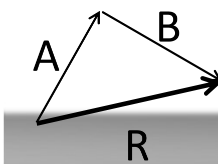
A jogger runs 145 m in a direction 20.0° east of north and then 105 m in a direction 35.0° south of east. Determine the magnitude and direction of jogger's position from her starting point.

	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	$\mathbf{135.6\, m}$	$\mathbf{76.1\, m}$

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

$$\theta = \tan^{-1} \frac{76.1\, m}{135.6\, m} = 29.3°\ N\ of\ E$$





1-08 Vector Addition

- Do independence of vectors lab

1-09 Projectile Motion

In this lesson you will…

- Define projectile motion and 2D motion
- Use kinematics equations to solve for missing 2D motion variables
- Use kinematics equations to characterize change in position and motion

Standards

- M1: Use vector analysis to characterize change in position and motion
- M2: Use graphs to characterize change in position and motion
- M3: Use kinematics equations to characterize change in position and motion

(Level 4)

NAD Standards

M2

- Define 2D motion

M3

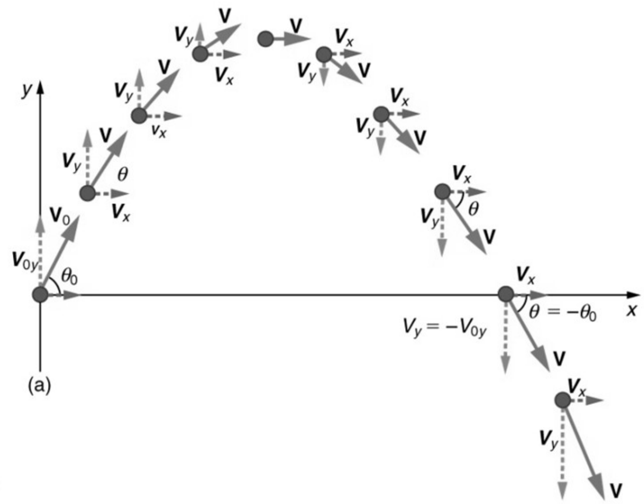
- Define projectile motion
- Use kinematics equations to solve for missing 2D motion variables
- Use kinematics equations to characterize change in position and motion

OpenStax High School Physics 5.3

OpenStax College Physics 2e 3.4

1-09 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



Note at highest point, vy = 0

1-09 Projectile Motion

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

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

1-09 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

$$v_{0y} = 0\frac{m}{s}, y_0 = 1.0\ m,$$
$$y = 0\ m, a_y = -9.8\frac{m}{s^2}, t = ?$$
$$y = \frac{1}{2}a_y t^2 + v_0 t + y_0$$
$$0\ m = \frac{1}{2}\left(-9.8\frac{m}{s^2}\right)t^2 + 0\frac{m}{s}t + 1.0\ m$$
$$-1.0\ m = -4.9\frac{m}{s^2}t^2$$
$$0.20\ s^2 = t^2$$
$$0.45\ s = t$$

1-09 Projectile Motion

- What was the velocity when it hit?

Both *x* and *y* motion

x-velocity doesn't change since no acceleration in *x*

<u>x</u>: $v_{0x} = 5.0\frac{m}{s}, t = 0.45\ s$

<u>y</u>: $v_{0y} = 0\frac{m}{s}, y_0 = 1.0\ m,$

$$y = 0\ m, a_y = -9.8\frac{m}{s^2},$$
$$t = 0.45\ s$$

<u>x-direction</u>

$$v_x = 5.0\frac{m}{s}$$

<u>y-direction</u>

$$v_y = a_y t + v_{0y}$$
$$v_y = -9.8\frac{m}{s^2}(0.45\ s) + 0\frac{m}{s}$$
$$v_y = -4.4\frac{m}{s}$$
$$v_R = \sqrt{\left(5.0\frac{m}{s}\right)^2 + \left(-4.4\frac{m}{s}\right)^2} = 6.7\frac{m}{s}$$

1-09 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

1-09 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.

1-09 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?

Hit at the same time since they fall down the same distance and have the same initial y-velocity.

Watch MythBusters bullet drop video

1-09 Projectile Motion

- A batter hits a ball at 35° with a velocity of 32 m/s. How high did the ball go?

<u>x:</u> $v_{0x} = 32\frac{m}{s}\cos 35° = 26.2\frac{m}{s}$

<u>y:</u> $y_{0y} = 32\frac{m}{s}\sin 35° = 18.4\frac{m}{s}, a_y = -9.8\frac{m}{s^2}, y_0 = 0\ m, y = ?, v_y = 0\frac{m}{s}$

<u>y-direction</u>:

$$v_y^2 = v_{0y}^2 + 2a_y(y - y_0)$$

$$0^2 = \left(18.4\frac{m}{s}\right)^2 + 2\left(-9.8\frac{m}{s^2}\right)(y - 0)$$

$$0 = 338.9\frac{m^s}{s^2} - 19.6\frac{m}{s^2}y$$

$$y = 17\ m$$

1-09 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: $y_{0y} = 32\frac{m}{s}\sin 35° = 18.4\frac{m}{s}, a_y = -9.8\frac{m}{s^2}, y_0 = 0\ m, y = 0\ m,\ t = ?$

y-direction:

$$y = \frac{1}{2}a_y t^2 + v_{0y}t + y_0$$

$$0 = \frac{1}{2}\left(-9.8\frac{m}{s^2}\right)t^2 + \left(18.4\frac{m}{s}\right)t + 0$$

$$0 = t\left(-4.9\frac{m}{s^2}t + 18.4\frac{m}{s}\right)$$

$$t = 0\ or\ t = 3.8\ s$$

1-09 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:

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

1-09 Projectile Motion

- A projectile launcher shoots a ball with v_0 = 11 m/s. If the ball lands 9.38 m away horizontally and 2 m higher, at what angle was the ball launched?

$$x = v_0 t$$
$$x = v_0(\cos\theta)t$$
$$9.38\,m = 11\frac{m}{s}(\cos\theta)t$$

$$y = \frac{1}{2}at^2 + v_0 t + y_0$$
$$2 = \frac{1}{2}\left(-9.8\frac{m}{s^2}\right)t^2 + \left(11\frac{m}{s}\right)(\sin\theta)t + 0$$
$$0 = -4.9\frac{m}{s^2}t^2 + 11\frac{m}{s}(\sin\theta)\mathrm{t} - 2$$

$$x = v_0 t$$
$$9.38\,m = 11\frac{m}{s}(\cos\theta)t$$
$$\frac{9.38\,s}{11\cos\theta} = t$$

Substitute (and drop units for convenience)

$$0 = -4.9\left(\frac{9.38}{11\cos\theta}\right)^2 + 11\sin\theta\left(\frac{9.38}{11\cos\theta}\right) - 2$$

$$0 = -3.563\ \sec^2\theta + 9.38\ \tan\theta - 2$$

$\sec^2\theta = 1 + \tan^2\theta$

$$0 = -3.563(1 + \tan^2\theta) + 9.38\tan\theta - 2$$
$$0 = -3.563 - 3.563\tan^2\theta + 9.38\tan\theta - 2$$
$$0 = -3.563\tan^2\theta + 9.38\tan\theta - 5.563$$

Solve to $\tan\theta$ with the quadratic formula

$$\tan\theta = \frac{-9.38 \pm \sqrt{9.38^2 - 4(-3.563)(-5.563)}}{2(-3.563)}$$
$$\tan\theta = 1.73024$$
$$\theta = 60.0°$$