

# Physics 1

MECHANICS: THE INTERACTIONS OF FORCES AND MATTER



# PHYSICS 1

SUGGESTED PACING: 3 LESSONS PER WEEK

Unit	Lesson	Topic	Pages
Unit 1. Kinematics	Intro	Introduction & Quiz Show Practice	-
	1	What is Physics?	4-7
	2	Mighty Measures	8-14
	3	Fun Physics Tricks	15-17
	4	Tracking Motion	18-22
	5	Graphing Motion	23-27
	6	Physics Memory Game	28
	7	Velocity	29-33
	8	Acceleration	34-36
	9	Function Carnival and Degree Golf	37-39
	10	Relative Motion and Combining Vectors	40-43
	11	LINEAR MOTION QUIZ SHOW	-
Unit 2. Laws of Motion	12	Assessment	44-47
	13	Forces	48-53
	14	Free Body Diagrams	54-58
	15	Cup Stack Challenge	59
	16	The Law of Inertia	60-63
	17	Mass vs Weight	64-66
	18	Inertia Experiments	67-70
	19	Newton's Second Law	71-75
	20	Actions and Reactions	76-79
	21	Balloon Races	80-81
	22	Gravity and Free Fall	82-86
	23	Space Station Physics	87-89
	24	Lab Reports and Gravity Project	90-95
	25	NEWTON'S LAWS QUIZ SHOW	-
	26	Kinetic vs Potential Energy	98-102
Unit 3. Work and Energy	27	Assessment	96-97
	28	Work	103-105
	29	Power	106-109
	30	Double Bounce	110-111
	31	Momentum	112-113
	32	Collisions	114-115
	33	Center of Mass	116-118
	34	Racing Wheels and Center of Mass	119-121

	<b>Lesson</b>	<b>Topic</b>	<b>Pages</b>
<b>Unit 3. Work and Energy</b>	35	Rotational Motion	122-123
	36	Simple Machines	124-126
	37	Tensegrity Table	127
	38	Mechanical Advantage	128-129
	39	Relativity	130-132
	40	Rube Goldberg Machine	133
	41	FINAL QUIZ SHOW	-
	42	Assessment	134-136

## SUPPLY LIST:

### Lesson 3 - Fun Physics Tricks

- 1 bottle with a narrow neck
- Piece of paper or a dollar bill
- 5 quarters
- 3 matches or flat-tipped toothpicks
- 1 shoelace
- 2 books of approximately the same size

### Lesson 15 - Cup Stack Challenge

- 5 stackable paper cups
- 4 index cards or squares of paper
- 15 coins (any type)
- 4-6 short lengths of string or ribbon
- Tape

### Lesson 18 - Inertia Experiments

#### Egg Splash

- Toilet paper tube
- 1 "light" egg
- 1 "heavy" egg
- Aluminum pie pan or piece of cardboard
- A large cup
- Rag or towel (for cleanup)

#### Tablecloth Pull

- Smooth cloth or scarf
- Bath towel
- Flat table surface
- Unbreakable dishes or water bottles

#### Inertia Hat

- Wire cutters (optional)
- Wire hanger
- 2 balls (tennis, wiffle) or other objects

### Lesson 21 - Racing Balloons

- 2 Balloons
- 2 straws
- 30+ feet of thread or fishing line
- 30+ feet of twine
- Tape
- Clip or clothespin (optional)

### Lesson 24 - Gravity Project

#### Water Rocket Lab\*

- Empty plastic 2 liter or 1 liter bottles
- A rubber cork and tubing to fit to a bike pump
- Fins to stabilize the bottle

- Bike pump

#### Hang Time Lab

- A tennis ball to throw
  - Camera or stopwatch for timing
  - Ball launcher
- #### Horizontal Motion and Gravity Lab
- 2 identical coins
  - Camera for timing
  - Ruler
  - Measuring tape

#### Lesson 30 - Double Bounce

- A larger ball that bounces such as a basketball or soccer ball
- A smaller ball that bounces such as a tennis ball or racquet ball
- Camera (for timing)
- Glue gun (optional)

#### Lesson 34 - Wheels and Rotation

#### Racing Wheels

- 12 Small paper plates
- 3 Pencils
- Pennies or other small weights such as nuts or bolts
- Tape or glue
- Sloped table or ramp
- Nail or drill to make a hole in a paper plate

#### Center of Mass

- Paperclip
- Pencil or pen
- Push pin
- Cardboard cereal box
- Straight edge
- String or yarn

#### Lesson 37 - Tensegrity Table

- At least 12 popsicle sticks
- 60 cm (2ft) of string
- A drill
- Hot glue, super glue, or duct tape

#### Lesson 40 - Rube Goldberg Machine

- Use any supplies you have on hand!

\*A water rocket kit is recommended for this activity

# PHYSICS – THE FUNDAMENTAL SCIENCE

Physics is a broad field of science dedicated to understanding matter, space, energy, and time. It has dozens of different areas of specialization!

If you could spend a day working with a physicist, which of these areas would you like to explore? Put a star or checkmark by your top three choices.

## CLASSICAL MECHANICS



The study of how everyday objects move and behave

## QUANTUM MECHANICS



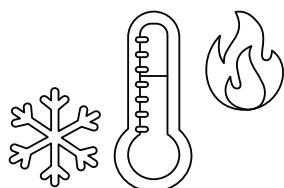
The study of how very small particles behave

## ELECTROMAGNETISM



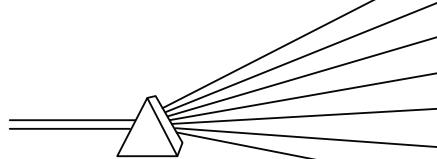
The study of electric and magnetic fields

## THERMODYNAMICS



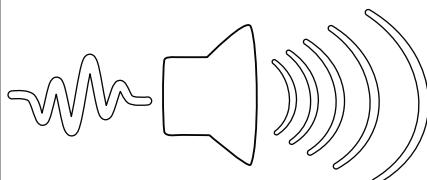
The study of heat, energy, and entropy

## OPTICS



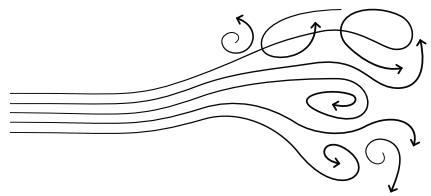
The study of the behavior and properties of light

## ACOUSTICS



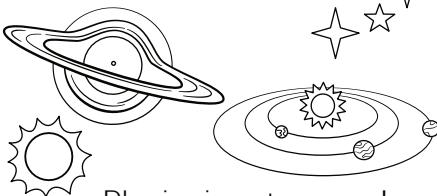
The study of mechanical waves such as sound

## FLUID DYNAMICS



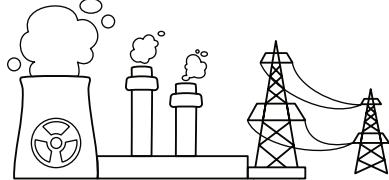
The study of the flow of liquids and gases

## ASTROPHYSICS



Physics in outer space! How stars, black holes, and solar systems work

## NUCLEAR PHYSICS



The study of atomic nuclei and the generation of nuclear energy

PICK ONE OF THE TOPICS YOU SELECTED ABOVE. WHAT DO YOU ALREADY KNOW ABOUT IT? WHAT ARE YOU CURIOUS ABOUT?

# FOR BEST LEARNING

## 1 DO THE HANDS-ON ACTIVITIES

Gather all of the supplies in advance. Record your results and share them with a friend.



WHEN WILL YOU GET SUPPLIES AND WHERE WILL YOU STORE THEM? WHO WILL YOU SHARE RESULTS WITH AND HOW?  
MAKE A SPECIFIC PLAN FOR DOING THE ACTIVITIES:

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## 2 USE THE NOTES

Fill them out! This can be done in advance, during, or after watching the video lesson.



MAKE A SPECIFIC PLAN FOR USING THE NOTES:

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## 3 LEARN THE VOCABULARY

Play the physics vocab memory game, use the vocab list to make flashcards, redefine the terms in your own words, or practice using physics terms in everyday conversations.



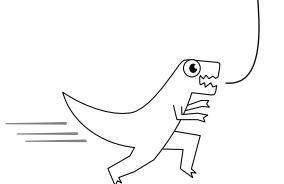
MAKE A SPECIFIC PLAN FOR LEARNING THE LANGUAGE OF PHYSICS:

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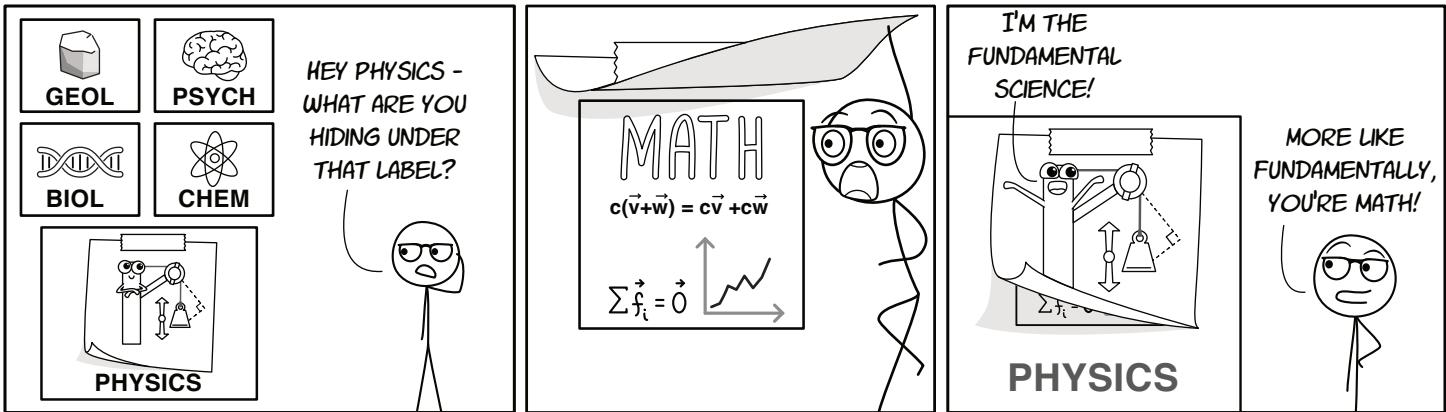
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WHAT DO YOU CALL A  
DISTANCE RAPTOR DIVIDED  
BY A TIME RAPTOR?



A VELOCIRAPTOR!



## 4 DO ALL OF THE PRACTICE PROBLEMS

Each lesson has a page or two of practice problems that should be completed individually after each lesson. Solve them on your own before looking at the answer key!

The practice problems will:

- Give you a solid foundation for more advanced science courses
- Strengthen your critical thinking and reasoning skills
- Show you how math can be used to solve real-world problems
- Prepare you to defeat Math Dad in our quiz shows



MAKE A SPECIFIC PLAN FOR CONQUERING THE PRACTICE PROBLEMS. WHEN AND WHERE WILL YOU WORK ON THEM?

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WHAT WILL YOU DO IF THERE IS A PROBLEM YOU DON'T UNDERSTAND?

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WHAT WILL YOU DO IF THERE IS A LESSON OR SET OF PRACTICE PROBLEMS THAT FEEL TOO EASY OR BORING?

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HOW WILL YOU MEASURE YOUR PROGRESS OR CHECK YOUR WORK?

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# ARE YOU READY FOR PHYSICS?

To build a strong knowledge base in physics you'll need some math skills! How do you feel about each of these areas? If your knowledge is shaky in one of these topics, you should strengthen it before starting this course.



## NUMBERS & ARITHMETIC

Strong arithmetic skills with addition, subtraction, multiplication, division, fractions, and decimals.

Can perform calculations using both positive and negative numbers and use a calculator to carry out more complex calculations.

For example: Use a calculator to find the decimal approximation of the number  $\sqrt{31}$  accurate to two decimal places.



## SLOPE & COORDINATE PLANE

Be able to plot and interpret points in the plane.

Can interpret the meaning of a simple graph.

Know that slope is rise over run.



## VARIABLES & EQUATIONS

Know that a variable is a letter or symbol representing an unknown value.

Be able to substitute a value in place of a variable.

Can solve a simple equation involving a variable.

For example:  $3 + a = 5$ . What is  $a$ ?  $4x = 12$ . What is the value of  $x$ ?



## EXPONENTS

Understand and be able to expand exponents.

For example:  $10^3$  means  $10 \cdot 10 \cdot 10$ , which equals 1,000.

Can recognize and interpret numbers in scientific notation (Optional. We won't use scientific notation often and it could be picked up during class.)

For example:  $4.5 \times 10^4 = 45,000$

# Unit 1: Kinematics

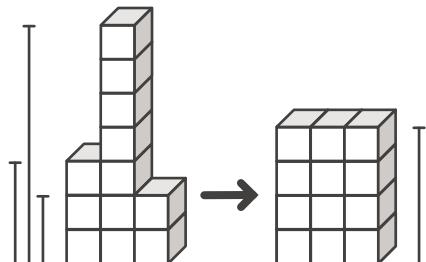
This unit covers how to describe and explain the motion of objects using graphs, diagrams, numbers, and words. Kinematics is all about how measurements are made!

## ACCELERATION

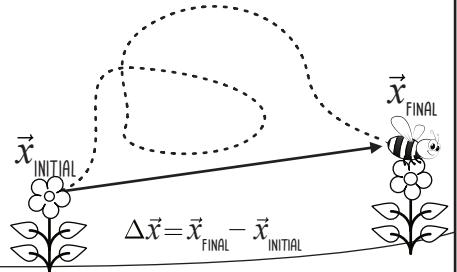


$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$$
 The rate of change of velocity

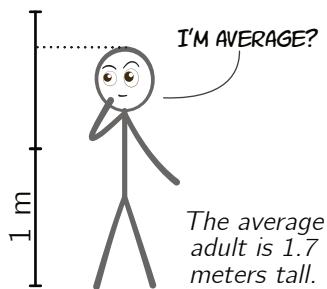
## AVERAGE



## DISPLACEMENT



## METER



$m$  A metric unit of length

## SCALAR



A quantity that has a magnitude (measurement) but no direction

## SPEED



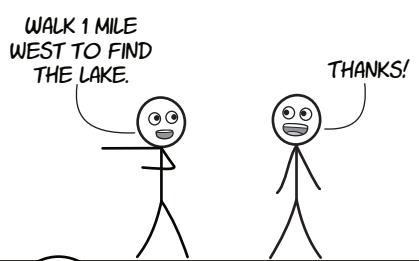
$$\frac{d}{t}$$
 Distance divided by time

## TEMPERATURE



Three different systems for measuring temperature

## VECTOR



$\vec{v}$  A quantity that has both magnitude and direction

## VELOCITY



$$\frac{\Delta \vec{x}}{\Delta t}$$
 Change in position divided by change in time

The science of motion!

**FILL IN THE BLANKS:**

one      advantage      units      standard      prefixes

The metric system or SI (International System of Units) is the international \_\_\_\_\_ of measurement. The SI has 7 base \_\_\_\_\_ that are defined in relation to universal constants. One \_\_\_\_\_ of SI is that it has only \_\_\_\_\_ unit for each quantity or type of measurement. SI systems uses the same \_\_\_\_\_ to represent multiples or powers of 10. Kilo means 1,000, so a kilometer will always have 1,000 meters and a kilogram contains 1,000 grams, etc.

**CONVERTING UNITS:**

Use the steps shown in the two examples below to complete the next conversions:

**1. HOW MANY FEET LONG IS A MARATHON?**

A marathon is 26.2 miles.

There are 5,280 feet in 1 mile.

$$26.2 \text{ mi} = 26.2 \text{ mi} \cdot 1$$

$$= 26.2 \text{ mi} \cdot \frac{5,280 \text{ ft}}{1 \text{ mi}}$$

$$= \frac{26.2 \text{ mi} \cdot 5,280 \text{ ft}}{1 \text{ mi}}$$

$$= 138,336 \text{ ft}$$

IN MATHEMATICS, WE CAN  
ALWAYS ADD ZERO, MULTIPLY  
BY ONE, OR SUBSTITUTE  
SOMETHING OF EQUAL VALUE.

**2. HOW MANY METERS TALL IS MATH DAD?**

There are 3.28 feet in 1 meter.

Math Dad is 5.5 ft tall.

$$5.5 \text{ feet} = 5.5 \text{ ft} \cdot 1$$

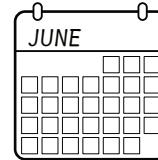
$$= 5.5 \text{ ft} \cdot \frac{1 \text{ m}}{3.28 \text{ ft}}$$

$$= \frac{5.5 \text{ ft} \cdot 1 \text{ m}}{3.28 \text{ ft}}$$

$$= 1.68 \text{ m}$$

**3. HOW MANY MARATHONS WOULD IT TAKE TO EQUAL THE CIRCUMFERENCE OF THE EARTH?**

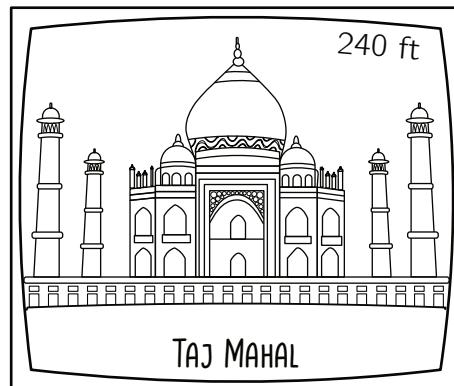
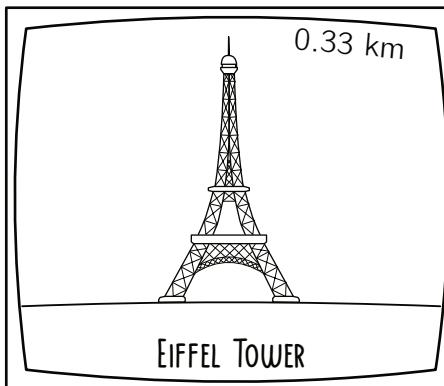
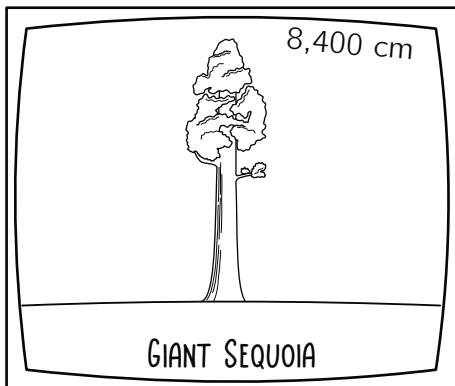
Circumference of the Earth = 24,902 miles.

**4. HOW MANY MINUTES ARE THERE IN JUNE?**

When we multiply a number by a unit conversion fraction, we're really just multiplying by 1!



Measuring is an important tool in physics. Can you rank the following from shortest to tallest? Each has been measured accurately, but the measurements are in different units!



Use the table to convert each of the measurements above to meters. Then sketch each object onto the grid below to see how they compare in height to the Great Pyramid of Giza.

#### IMPERIAL SYSTEM

1 foot = 12 inches

1 mile = 5,280 feet

#### METRIC SYSTEM

1 meter = 1,000 millimeters

1 meter = 100 centimeters

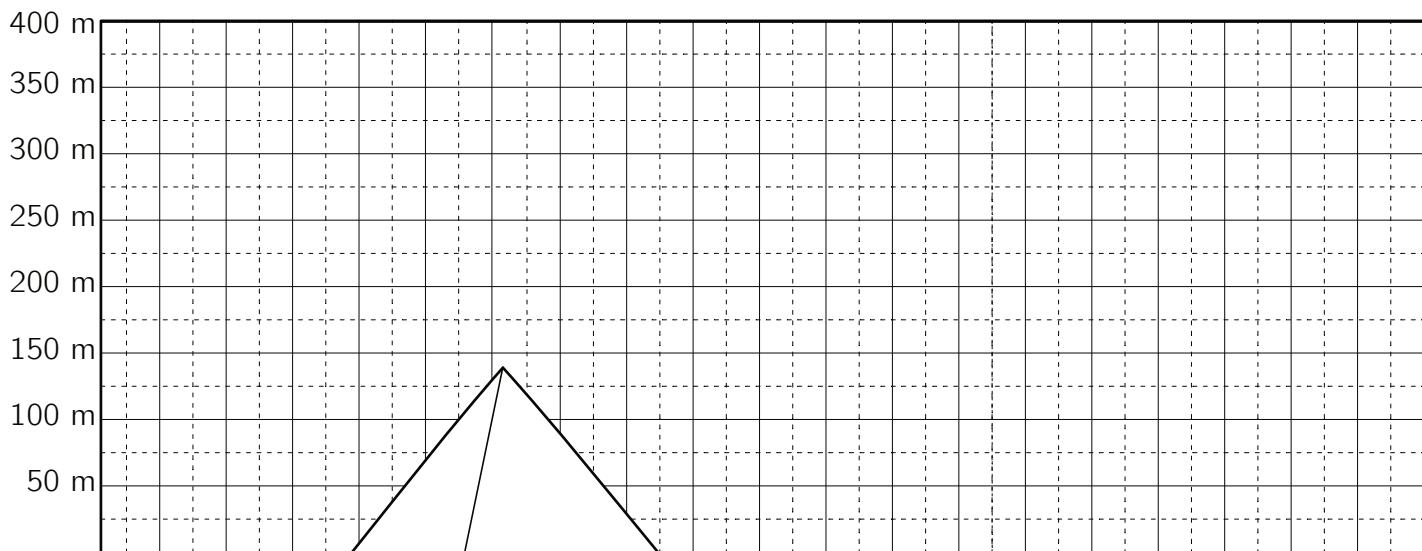
1 kilometer = 1,000 meters

#### CONVERTING IMPERIAL TO METRIC

1 inch ≈ 2.54 centimeters

1 mile ≈ 1.609 kilometers

1 foot ≈ 0.3 meters



# DIRECT VS INDIRECT MEASUREMENT

Some things, like the volume of a jar, can be measured directly. When candy is in a sealed jar, the number of candies can't be counted directly, but measurements can be used to give a good *estimation*.

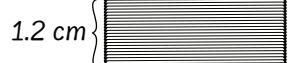
*How many candies in the jar?*



1 pint jar =  $473 \text{ cm}^3$   
1 candy =  $1.65 \text{ cm}^3$   
17 candies fit on the bottom row of the jar  
The jar is almost 10 candies tall

A single piece of paper is too thin to be measured with a ruler – or is it?  
Use the clues below to measure the thickness of a piece of paper *indirectly*!

*How thick is 1 piece of paper?*



A stack of 100 papers is 1.2 cm tall.

## A MEETING OF IMPERIAL MEASURES

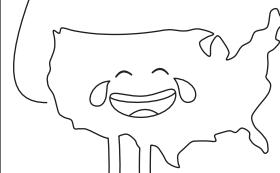
WHAT'S ON THE AGENDA FOR TODAY'S MEETING?



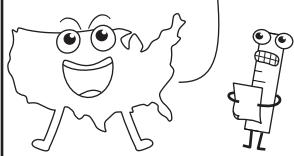
THERE HAVE BEEN COMPLAINTS THAT OUR SYSTEM IS MORE DIFFICULT TO USE.



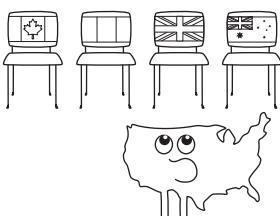
HA! METRIC IS BORING. WHO WOULD WANT TO DIVIDE BY 1,000 WHEN THEY COULD DIVIDE BY 5,280 INSTEAD?



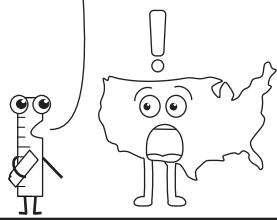
IMPERIAL MEANS EMPIRE, SO TAKING OVER THE WORLD IS OUR DESTINY! I BET WORLD DOMINATION IS ON THE AGENDA!



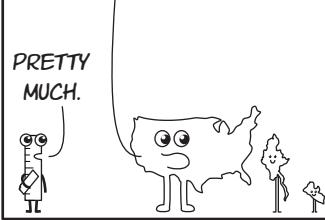
HEY, WHERE ARE CANADA, IRELAND, THE UNITED KINGDOM, AND AUSTRALIA?



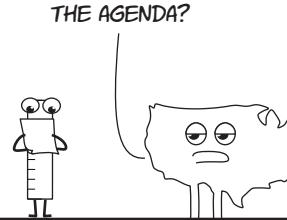
THEY ALL SWITCHED TO METRIC MORE THAN THIRTY YEARS AGO.



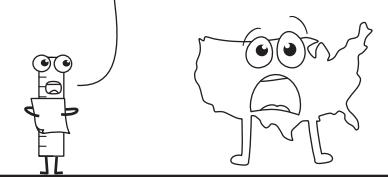
THE USA, LIBERIA, AND MYANMAR ARE THE ONLY ONES STILL USING MILES AND FEET?



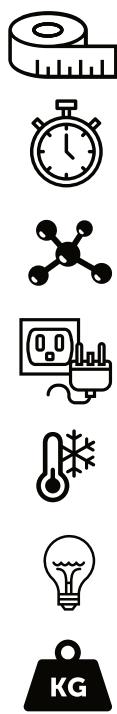
I GUESS WE SHOULD START THE MEETING. WHAT'S FIRST ON THE AGENDA?



A PETITION FOR CONVERTING TO THE METRIC SYSTEM. AUGH!!



## THE BASE UNITS



Length <b>meter (m)</b>
Time <b>Second (s)</b>
Quantity <b>Mole (mol)</b>
Electric current <b>Ampere (A)</b>
Temperature <b>Kelvin (K)</b>
Luminous intensity <b>Candela (cd)</b>
Mass <b>Kilogram (kg)</b>

## WHERE THEY CAME FROM

The distance from the North Pole to the equator divided by ten million
1/86,400 of a day
The number of atoms in 12 grams of carbon
1/10 the electric current that produces a certain amount of force
Kelvin = Celsius + 273 degrees (the C° temperature scale comes from the freezing/boiling points of water)
The brightness of a standard candle flame
The weight of one liter of water

## BASE UNITS CAN BE COMBINED

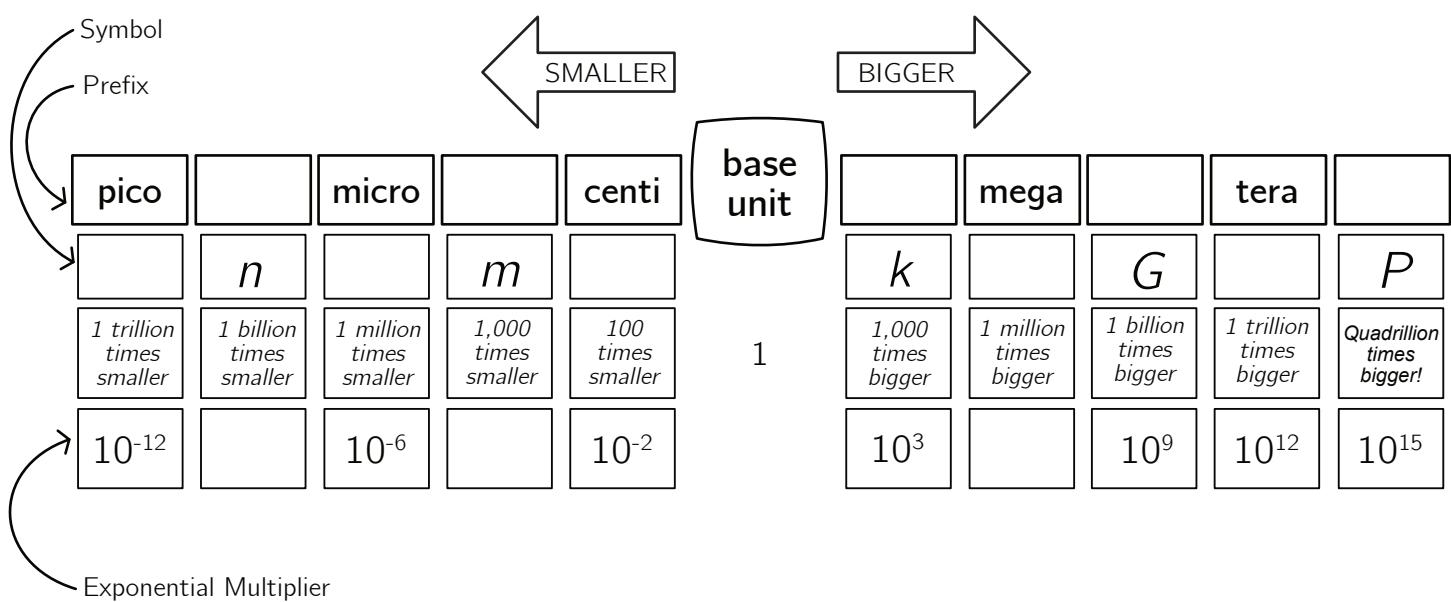
### TO MAKE MANY MORE UNITS!

Circle the units you've seen before. Put a box around ones that are new or unfamiliar.

hertz	pascal
newton	watt
volt	ohm
lumen	joule
farad	sievert
coulomb	

## SI PREFIXES

Fill in the missing prefixes, symbols, and multipliers below:

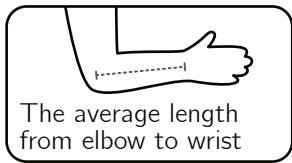


For more about metric prefixes and notation, check out the table in the appendix!

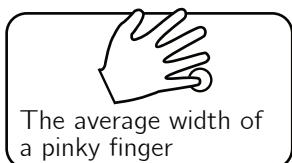
# PRACTICE PROBLEMS – MIGHTY MEASURES

## MATCHING LENGTHS:

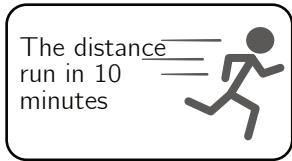
Draw a line to match each distance with its best measurement.



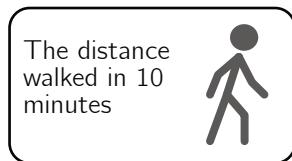
1 km



1 in



1 yd



1 mi

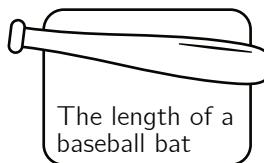
## A TABLE ON COMPUTER DATA:

Use your knowledge of the metric system to complete the table below and fill in the blanks below:

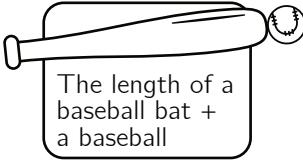
<b>Unit:</b>	<b>Number of bytes:</b>
byte	1
Kilobyte (KB)	1,000
Megabyte (MB)	
Gigabyte (GB)	
Terabyte (TB)	
Petabyte (PB)	



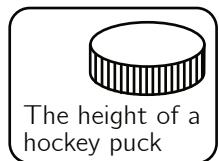
1 mm



1 ft



1 cm



1 m

\_\_\_\_\_ KB = 1 MB.

\_\_\_\_\_ megabytes = 1 gigabyte.

1 terabyte = \_\_\_\_\_ megabytes.

\_\_\_\_\_ GB = 1 PB

How many kilobytes are in a petabyte?

\_\_\_\_\_

## PRACTICE PROBLEMS – MIGHTY MEASURES

Convert units to answer each question. Practice doing neat work!

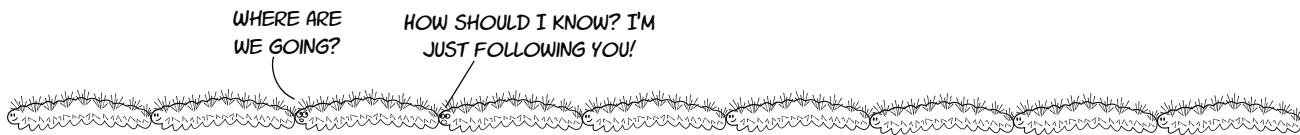
1 Jerry says he'll trade Jill 41 dimes for 16 quarters. Jill agrees. Who has more money after the trade and why?

2 How many dollars are the same value as 61 quarters?

3 How many Abs are in 10 Gabs?

1 Ab = 4 Babs
3 Babs = 7 Cabs
2 Cabs = 3 Dabs
7 Dabs = 1 Fab
6 Fabs = 1 Gab

**Challenge Question** How many Fabs are in 8 Babs?

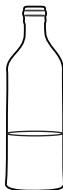


**Challenge Question**

The pine processionary caterpillar (*Thaumetopoea pityocampa*) is 4 cm long. When migrating, the caterpillars march in a single-file line. If a line of caterpillars is just under 1 mile long, then how many caterpillars are marching in the line?

# FUN PHYSICS TRICKS

## MATERIALS



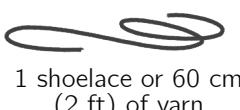
1 water bottle with a narrow neck and lid that can be partially filled with water



3 matches or flat-tipped toothpicks



2 books that are approximately the same size



1 shoelace or 60 cm (2 ft) of yarn



A dollar bill or similarly-sized piece of paper



5 quarters

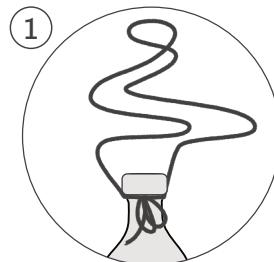
## GOALS

- ★ Experience curiosity and wonder about physics!
- ★ Get hands-on experience with physics principles that we will learn about later in this course.
- ★ Bonus: Learn 3 tricks that can stump your friends and family members!

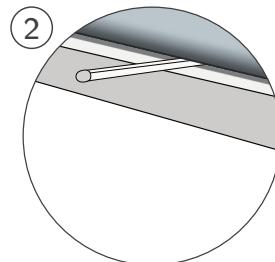
### 1 MIGHTY MATCH CHALLENGE

Can you hang a water bottle from the edge of a table using only 3 matches and yarn?

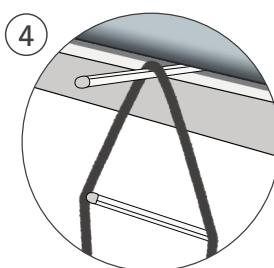
1. Tie the yarn to a water bottle that is  $\frac{1}{4}$  full of water. For best results, the bottle should not weigh more than 0.4 kg (1 pound or 16 ounces). The yarn should extend from the bottle in one long loop. Make sure the yarn is secure and supports the weight of the bottle.



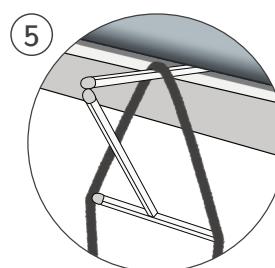
2. Place a match on the edge of a table so that it dangles a bit more than half-way over the edge. Place a counterweight (such as the two books) on the end of the match to hold it in place.



3. Hang the bottle from the match so that the string is up against the side of the table.

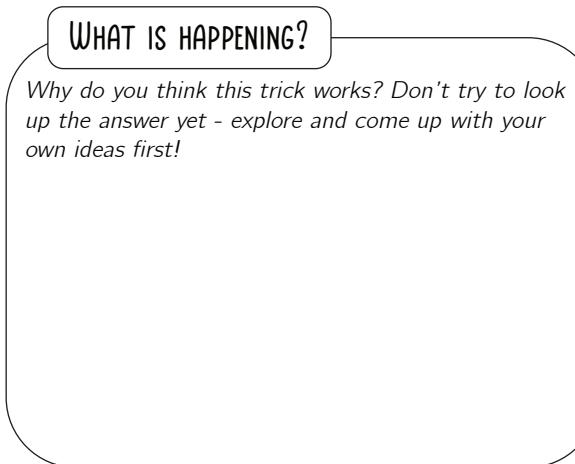


4. Place a second match about one match length below the match that is placed on the table and orient it so that it is wedged between the two strands of string.



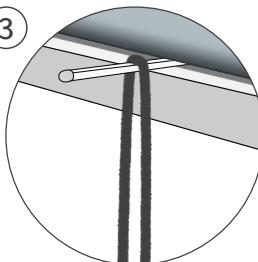
5. Wedge a third match between the two matches so that the heads are touching. Adjust as needed.

6. Once the matches are steady, remove the counterweight.



#### WHAT IS HAPPENING?

Why do you think this trick works? Don't try to look up the answer yet - explore and come up with your own ideas first!



## FUN PHYSICS TRICKS

### ② DOLLAR BILL CHALLENGE

Can you pull the dollar from beneath the coins without them falling off?

1. Place a dollar bill on a bottle and then place 5 large coins such as quarters on top. Challenge a friend to remove the bill without touching the bottle or knocking off the coins.

2. To remove the bill, pinch one end of the bill with one hand. Don't pull. This hand need to remain stationary.

3. Push down with your other index finger to form a bit of a valley.

4. Slap down quickly with the flat index finger, pushing on the area where the dip in the dollar bill was. The other hand that is pinching the dollar bill should remain stationary.

With a bit of practice, you'll be able to push fast enough on the bill that it will slide out but the the coins will stay in place!



#### WHAT IS HAPPENING?

Why do you think this trick works? Don't try to look up the answer yet. First explore and come up with your own idea!

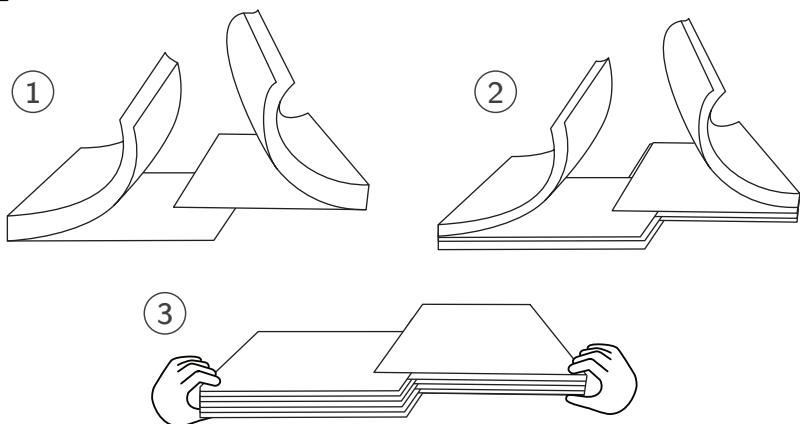
### ③ BOOK PULL CHALLENGE

Can you pull two books apart when the pages are overlapped?

1. Take two books or two packs of post-it notes and place them on a table or other flat surface. Hold up all but the back cover and overlap the back covers so that  $\frac{1}{4}$  to  $\frac{1}{2}$  of one of the pages is covered by the other book.

2. Let the pages flip down so that they alternate.

3. Once the pages have been interwoven and the books are closed, challenge someone to hold on the spine of each book and pull them apart.



#### WHAT IS HAPPENING?

Why do you think this trick works? Don't try to look up the answer yet. Explore and come up with your own ideas first!

## 1 MIGHTY MATCH CHALLENGE

Did the demonstration work? What tips would you give someone else trying this for the first time? Did the activity spark any questions or discoveries?

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## 2 DOLLAR BILL CHALLENGE

Did the demonstration work? What tips would you give someone else trying this for the first time? Did the activity spark any questions or discoveries?

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## 3 BOOK PULL CHALLENGE

Did the demonstration work? What tips would you give someone else trying this for the first time? Did the activity spark any questions or discoveries?

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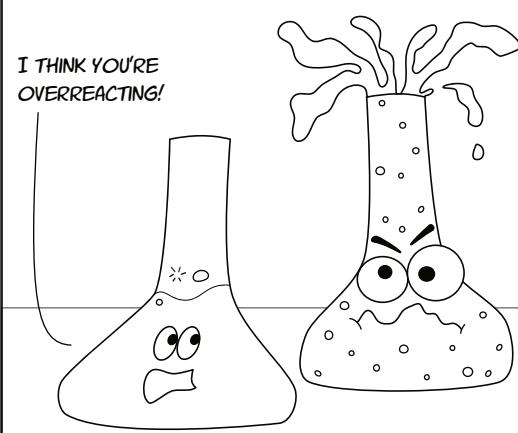
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## EXPERT:

A PERSON WHO  
HAS MADE ALL  
THE MISTAKES  
THAT CAN BE  
MADE IN A VERY  
NARROW FIELD.

-NIELS BOHR

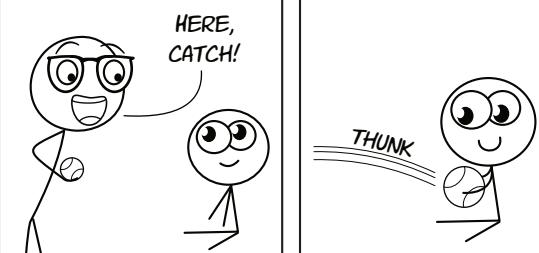
I THINK YOU'RE  
OVERREACTING!



If at first you  
don't succeed,  
analyze, revise,  
and then try  
again.

# MEASURING MOTION

PLAYING BALL WITH A PHYSICIST



YOU CALCULATED THE FORCE OF GRAVITY INTERACTING WITH MY PUSH, CONSIDERED AIR RESISTANCE AND ROTATION AND EXTENDED YOUR ARM AT JUST THE RIGHT MOMENT! YOU'RE A GENIUS IN PHYSICS!



You already have a lot of experience with **mechanics**, the branch of physics that studies the motion of objects. Understanding vectors will help give you tools to make models and speak the language of physics!

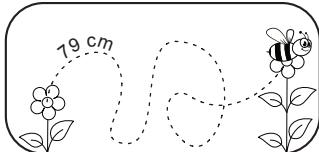
The terms illustrated below are: acceleration, displacement, distance, mass, speed, temperature, temperature gradient, time, velocity, and weight. Write each term next to the matching illustration.

## SCALARS

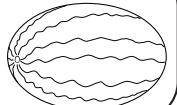
VS

## VECTORS

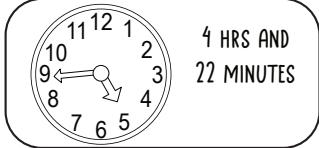
DEFINITION:



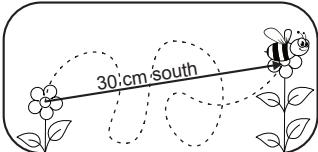
THE AMOUNT OF MATTER IN AN OBJECT (ITS SIZE)



0.5 METERS PER SECOND



DEFINITION:



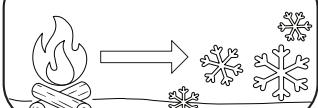
DOWNTWARD FORCE DUE TO EARTH'S GRAVITY



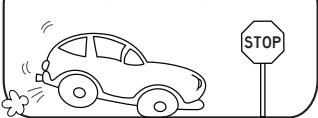
+0.5 METERS PER SECOND



A STEADY TEMPERATURE GRADIENT



A CAR SLOWING 10 M/S PER SECOND



## FILL IN THE BLANKS:

vector   magnitude   direction   scalar

In physics, the size or measurement of something is called its \_\_\_\_\_ . A quantity that tells us the magnitude but NOT the direction is called a \_\_\_\_\_ quantity. Often, we need to know both measurement AND \_\_\_\_\_. The direction can be described in relation to an object using terms like up, down, north, south, east, west, left, or right. A quantity that has both a magnitude and a direction is called a \_\_\_\_\_ quantity.

CIRCLE ALL OF  
THE VECTORS:

3 liters

5 ft per second  
east of the  
yellow car

100 square  
kilometers

60  
kilometers  
per hour

20 meters above

24 lbs  
downward

6 kilometers  
south

21° North

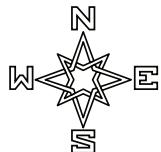
42

98 grams

20° Celsius

4 gallons  
per minute

Below are the courses for three different races. Use the scale and compass to estimate both the distance and displacement from the start of each race to the finish of each race.



START

FINISH

Distance: \_\_\_\_\_



Displacement: \_\_\_\_\_

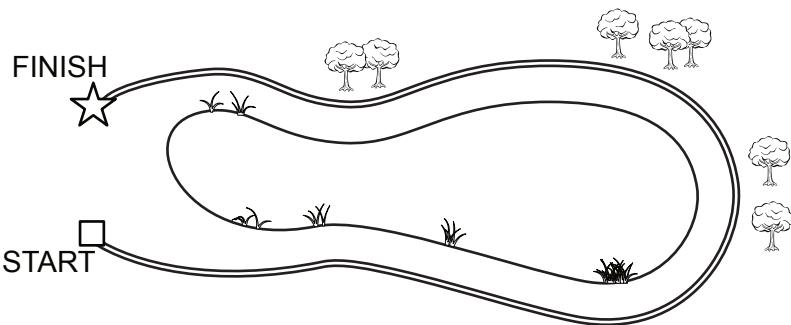
FINISH



START

Distance: \_\_\_\_\_

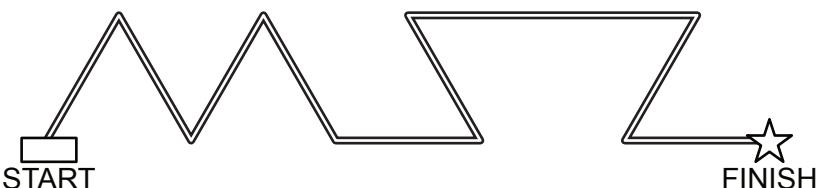
Displacement: \_\_\_\_\_



START

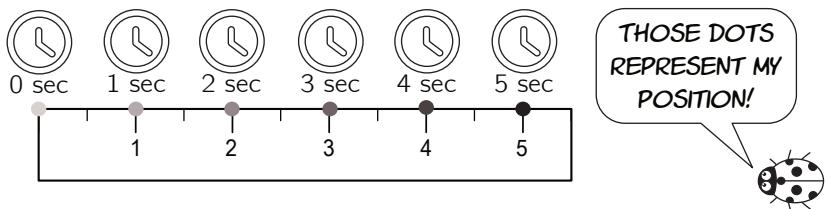
Distance: \_\_\_\_\_

Displacement: \_\_\_\_\_



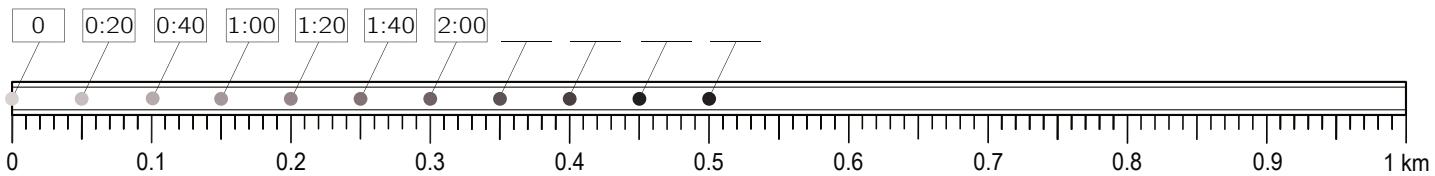


When we know the distance traveled and how much time it took, we can calculate how fast an object was moving, or its **speed**. The ladybug on the ruler moved 5 cm in 5 seconds, so its speed is 5 cm/5 seconds or 1 cm/s.



## CALCULATING SPEED

*The dots below indicate the position of a runner every 20 seconds as they run along a path.*

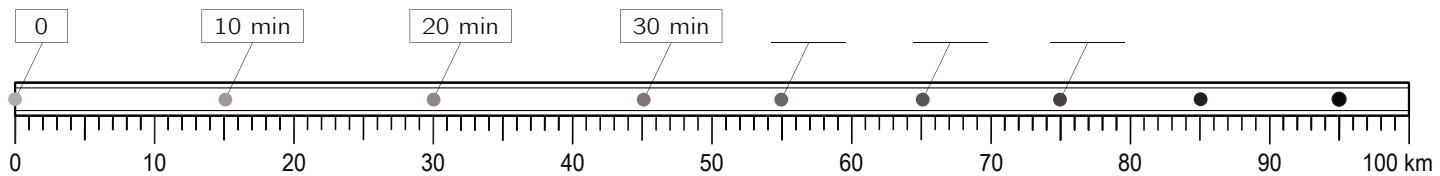


How far did they run? Be sure to include units in your answer!

How fast did they run? (Answer in km/hr)

Assuming the runner kept the same pace, how long will it take to run 1 kilometer?

*The dots below indicate the position of a car every 10 minutes driving south.*



How fast did the car travel during the first 45 km?

When did the car slow down?

How long did it take the car to reach the 75 km mark?

## PRACTICE PROBLEMS – TRACKING MOTION

### IS IT A VECTOR?

Draw lines to classify each measurement below as either a vector, a scalar, or neither a vector or scalar.

100 kg

VECTOR

400 ft<sup>2</sup>

-10 °F

enormous

8 m/s<sup>2</sup> down

SCALAR

20 gal/min

29 cm

32

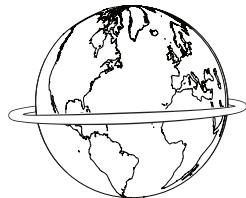
30 m south

NEITHER

north

### MEASURE THIS MOTION:

- ① Eli travels around the equator of the world in 70 days, arriving back in the exact same position from which he started his journey. What is his displacement?

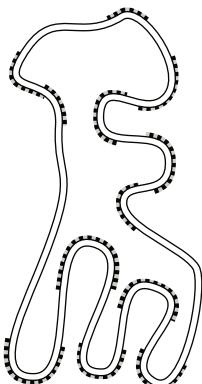


- ② Aisha and Arjun are training to run a 5K race. They ran for 24 minutes and want to know if they reached their daily running goal of completing 3 kilometers. Which will be most useful in answering their question: distance or displacement?

- ③ Kat drove 200 miles in 4 hours. What was her average speed?

## PRACTICE PROBLEMS – TRACKING MOTION

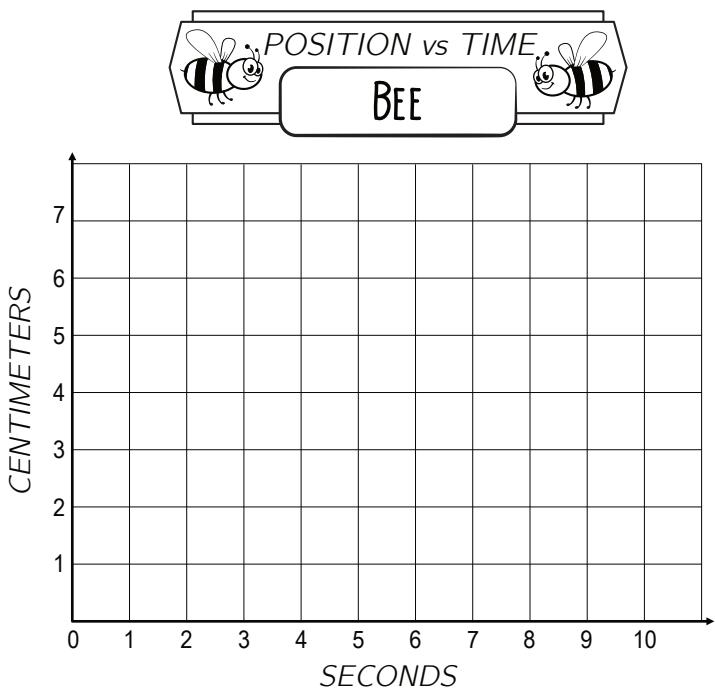
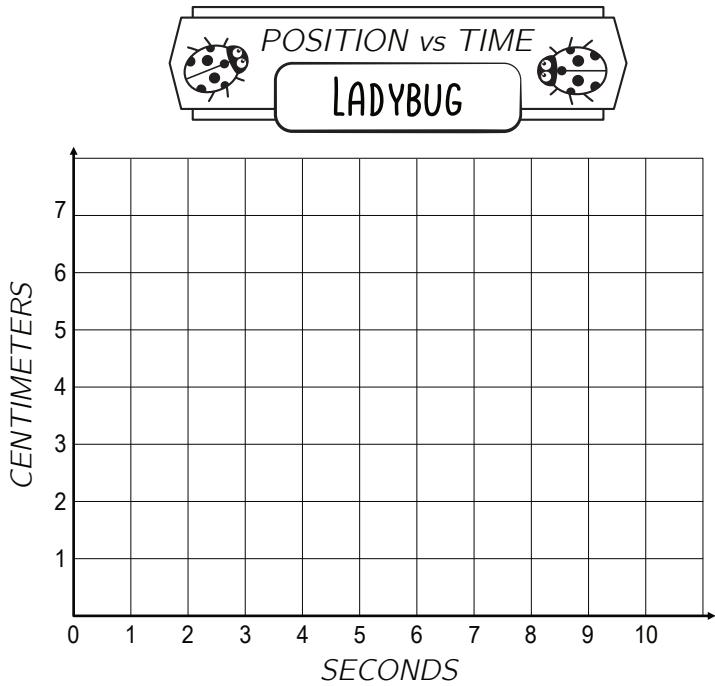
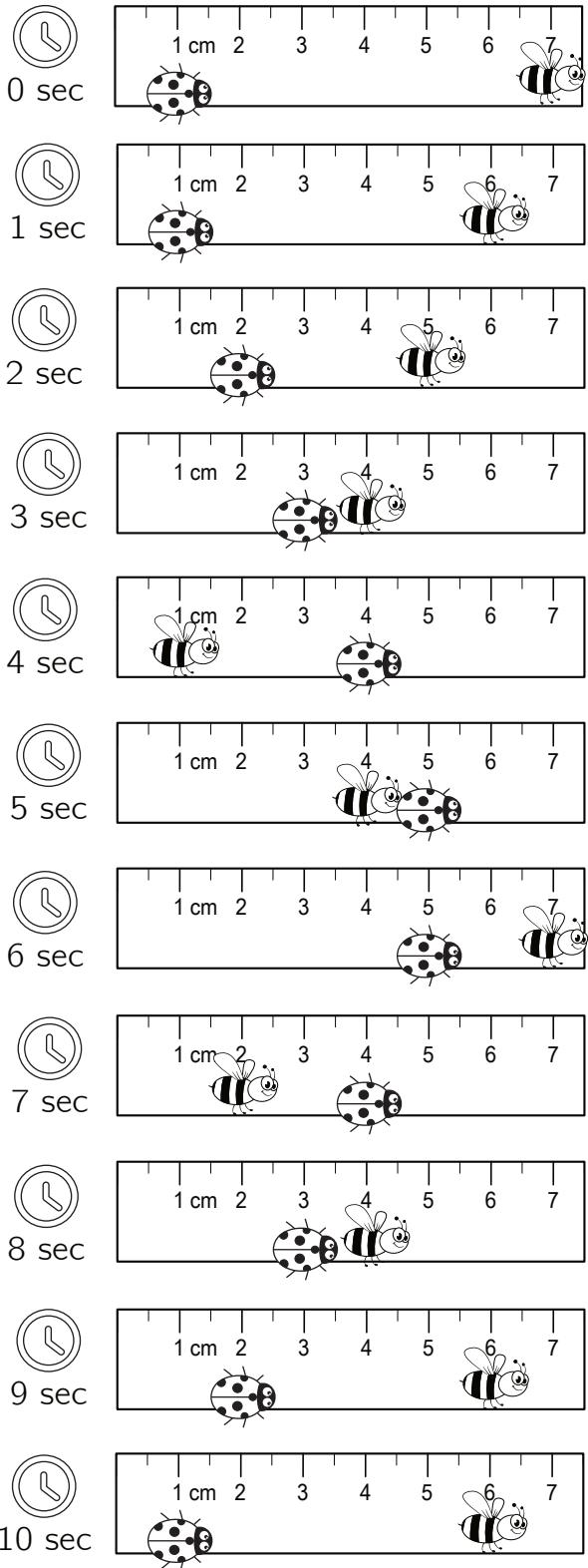
- 4 A car is driving on a freeway at a speed of 100 km/h.
- How far does the car travel in 1 min?
  - A blink lasts for about 0.3 s. How many meters does the car travel while the driver blinks?
- 5 The formula showing the relationship between  $r$  (rate),  $d$  (distance), and  $t$  (time) is often written as  $d = rt$ . Rearrange the variables to solve for  $r$  and  $t$ .
- 6 On her bike, Jade travels  $n$  miles north and then turns around and travels  $s$  miles south.
- Use  $s$  and  $n$  to write an expression that shows how far Jade traveled.
  - If Jade travels directly north and then turns around and travels directly south, will her **displacement** be the same as the total **distance** traveled?
  - Calculate Jade's displacement when  $n = 4$  and  $s = 7$ . Then write a sentence explaining what the calculation means.
- 7 A go-kart track has a length of 500 m.
- What is the average speed in m/s of a go-kart that completes 3 laps in 2.5 minutes?
  - How many laps would be completed in 4 minutes at an average speed of 8 m/s?
  - What is the displacement for a go-kart that has completed 7 complete laps?



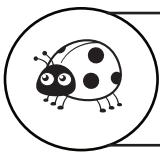
# GRAPHING MOTION

Graphs are useful for sharing information. They let us see a lot of data at the same time and help us understand the relationship between two or more things.

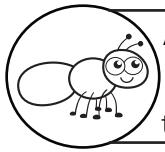
Graph the movement of the bee and ladybug below with **position** on the **vertical axis** and **time** on the **horizontal axis**.



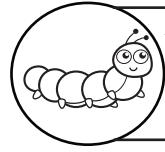
Match the time/position graph with the correct insect:



A ladybug starts at the 7 cm mark and then runs back to the start of the ruler.

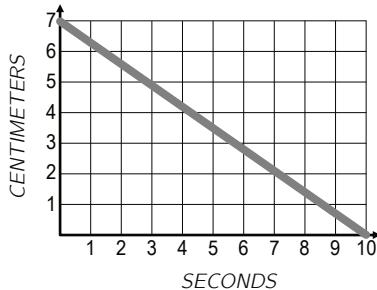


An ant travels to 3 cm and rests for 5 seconds before going forward to the 7 cm mark.

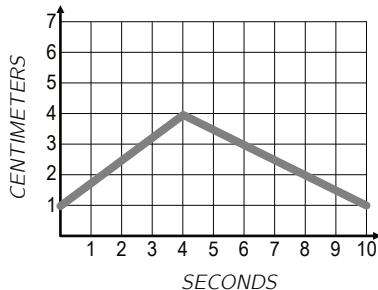


A caterpillar walks from the 1 cm mark to 4 cm and then back to 1 cm.

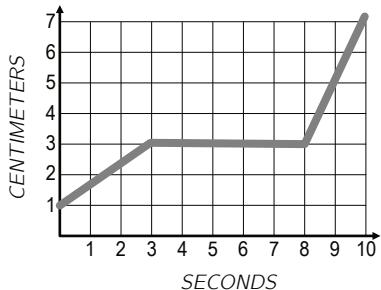
GRAPH 1



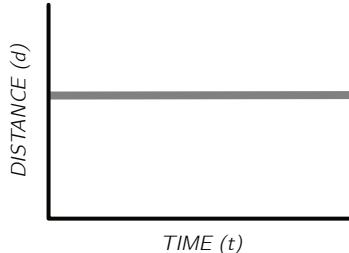
GRAPH 2



GRAPH 3



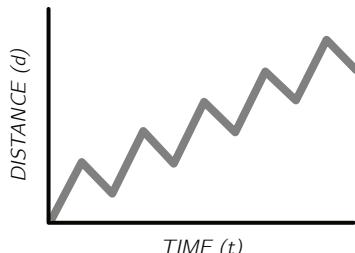
The graphs below represent the position of 3 birds on the ruler.  
Write a sentence or two describing what each bird is doing.



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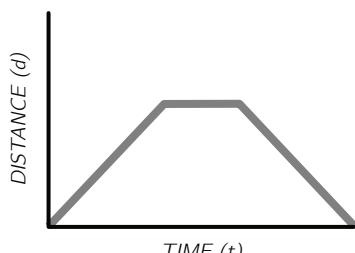
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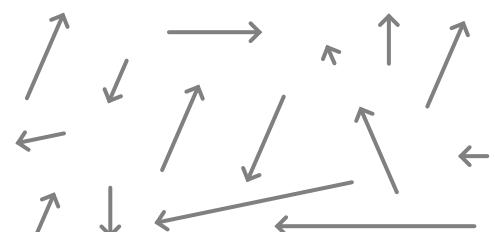
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# PLOTTING VECTORS

VECTORS have  
both \_\_\_\_\_  
and \_\_\_\_\_

Vector quantities are often represented by an arrow. Identify the vectors that are the same.



The Coast Guard boat received a call for help from a small boat. Which vector would result in a rescue?

**VECTOR A**   
 $d = 10 \text{ miles}$   
 8 mi E, 6 mi N  
 (8,6)

**VECTOR B**   
 $d = 10 \text{ miles}$   
 8 mi W, 6 mi S  
 (-8,-6)

**VECTOR C**   
 $d = 10 \text{ miles}$   
 6 mi E, 8 mi N  
 (6,8)

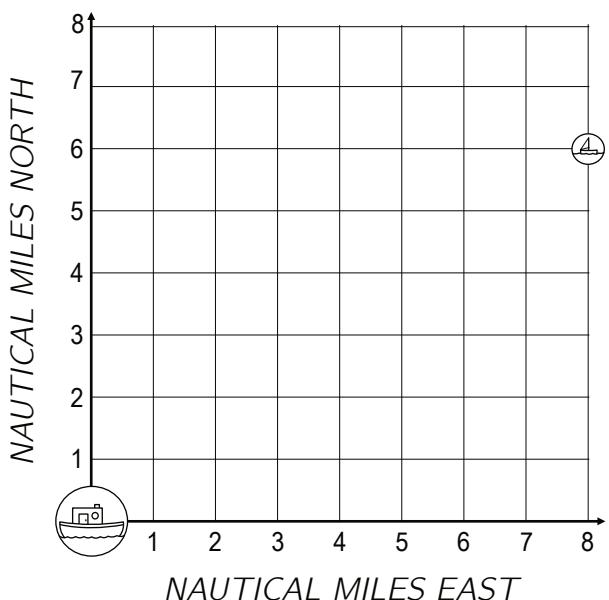
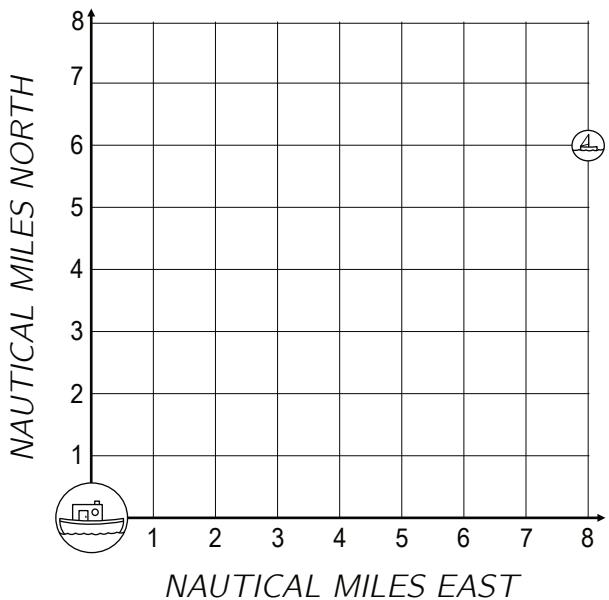
**VECTOR D**   
 $d = 5 \text{ miles}$   
 4 mi E, 3 mi N  
 (4,3)

**VECTOR E**   
 $d = 10 \text{ miles}$   
 10 mi N  
 (0,10)

**VECTOR F**   
 $d = 17 \text{ miles}$   
 15 mi E, 8 mi N  
 (15,8)

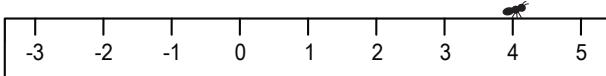
Which vectors have the correct magnitude but the wrong direction?

Which vectors have the correct direction but the wrong magnitude?



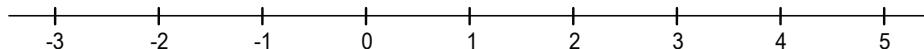
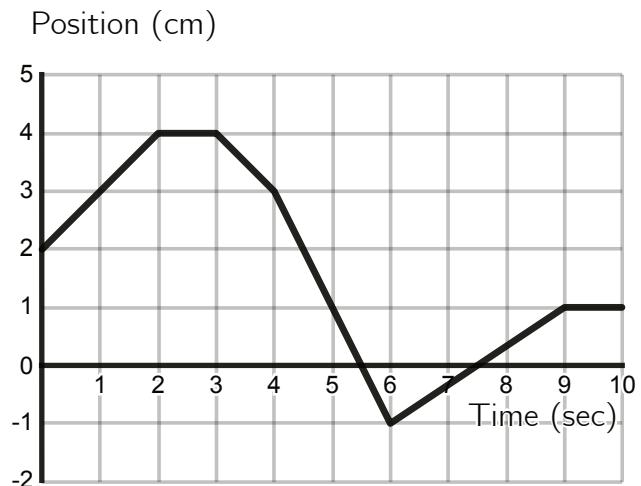
Identify 2 or more vectors that the Coast Guard could combine to reach the boat.

## PRACTICE PROBLEMS – GRAPHING MOTION



The graph to the right shows the position of an ant walking back and forth across an unusual ruler that includes negative numbers.

- ① Where did the ant start her journey?
- ② When was ant at rest?
- ③ When was the ant crawling to the right?
- ④ When was the ant at the 1 cm mark?
- ⑤ When was the ant traveling fastest?
- ⑥ Use the number line to trace the path of the ant from start (0 seconds) to finish (10s)



- ⑦ Write a short narration explaining the meaning of the graph. How would you explain the ant's motion it to a person who couldn't see the graph?

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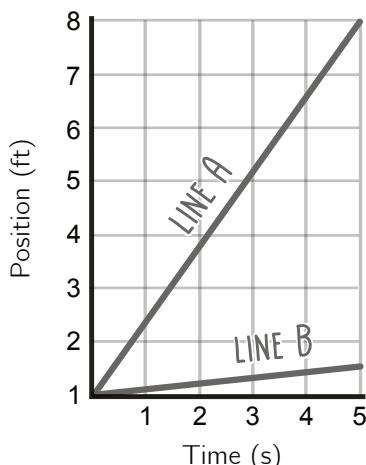
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## PRACTICE PROBLEMS – GRAPHING MOTION

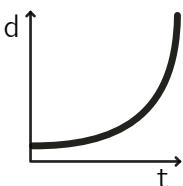
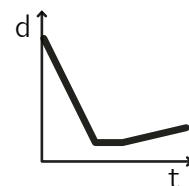
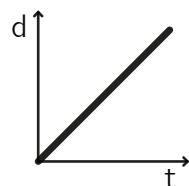
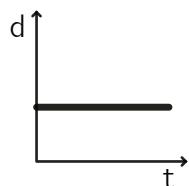
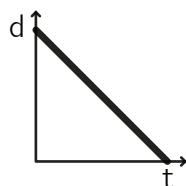
### 8 FAST OR SLOW?

One of these lines represents the motion of a rabbit moving forward very quickly. The other is for a tortoise moving slowly. Which is which and how can you tell?



### 9 MATCHING GRAPHS:

Below are 5 different graphs of distance versus time (which work the same as position vs time graphs). Match each graph with the appropriate description.



THE OBJECT IS MOVING FORWARD AT A STEADY SPEED

THE OBJECT IS NOT MOVING.

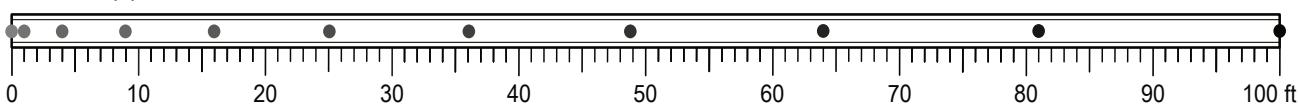
THE OBJECT IS MOVING BACKWARD AT A STEADY SPEED

THE OBJECT STARTS MOVING SLOWLY BUT THEN MOVES MUCH FASTER

THE OBJECT MOVES BACKWARDS AND THEN PAUSES BEFORE MOVING FORWARD SLOWLY

### 10

The dots below indicate the distance that a rock falls every 0.25 seconds after being dropped.



How long did it take for the rock to fall 60 feet?

When was the rock falling slowest?

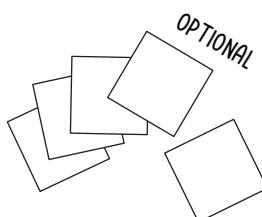
How fast was the rock falling on average from 1 s to 2 s?

# PHYSICS VOCAB MEMORY GAME

## MATERIALS



The printable  
memory cards



72 pieces of cardboard  
cut to 2.5" squares



glue or tape

## GOALS

★ Learn the vocabulary terms we will be using in this physics class!

★ Bonus: Improve your memory skills.

## PHYSICS MEMORY GAME

To create thicker cards that are easier to turn over, cut out 72 pieces of thin cardboard that measure 2.5 square inches. Use glue to place the vocabulary cards on one side of the cardboard. Leave the other side blank OR print the physics icons and glue them to the reverse side.

### HOW TO PLAY:

Shuffle the cards and lay them on the table, face down, in rows.

To determine who has the first turn, each person should choose a card. If matching cards are drawn, set them aside and draw new cards. The player with the card that comes first, alphabetically, is the person who will have the first turn.

On each turn, a player turns over two cards. If the cards are identical (a match!) the player puts that match in their pile. They then get to choose two additional cards. An additional (optional) step to improve learning: the player can only keep their match if they can define the physics term on the card in their own words.

When a player turns over two cards that do not match, those cards are turned face down again (in the same position) and it becomes the next player's turn. Continue playing until all of the cards have been paired. The person with the most pairs at the end of the game wins.

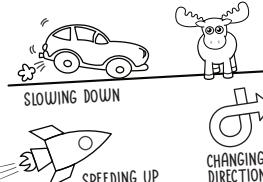
## VARIATIONS:

1. **One and Done.** Simply alternate turns until all of the cards have been paired. Players who find a match have no bonus turn.

2. **Connection Extension.** Each player can take two and only two turns if they use their vocabulary words in a sentence. For example, if a player chooses "acceleration" and "average" they could say, "The average horse has faster acceleration than the fastest human." Then they would turn over two additional cards for their bonus turn.

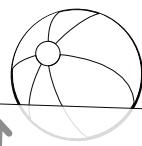
If the player cannot think of a sentence, they do not get to take their bonus turn. If the player chooses two words that match during their first turn, their sentence should use that word twice. For example, "The average houseplant thrives with below-average light."

## ACCELERATION



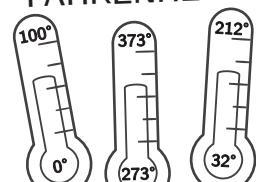
$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$  The rate of change of velocity

## BUOYANCY



$F = \rho g V$  Upward force exerted by a liquid on an object immersed in it

## Celsius vs Kelvin Fahrenheit



$^{\circ}\text{K}$   
 $^{\circ}\text{C}$   
 $^{\circ}\text{F}$  Three different systems for measuring temperature

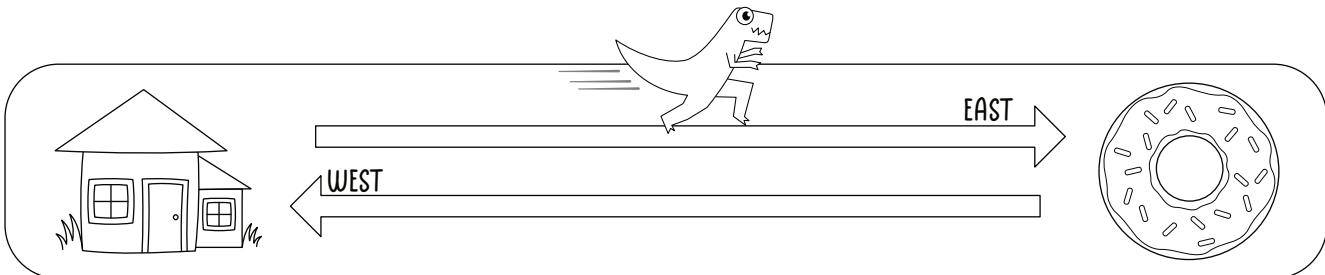
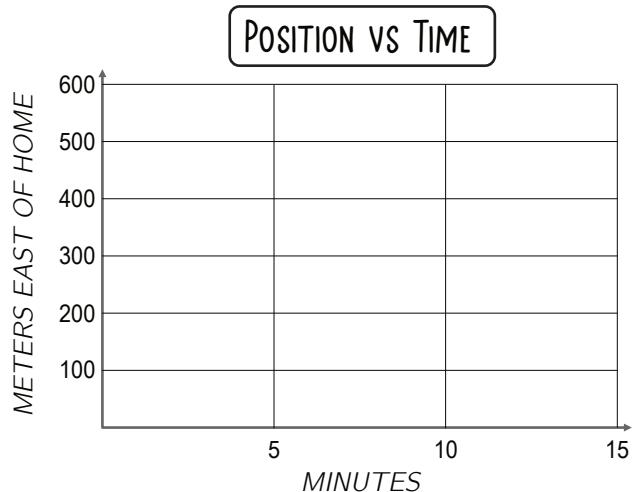
# VELOCITY

Velocity is the speed of something in a given direction. The box below describes a dinosaur's activity over 15 minutes. Use that information to plot the dinosaur's motion on the position/time graph. Then calculate its speed and velocity for each interval.

0-5 min → The dinosaur runs to a donut shop 500 meters east of his home.

5-10 min → At the donut shop, the dinosaur eats 1 donut.

10-15 min → The dinosaur runs 500 meters to return back home.



WHAT WERE THE SPEED AND VELOCITY OF THE DINOSAUR DURING EACH INTERVAL?

Interval 1 [0-5 min] speed: \_\_\_\_\_ velocity: \_\_\_\_\_

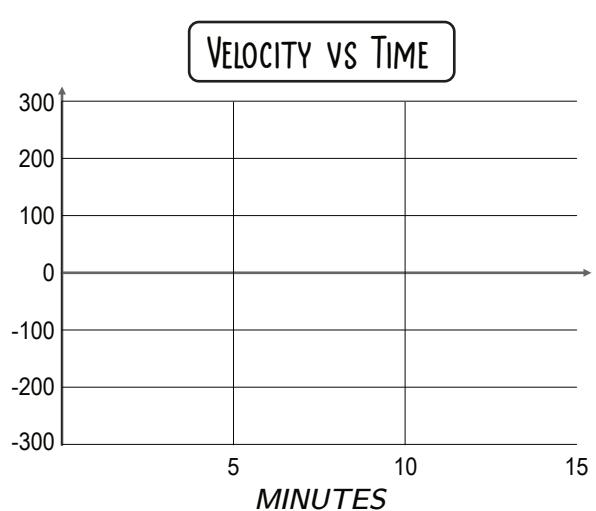
Interval 2 [5-10 min] speed: \_\_\_\_\_ velocity: \_\_\_\_\_

Interval 3 [10-15 min] speed: \_\_\_\_\_ velocity: \_\_\_\_\_

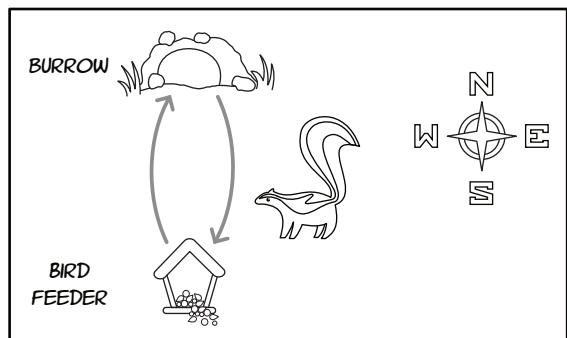
Now plot the dinosaur's journey on a **velocity** vs time graph!

CAN A VELOCITY BE NEGATIVE?  
YES!  
Positive and negative can be used to show direction, just like east and west or up and down!

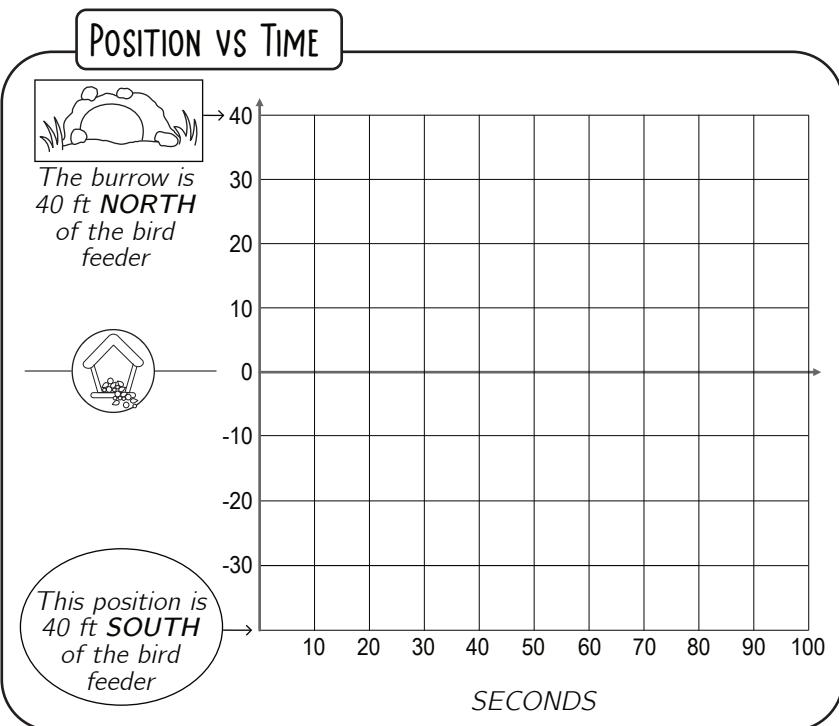
VELOCITY  
(METERS PER MINUTE WHILE TRAVELING EAST)



The box and picture below describes a skunk's travel during 50 seconds. Use this information to plot the skunk's motion on the position/time graph.



- 0-20 s** The skunk traveled 40 ft south from its burrow to visit a bird feeder at 2 feet per second.
- 20-30 s** At the bird feeder, the skunk ate bird seed for 10 seconds.
- 30-50 s** The skunk traveled north at the same rate as before.



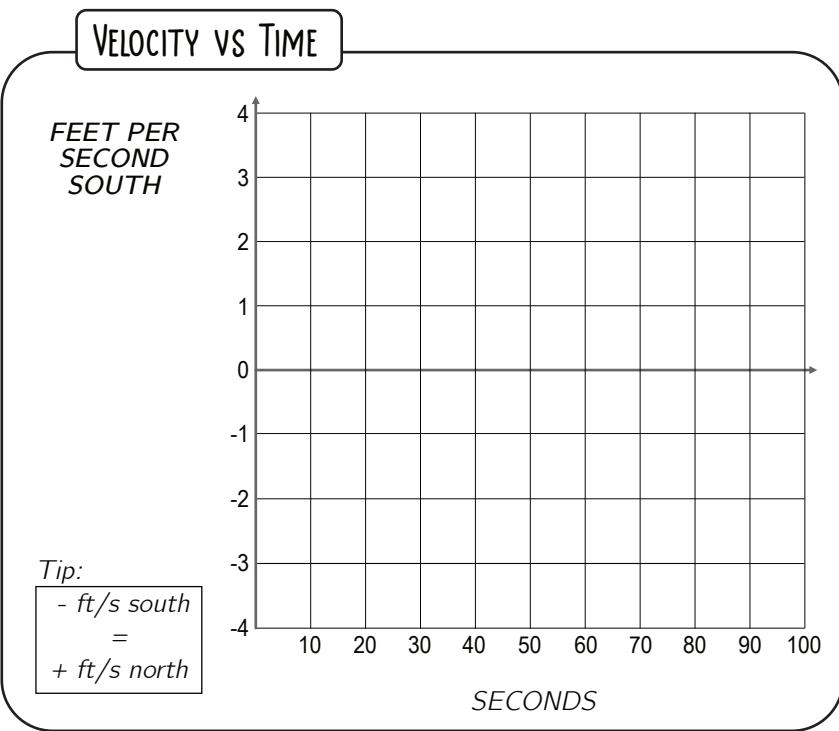
When the skunk is traveling at 2 ft/s toward the bird feeder, which direction is it going?  
(circle the answer)

2 ft/s south      or      2 ft/s north

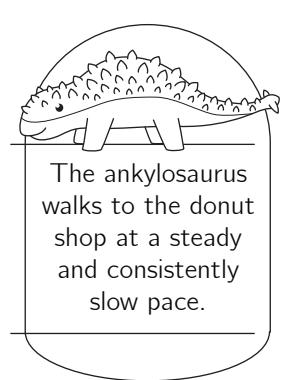
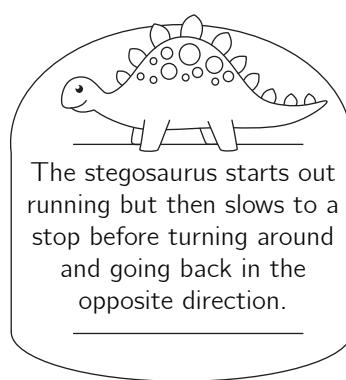
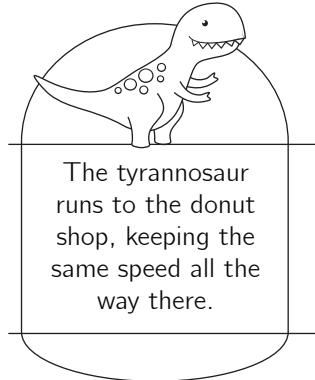
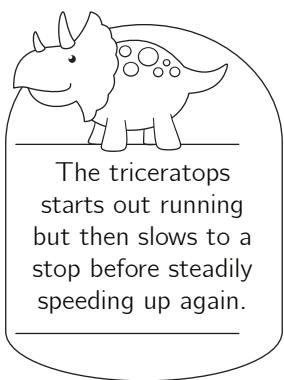
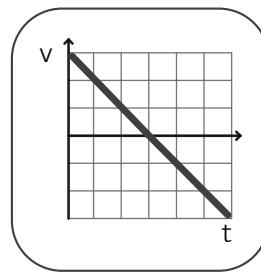
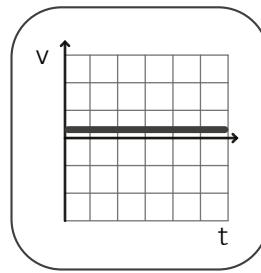
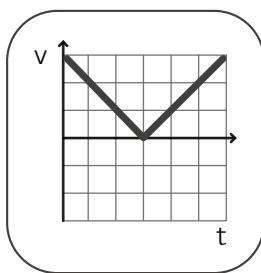
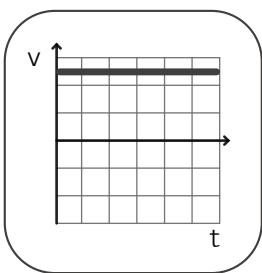
Velocity traveling toward feeder (0-20 s): \_\_\_\_\_  
Velocity at feeder (20-30 s): \_\_\_\_\_  
Velocity traveling away from feeder (30-50 s): \_\_\_\_\_

### BONUS CHALLENGE!

A squirrel and a tortoise also live in the burrow. They leave at the same time as the skunk to visit the bird feeder, but the squirrel does everything *twice as fast* and the tortoise does everything *half as fast*. Can you plot each animal's motion on the graphs?



BELow ARE 4 DIFFERENT VELOCITY VERSUS TIME GRAPHS FOR DINOS GOING TO THE DONUT SHOP.  
MATCH EACH GRAPH WITH THE CORRECT DESCRIPTION.



### DINOSAUR VS THE DONUT TRUCK

A dinosaur is chasing a donut delivery truck heading south. The truck takes off quickly, but it has to stop along the way. The dinosaur runs at a steady pace the entire time. Use the facts below to determine whether the dinosaur will get its donuts.

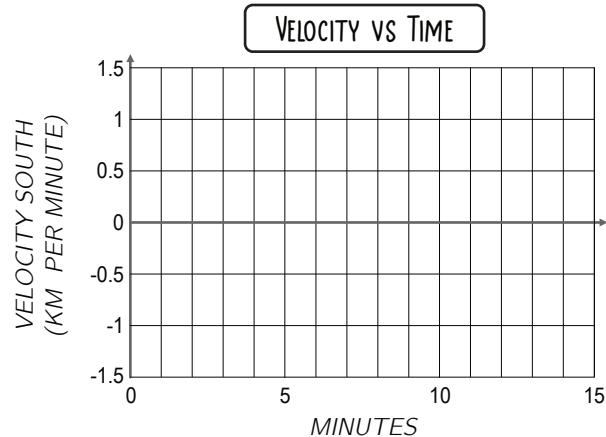
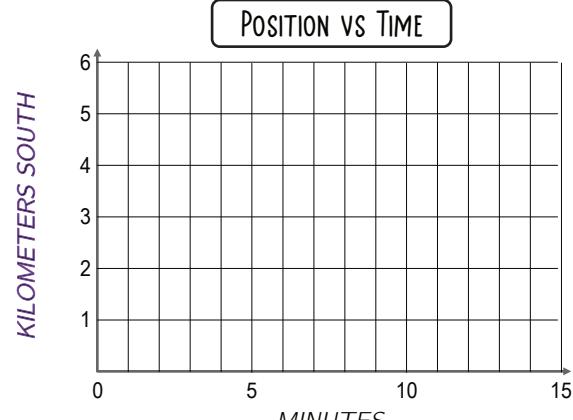
The donut truck

- drives for 3 minutes at 60 km/h,
- stops for 2 minutes,
- drives 30 km/h for 2 minutes,
- stops for 2 minutes, and
- drives 12 km/h after that.

The dinosaur can only run for 15 minutes

- It runs at 24 km/h the whole time.

Plot the position function and the velocity function for this chase and determine whether the dinosaur catches the truck. Pay close attention to units.



## PRACTICE PROBLEMS – VELOCITY

1 A car travels 240 km north in 3 hours. What is the average velocity of the car?

2 A car travels west at 60 mi/h for 4 hours. What is the displacement of the car?

3 Two cats, Belle and Carma, challenge Abe to a 100 m race. Belle is twice as fast as Abe, but Abe is twice as fast as Carma. Abe agrees to race the cats as long as they run as a team where they each run half the distance. Who will win the race?



Abe  
speed: 8 m/s



Belle  
speed: 16 m/s



Carma  
speed: 4 m/s

4 A bank robber left a note telling an accomplice where he buried stolen gold:

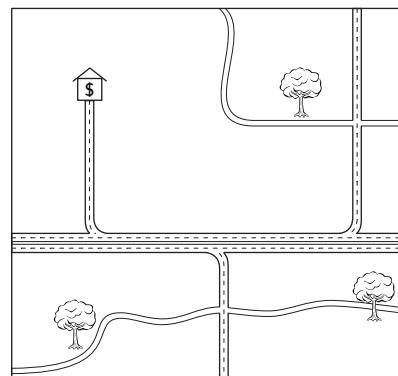
START AT THE BANK AND THEN GO

- 30 KM/H SOUTH FOR 10 MINUTES TO GET TO THE FREEWAY
- 60 KM/H EAST FOR 25 MINUTES AND TAKE THE EXIT
- 15 KM/H NORTH FOR 8 MINUTES ALONG THE DIRT ROAD
- 12 KM/H WEST FOR 20 MINUTES ON A BUMPY DIRT ROAD

THE GOLD IS UNDER THE BIG Sycamore TREE TO THE RIGHT OF THE ROAD.

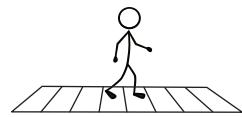
The police intercepted the note, and they are standing by with a helicopter.

Explain to the police how the helicopter can find the location on a map.



## PRACTICE PROBLEMS – VELOCITY

- ⑤ Sandy is walking east along a moving sidewalk making progress at a rate of 12 ft/s. If Sandy's usual walking speed is 7 ft/s, how fast, and in what direction are the steps of the moving sidewalk moving?



- ⑥ Bob jogs onto the east end of the moving sidewalk running at a velocity of 9 ft/s west. What will his new velocity be now that he is on the moving sidewalk.

- ⑦ Write a short summary of the story of the Tortoise and the Hare. Then draw and label a position graph and a velocity graph to go along with the story.

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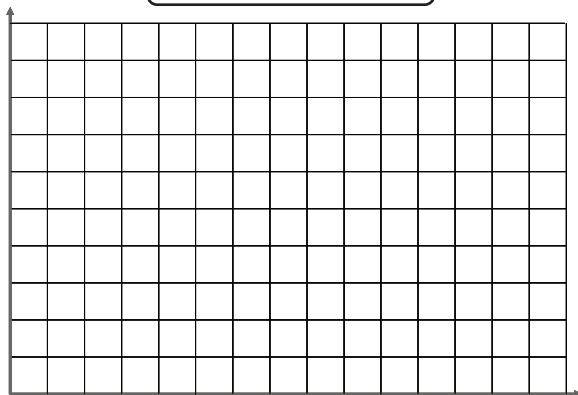
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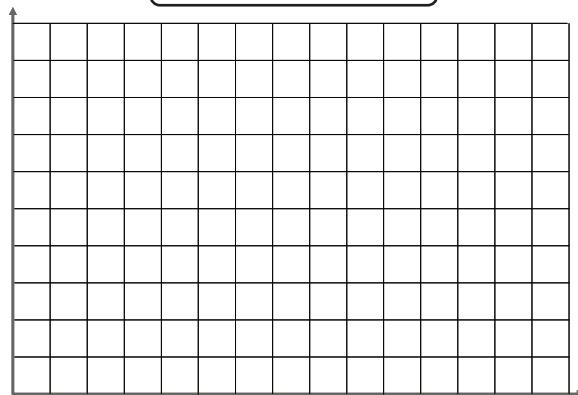
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POSITION VS TIME

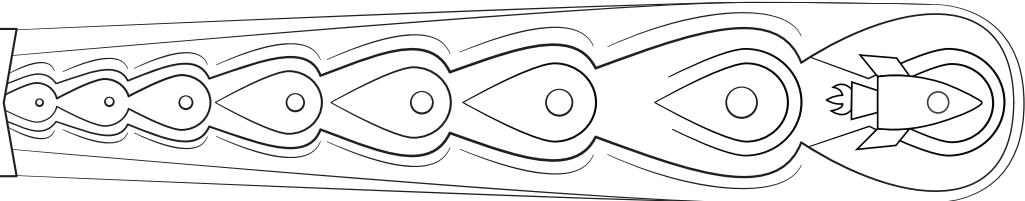


VELOCITY VS TIME



# ACCELERATION

A change in velocity such as speeding up, slowing down, or changing direction!



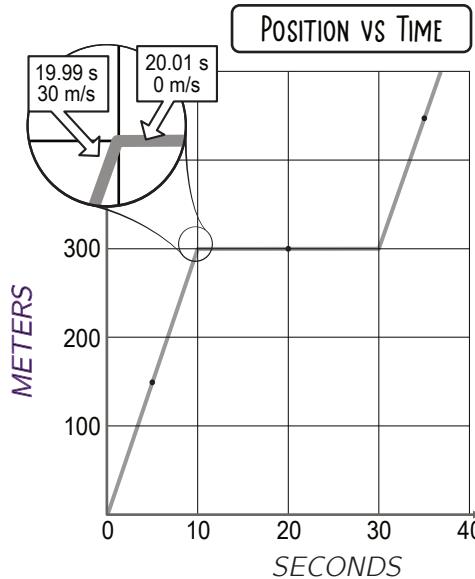
A car is driving at 30 meters per second (about 67 mph). It stops at a stop sign and then continues driving at the same speed as before. If the car's position followed the motion plotted on this graph exactly, what would happen to the driver?

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Draw a new line on the graph that represents a safer way to come to a stop and then start driving again. Be sure your line connects all of the black dots.



## CHANGING SPEED 1

- A dinosaur started walking east from home while carrying two donuts. Its starting pace was 10 meters per minute.
- At 5 minutes, the dinosaur ate a donut and increased its speed to 50 meters per minute.
- At 10 minutes, the dinosaur ate another donut and increased its speed to 100 meters per minute.

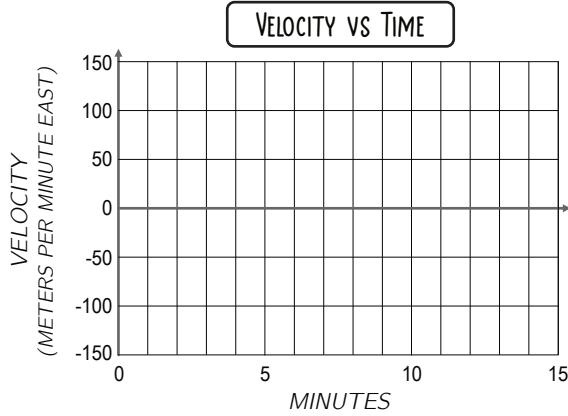
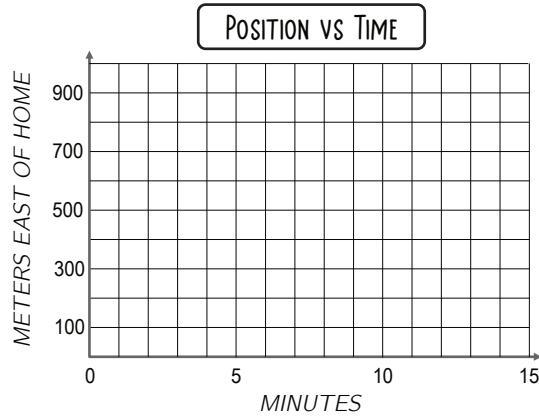
Is the dinosaur slowing down or speeding up? How can you tell from the graph?

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Graph the velocity vs time for the donut-fueled dinosaur.



# VELOCITY

VS

# ACCELERATION

Velocity is \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Example Units: \_\_\_\_\_

Find the average acceleration of a car that accelerates from 0 mph to 60 mph in 3 seconds.

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

Acceleration is \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

Example Units: \_\_\_\_\_

WHAT 3 PARTS OF A CAR CAN BE USED TO CHANGE ITS ACCELERATION?



1.

2.

3.

## CHANGING SPEED 2

- A boat is 1,000 meters east of the shore and moving toward the shore at 200 meters per minute.
- After traveling for 3 minutes, it runs low on fuel. Its speed drops to 30 meters per minute.
- At 10 minutes the boat begins traveling with the currents toward shore at 10 meters per minute.

Is the boat slowing down or speeding up?  
How can you tell from the graph?

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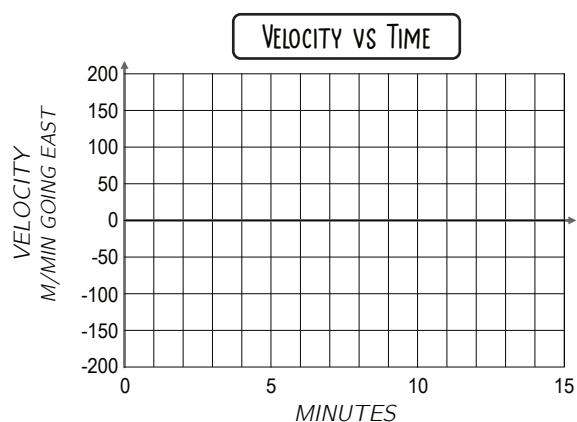
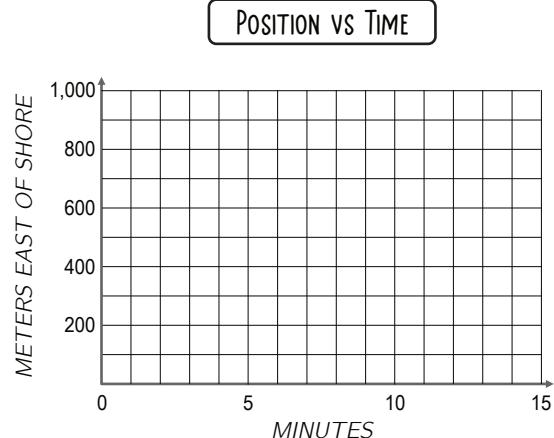


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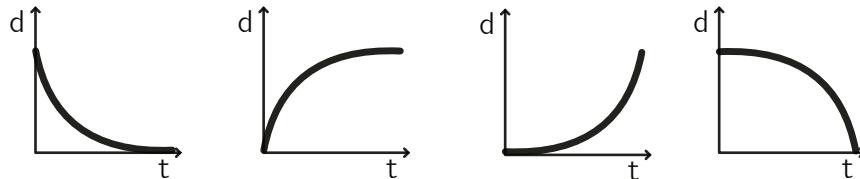
Graph the velocity vs time for the boat.



## PRACTICE PROBLEMS – ACCELERATION AND FORCES

- ① Eliza runs 6 m/s for 12 seconds and then 2 m/s for 4 seconds? What was Eliza's average speed?
- ② Over a 4 second period, a car's velocity drops from 90 km/h westward to 70 km/h. What is the car's average acceleration over those 4 seconds?
- ③ An object starts at rest and then accelerates  $2 \text{ m/s}^2$  south for 10 seconds. What is its velocity after 10 seconds?
- ④ A bus moving at 20 m/s northward ( $t = 0$ ) slows at a rate of 4 m/s each second. How long does it take for the bus to come to a stop?

Which graph might be the graph of the displacement of the bus northward?



- ⑤ Mark each statement as True or False.
- T F When speed is constant, there is no acceleration.  
T F When acceleration is constant, velocity is constant.  
T F An object's instantaneous velocity is always greater than its average velocity.  
T F A positive acceleration shows up on a position graph as a curve shaped like part of a smile (concave up).  
T F The slope of a velocity-vs-time graph shows an object's acceleration.  
T F If velocity increases from 5 ft/s to 12 ft/s, then acceleration is 7 ft/s.

# FUNCTION CARNIVAL

## MATERIALS



A computer with the Desmos activity *FUNCTION CARNIVAL* open in a browser window



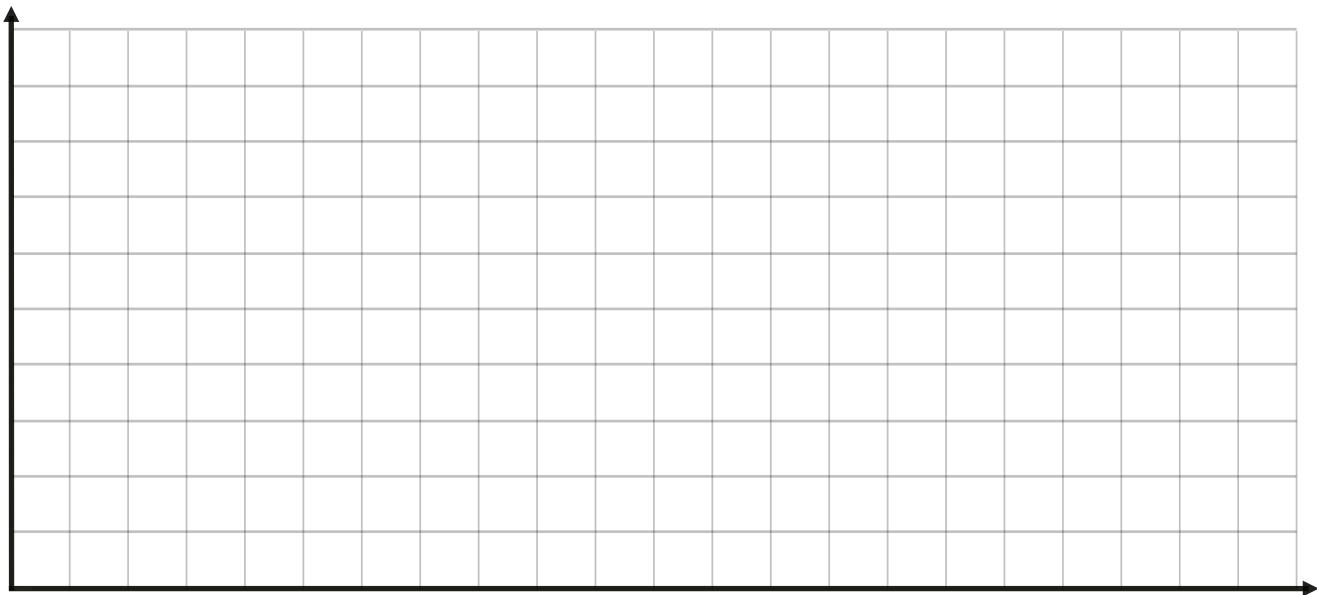
This worksheet



Pencil or pen

## GOALS

- ★ Increased understanding of how graphs work!
- ★ A stronger ability to track movement with position vs time graphs.
- ★ Bonus: get to play with fun animations.



Draw your own graph that shows position vs time in the space above. Be sure to label the axes. Then write a story about what your graph describes.

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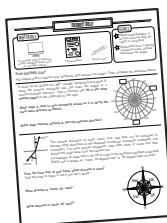
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# DEGREE GOLF

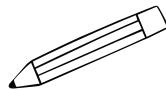
## MATERIALS



A computer with the Desmos activity *DEGREE GOLF* open in a browser window



This worksheet



Pencil or pen

## GOALS

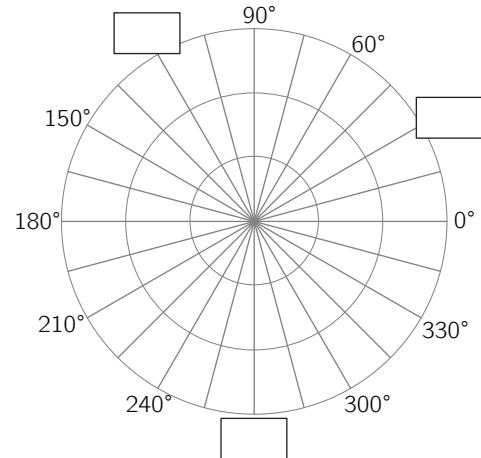
- ★ Better understanding of vectors and how they are useful in navigation.
- ★ Understand how to specify a direction using cardinal directions and angles.

## PLAY DEGREE GOLF

Play degree golf to improve your familiarity with vectors and angles. Then complete the questions below:

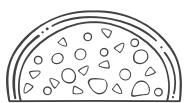
A circle can be divided into  $360^\circ$ . Usually, mathematicians place  $0^\circ$  along the positive horizontal axis and mark the angles in a counterclockwise direction. Take a moment and **fill in the three missing angles** on the angle grid to the right.

What angle is used to spin something around so it is facing the exact same direction as before?



What angle matches jumping to face the opposite direction?

A slice is going to be cut from a pizza so that the center of the pizza (the point of the slice) matches a specific angle. Match the pizza slices with the labels showing the correct angle.



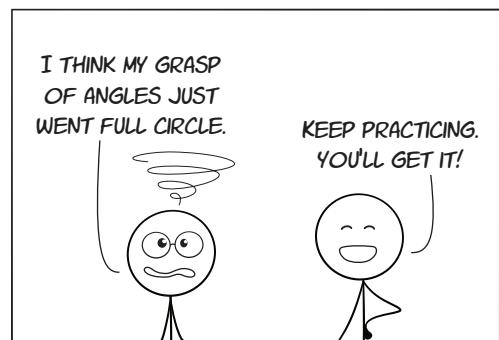
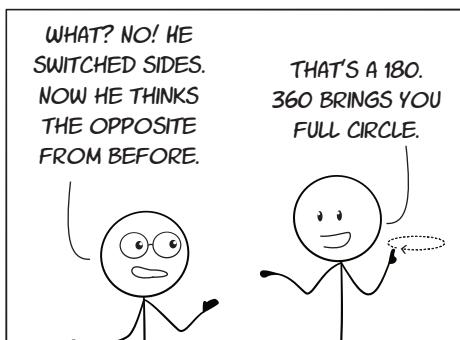
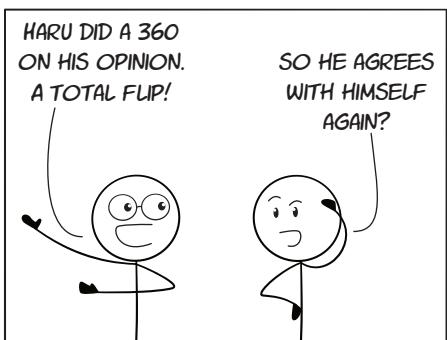
$90^\circ$  slice

$30^\circ$  slice

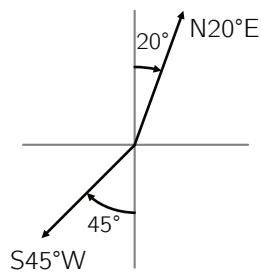
$180^\circ$  slice

$60^\circ$  slice

$120^\circ$  slice



## DEGREE GOLF



The cardinal directions of north, south, east, and west can be combined to describe other directions on the diagonals (northeast, southeast, southwest, and northwest). For more precise navigation, start with north or south and then declare the angle away from the vertical line.

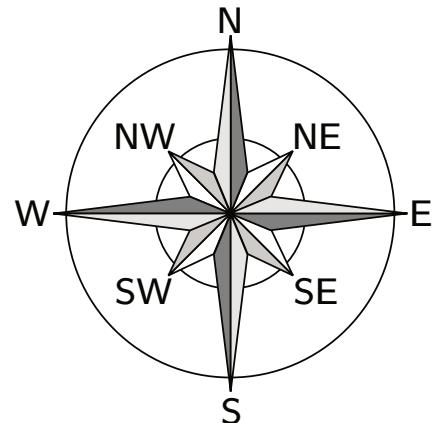
For example, an angle that is  $20^\circ$  off of north in the northeast quadrant is denoted N $20^\circ$ E and is spoken as, "north, 20 degrees east" or "20 degrees east of north."

From the front door of your home, which direction is north?

*Take the time to figure it out if you don't know!*

What direction is "south,  $45^\circ$  east?"

What direction is "north,  $10^\circ$  west?"



The cat army has gone high-tech. Their radar grid shows the location of four mice relative to their radar station. The station is in the center. Determine a heading (the direction from the center) to reach each mouse using the cardinal directions.

Heading for A: South  $30^\circ$  West

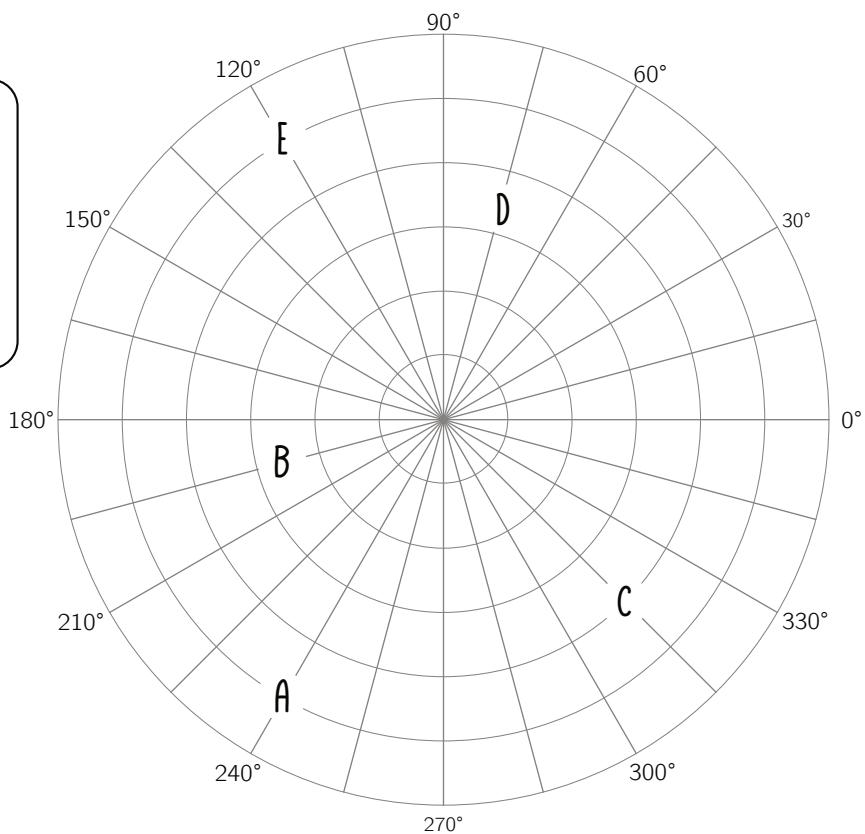
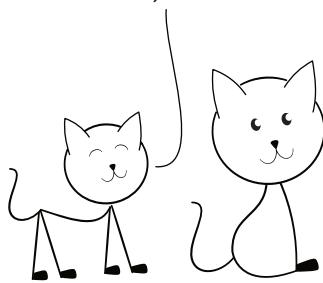
Heading for B:

Heading for C:

Heading for D:

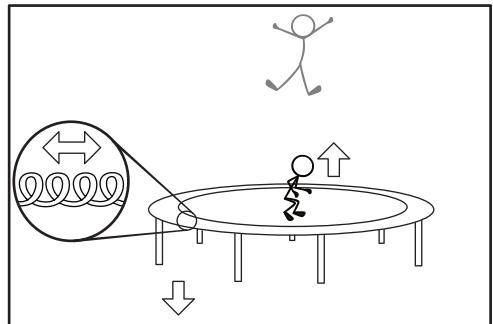
Heading for E:

TODAY, WE CONQUER THE MICE.  
TOMORROW, THE WORLD!

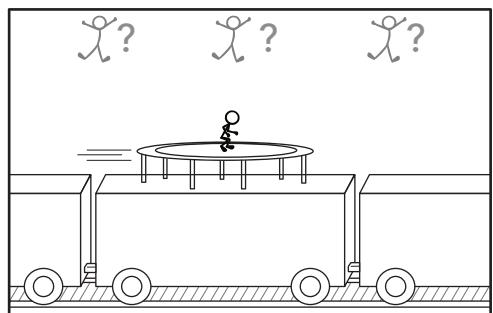


**MOTION COMMOTION**

What forces are involved when Omar jumps on a trampoline? If he jumps straight up from the center of the trampoline, where will he land?



What would happen if Omar jumped on a trampoline that was on a train moving west at 20 mph?

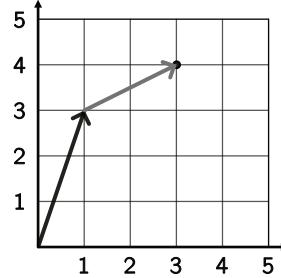
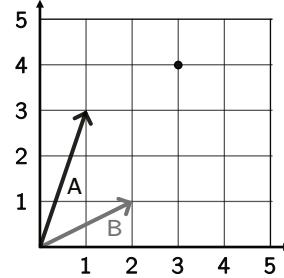
**ADDING VECTORS**

The vector A goes from point (0,0) to (1,3). The vector B reaches from the origin to point (2,1).

## 1. ADD THE COORDINATES

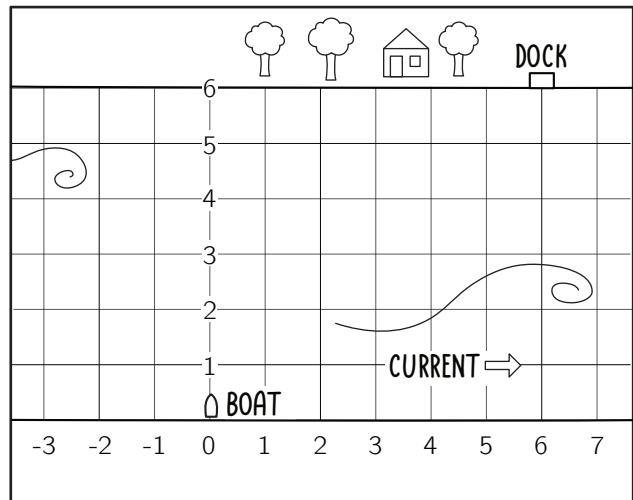
$$\vec{A} + \vec{B} = \langle 1, 3 \rangle + \langle 2, 1 \rangle \\ = \langle 3, 4 \rangle$$

## 2. GRAPH VECTOR B STARTING AT THE END OF VECTOR A



The boat's speed is 4 feet per second and the river current moves at 3 feet per second. Where will the boat land if it travels perpendicular from the shore?

In spring, the river current increases to 6 ft/s. Where should the boat leave from to reach the dock? Note: The boat will travel perpendicular to the shore at a rate of 4 feet per second.



# VECTOR VOYAGES IN THE INDIAN OCEAN



Three boats are leaving from the Maldives. Draw one vector for each week of travel. Then add a wind correction vector to find the ships position after each week. In which geographic region will each boat land? Approximately how many weeks will each voyage take?

- ① THE SHIP **NACHO BOAT** SAILS DIRECTLY WEST AT 3 SQUARES PER WEEK.

WEEK 1: THE WIND BLOWS 1 SQUARE TO THE NORTH

WEEK 2: NO WIND

WEEK 3: NO WIND

- ② THE SHIP **BOATY McBOATFACE** SAILS DIRECTLY NORTH AT 2 SQUARES PER WEEK.

WEEK 1: THE WIND BLOWS FROM NORTHWEST TO SOUTHEAST (3 SQUARES TO THE SOUTH AND 3 SQUARES TO THE EAST)

WEEK 2: THE WIND CONTINUES BLOWING TO THE SOUTHEAST (1 SQUARES TO THE SOUTH AND 3 SQUARES TO THE EAST)

WEEK 3: THE WIND BLOWS 2 SQUARES TO THE EAST

- ③ THE SHIP **SEAS THE DAY** SAILS DIRECTLY NORTH AT 3 SQUARES PER WEEK.

WEEK 1: THE WIND BLOWS 2 SQUARES TO THE WEST

WEEK 2: THE WIND BLOWS 4 SQUARES TO THE EAST

WEEK 3: THE WIND BLOWS 3 SQUARES TO THE NORTH

- ④ THE BOAT **FISHCAPADES** CAN SAIL AT A RATE OF 3 SQUARES PER WEEK. USING THE 4 CARDINAL DIRECTIONS (NORTH, EAST, SOUTH, AND WEST) CAN YOU PLOT VECTORS FOR IT TO REACH THE ARABIAN PENINSULA WITHIN 3 WEEKS?

THE WIND FORECAST IS AS FOLLOWS:

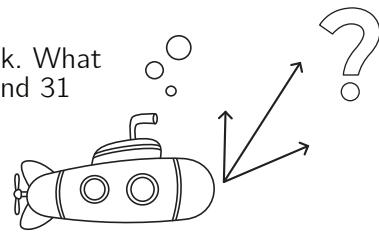
WEEK 1: THE WIND BLOWS FROM SOUTHEAST TO NORTHWEST (3 SQUARES TO THE NORTH AND 4 SQUARES TO THE WEST)

WEEK 2: NO WIND

WEEK 3: THE WIND BLOWS 4 SQUARES TO THE NORTH

# PRACTICE PROBLEMS – RELATIVE MOTION AND COMBINING VECTORS

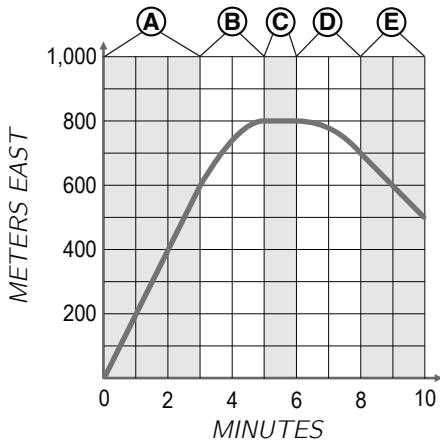
- 1 A submarine is located 6 km south and 2 km east of the shipwreck. What vector should they follow to reach an island that is 10 km north and 31 km east of the shipwreck?



- 2 Math Dad pushes a couch with enough force to move it 3 feet east. But at the same time, 15 Unbeatable Science Kids are pushing the other side of the couch with a force that would move it 5 feet west! In what direction and how far will the couch move?

- 3 A plane leaves Las Vegas and its engines push it at a rate of 800 km/h facing due east. As it flies it faces a strong headwind of 200 km/h that blows due west. What will the position of the plane be after 5 hours of flying?

- 4 In this position vs time graph for a dinosaur, what is happening in section A?
- The dinosaur moves east at 200 meters per minute.
  - The dinosaur moves west at 200 meters per minute.
  - The dinosaur moves east at 100 meters per minute.
  - The dinosaur moves west at 100 meters per minute.
  - The dinosaur does not move.



- 5 What is the dinosaur doing in sections C and E?

- 6 In which section is the dinosaur moving west?

POSITION VS TIME

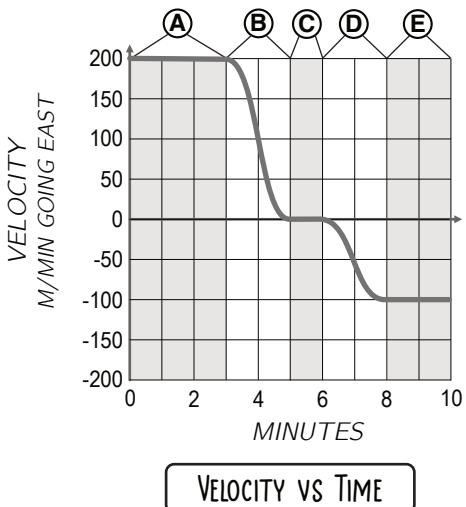


- 7 In which sections does the dinosaur have a constant speed?

- 8 In which sections is the speed of the dinosaur changing?

# PRACTICE PROBLEMS – RELATIVE MOTION AND COMBINING VECTORS

- 9** In this velocity vs time graph what is happening in section A?
- The dinosaur is moving east at a constant speed
  - The dinosaur is accelerating (speeding up)
  - The dinosaur is decelerating (slowing down)
  - The dinosaur is not moving



- 10** In this velocity vs time graph what is happening in section B?
- The dinosaur is moving at a constant speed
  - The dinosaur is accelerating (speeding up)
  - The dinosaur is decelerating (slowing down)
  - The dinosaur is not moving

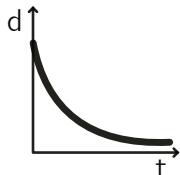
- 11** In a position vs time graph, what is the slope?



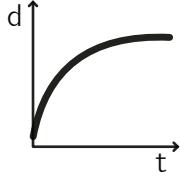
- 12** In a velocity vs time graph, what is the slope?

## 13 MATCHING GRAPHS:

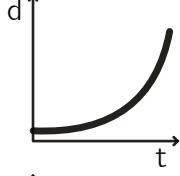
Match each graph with whether it shows an object speeding up or slowing down.



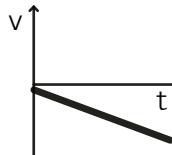
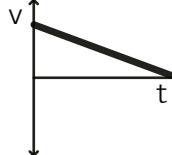
Speeding up



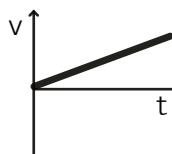
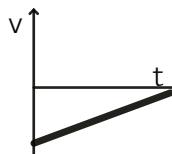
Slowing Down



POSITION vs TIME



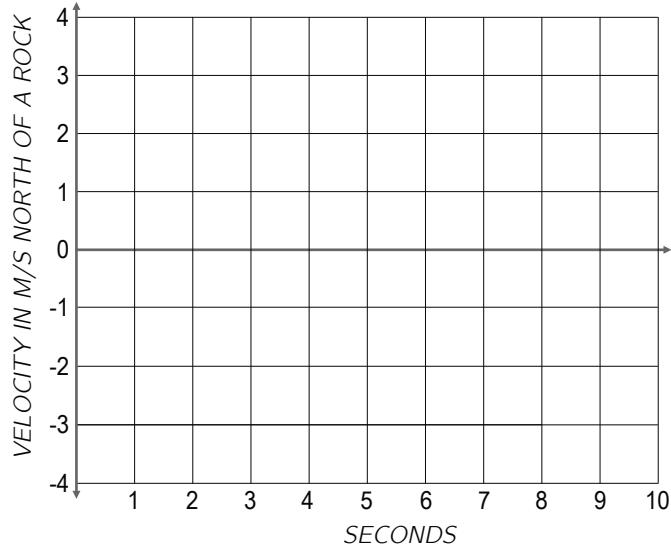
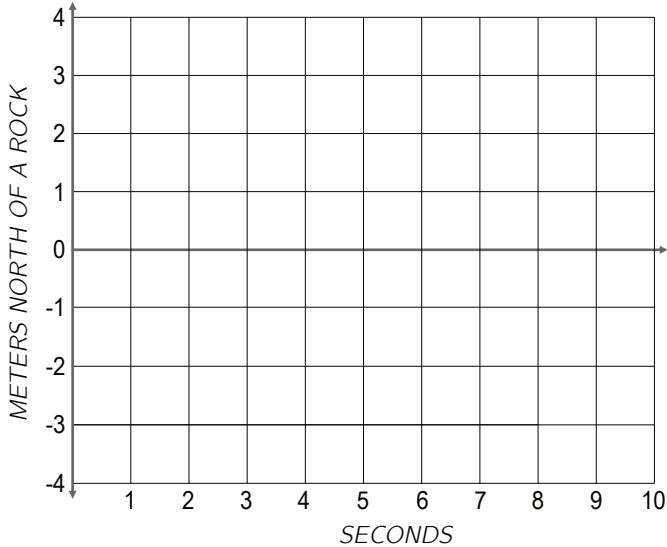
VELOCITY vs TIME



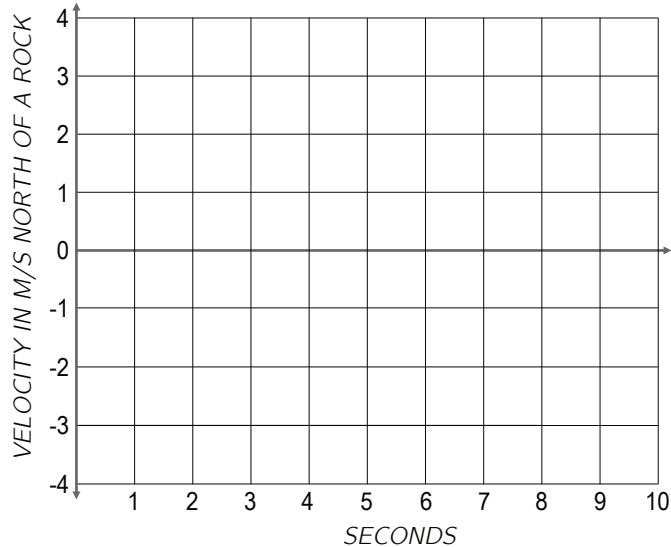
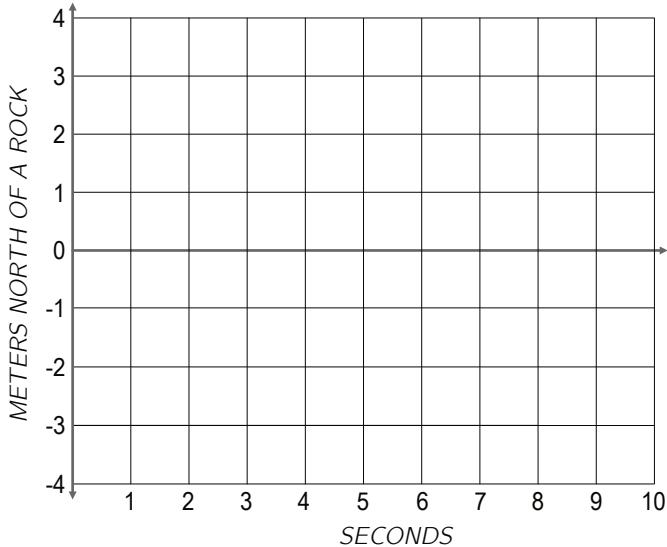
# ASSESSMENT

BE SURE TO HAVE A PENCIL AND SCRATCH PAPER!

- 1 A dog is standing still 2 meters south of the rock and does not move for 10 seconds. Draw the position vs time and velocity vs time graphs for the dog:



- 2 Meanwhile, the squirrel started at 4 meters south of the rock and ran north at a constant rate of 1 meter per second. Graph the squirrel's motion on each graph:



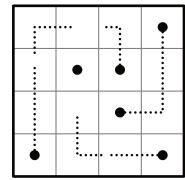
3

	A	1		E
			4	
		3		
B	2			D
		C		5

## PIPE FLOW MATCHING - UNIT 1

Match each unit with the quantity being measured by joining them with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

- |                 |                     |
|-----------------|---------------------|
| 1. volume       | A. kg               |
| 2. mass         | B. cm               |
| 3. velocity     | C. m/s              |
| 4. acceleration | D. m/s <sup>2</sup> |
| 5. length       | E. mL               |



- 4** Which statements about a moving object are true?
- If you know the current velocity, then you also know the current speed.
  - If you know the current speed, then you also know the current velocity.
  - If you know the total displacement, then you know how far it traveled.
  - If you know how far it traveled, then you know the total displacement.
- 5** A ball rolling down a ramp has a downward acceleration of  $3 \text{ m/s}^2$ . If it starts at rest, how fast will it be going after 5 seconds?
- 8 m/s
  - 15 m/s
  - 20 m/s
  - 45 m/s
- 6** Ezra travels 4 miles east from his home to the store and then returns home. What is his displacement for the trip?
- 0 mi
  - 4 mi
  - 8 mi
- 7** Which distance below is closest to 10 ft?
- 25 m
  - 200 mm
  - 0.1 km
  - 300 cm
- 8** What is the total distance traveled by a car that goes 80 km/h for 30 minutes, 90 km/h for 20 minutes, and 100 km/h for 12 minutes?
- 60 km
  - 75 km
  - 90 km
  - 105 km
- 9** Jory runs 10 m/s for 4 seconds and then 4 m/s for 2 seconds? What was Jory's average speed?
- 5 m/s
  - 6 m/s
  - 7 m/s
  - 8 m/s
- 10** What is the displacement for an object that moves 6 m west, 7 m east, 9 m west, and 4 m east?
- 20 m west
  - 4 m west
  - 3 m east
  - 30 m east
- 11** Circle T or F to mark each statement as either True or False:
- T    F    Velocity is a scalar quantity.
- T    F    If an object is at rest, its position vs time graph will show a horizontal line.
- T    F    The units m/s are units of acceleration.
- T    F    The slope of a line on a position function is the object's velocity.
- T    F    If an object's velocity is constant, then acceleration is zero.
- T    F    If an object's average velocity over a time interval is  $\vec{0}$ , then its average speed is also 0.
- T    F    Temperature and distance are vectors.
- T    F    A scalar quantity has a magnitude and a vector quantity does not.
- T    F    Acceleration is positive when velocity is increasing.

- (12)** A position-vs-time graph is displayed. Select each true statement below.



- A. The object decelerated.
- B. The object's velocity was positive.
- C. The object's velocity was decreasing.
- D. The object's acceleration was positive.

- (13)** A velocity-vs-time graph is displayed. Select each true statement below.



- A. The object changed direction.
- B. The object was decelerating the whole time.
- C. The object traveled the same speed the whole time.
- D. The object returned to its starting point.

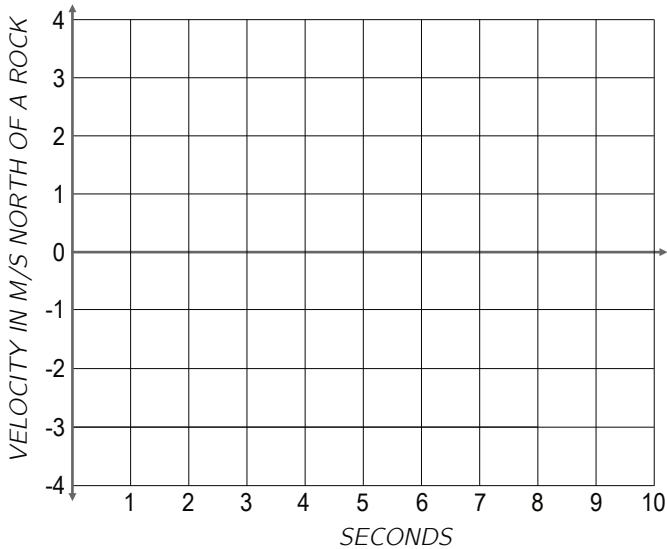
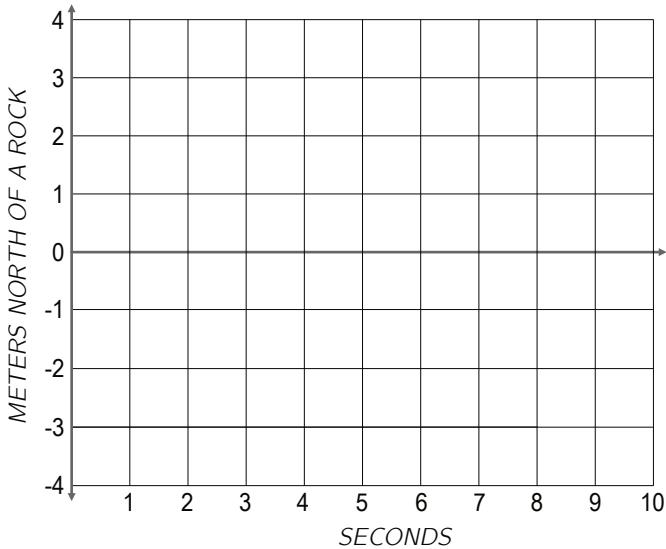
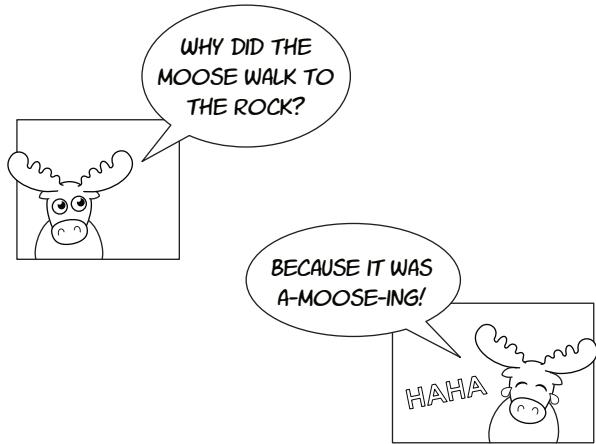
- (14)** Which statement is true for an object moving at constant velocity of 4 km/h?

- A. The acceleration is 0 km/h<sup>2</sup>.
- B. The acceleration is increasing.
- C. The acceleration is negative.
- D. The acceleration is positive.

- (15)** A moose is standing 4 meters north of a rock. Then, over a 10-second interval, it

- walks 6 m south over 3 seconds,
- stops and waits 4 seconds,
- Then walks to the rock at a constant speed.

Use the graphs below to plot the moose's position and velocity.



## MAD LIB

ASK SOMEONE FOR A WORD THAT MATCHES EACH PART OF SPEECH. THEN, FILL IN THE WORDS ON EACH CORRESPONDING BLANK.

When an object is moving over time, we describe its \_\_\_\_\_ in terms of its position, velocity, and acceleration. Position is the \_\_\_\_\_ of an object. It's important to know where the object is at any given \_\_\_\_\_.

Velocity is the rate at which the \_\_\_\_\_ from one position to another. It's like how quickly you can \_\_\_\_\_ the street or how fast a \_\_\_\_\_ can \_\_\_\_\_.

Acceleration is the rate at which the \_\_\_\_\_ changes its velocity. If it can quickly \_\_\_\_\_ its speed, it has a high acceleration!

## WORD SEARCH

LOCATE EACH OF THE WORDS BELOW ON THE 3D STACK OF LETTERS. THE WORDS MAY BE DIAGONAL, FORWARD, OR BACKWARD.

VELOCITY

POSITION

ACCELERATION

DISPLACEMENT

DISTANCE

SPEED

GRAVITY

SECOND

KILOGRAM

METER

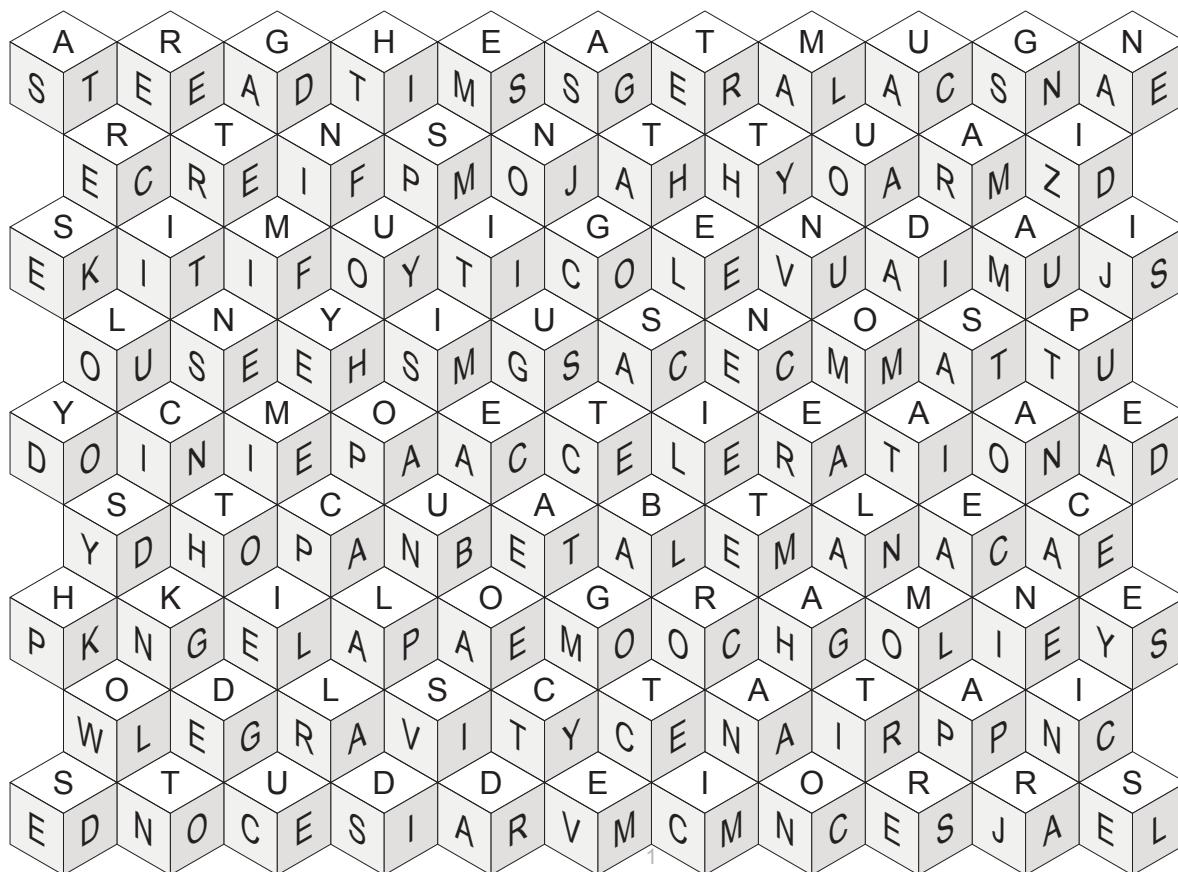
VECTOR

SCALAR

MAGNITUDE

TIME

MOTION



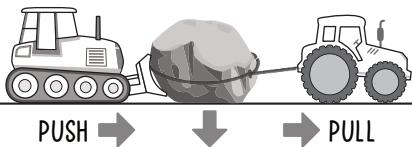
# Unit 2: Laws of Motion

In this unit, we'll learn about forces and Newton's Laws of Motion.

## THE LAWS OF MOTION

1. LAW OF INERTIA
2.  $F = ma$  (FORCE IS EQUAL TO MASS TIMES ACCELERATION)
3. FORCES BETWEEN OBJECTS ALWAYS COME IN EQUAL AND OPPOSITE PAIRS

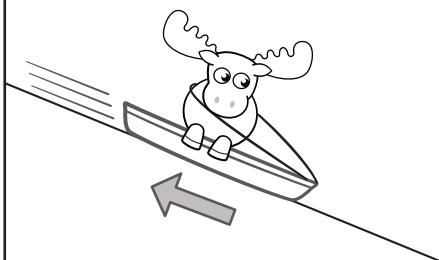
## FORCE



$$\vec{F} = m\vec{a}$$

A push or pull that can make objects move, change, or bend

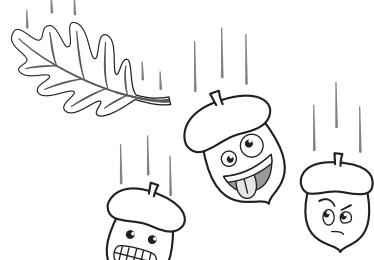
## FRICITION



$$\vec{F} = \mu \vec{N}$$

Resistive force between objects in contact

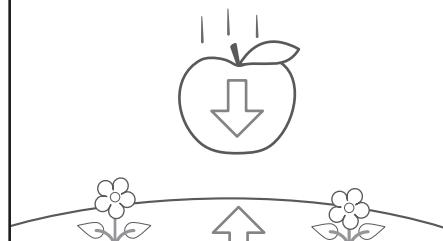
## FREE FALL



$$9.8 \text{ m/s}^2 \text{ on Earth}$$

Downward acceleration under the force of gravity only

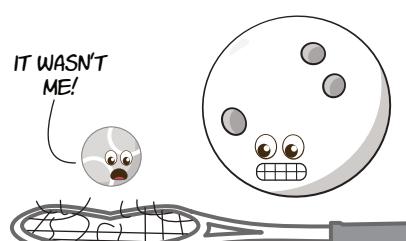
## GRAVITY



$$F = G \frac{m_1 m_2}{r^2}$$

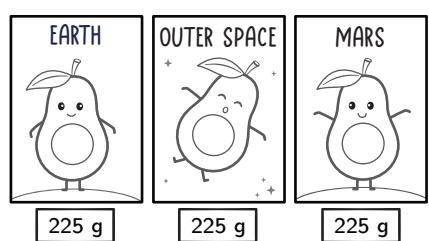
The force that pulls objects toward each other

## INERTIA



Resistance to a change in motion  
MORE MASS = MORE INERTIA

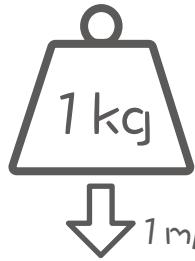
## MASS



$$\text{kg or g}$$

The amount of matter in an object or particle

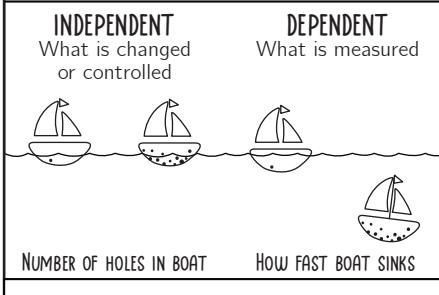
## NEWTON



$$1 \text{ kg} \cdot \text{m/s}^2$$

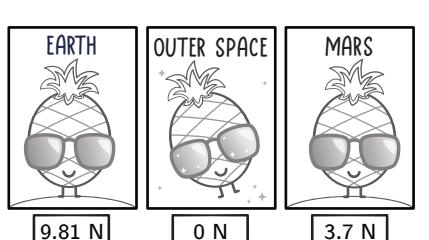
The force that gives 1 kg an acceleration of 1 m/s<sup>2</sup>

## VARIABLE



Any factor, condition, or trait that can exist in different amounts or types.

## WEIGHT



$$W = m \cdot g$$

The force acting on an object due to gravity

# UNDERSTANDING FORCES

FILL IN THE BLANKS:

two interaction motion

A force is an \_\_\_\_\_ that can cause the \_\_\_\_\_ of an object to change. A force must occur between \_\_\_\_\_ or more objects.

*In the simplest sense, a force is a push or a pull. The source of that force can be in direct contact with the object (a contact force) or not (a non-contact force).*

## CONTACT FORCES



PUSH (applied)



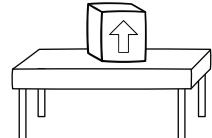
PULL / TENSION (applied)



FRICTION (surface resistance)



DRAG (air resistance)



NORMAL

## NON-CONTACT FORCES



MAGNETIC



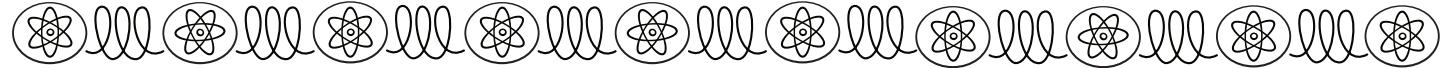
ELECTROSTATIC



GRAVITY

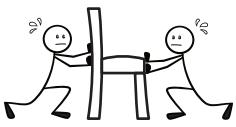
When identifying forces, ask these questions:

- ① IS A NON-CONTACT FORCE INFLUENCING THE OBJECT? *Is there a magnet or planet nearby?*
- ② IS ANYTHING TOUCHING THE OBJECT? *If yes, identify the contact forces!*
- ③ HOW IS THE OBJECT MOVING? *Is the velocity constant or is the object accelerating?*



# NET FORCES

Bob is strong enough to push the chair across the floor. Draw arrows showing what forces you expect to be acting on the chair, then describe them and predict whether the chair will move or not.

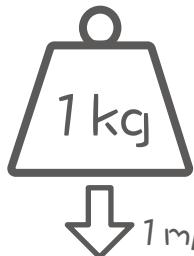
	SCENARIO	FORCES?	MOVEMENT?
1	THE CHAIR RESTS ON THE FLOOR 		
2	BOB PUSHES THE CHAIR ACROSS THE FLOOR 		
3	TWO BOBS PUSH THE CHAIR WITH EQUAL FORCE IN THE SAME DIRECTION 		
4	TWO BOBS PUSH THE CHAIR WITH EQUAL FORCE IN THE OPPOSITE DIRECTION 		

When multiple forces are acting on an object, the vector sum or resultant force is called the **net force**.

Each Bob pushes a chair with 70 N of force. What is the **net applied force** in each situation (without friction)?



## NEWTON



Net force is measured in **newtons (N)**. A force of 1 newton can accelerate 1 kg of material by  $1 \text{ m/s}^2$ .

To find the net force for forces applied in the **SAME** direction,

To find the net force of forces applied in **OPPOSITE** directions,

## MISCONCEPTION ALERT!

Bob gives the chair a huge push and then lets go. The chair goes forward and then stops moving. **Why did it stop?** One of these answers is correct. The other is a common misconception. Can you mark the correct one?

*Hint: What if Bob gave the same push to a chair on a greased rollerskating rink? In a space station?*

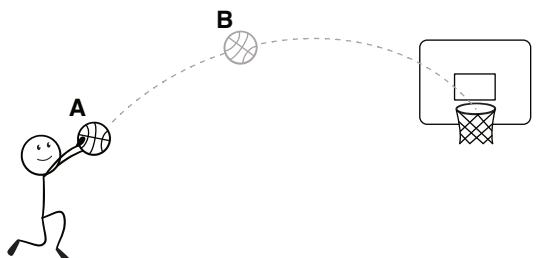
- BECAUSE BOB STOPPED PUSHING
- BECAUSE OF FRICTION

I COVERED THE RINK IN GREASE SO THAT THERE'S VIRTUALLY NO FRICTION!

THE PHYSICISTS LOVE IT!

SOUNDS LIKE A BAD IDEA!

Forces are required to \_\_\_\_\_ the way an object moves. Forces are NOT required for an object to \_\_\_\_\_.



Lily is playing basketball. When she makes the 3-pt throw she applies a push to the ball. What other forces does the ball experience at point A?

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---

Is the ball experiencing all of the same forces at point B?

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MECHANICAL EQUILIBRIUM = BALANCED FORCES = NET FORCE OF ZERO

Put a check mark next to each situation which has CONSTANT velocity:

- BOOK RESTING (NOT MOVING) ON A TABLE
- SEMI TRUCK SPEEDING UP
- BICYCLE SLOWING DOWN
- LARGE ROCK SITTING IN A GARDEN
- MARMOSET CLIMBING A TREE WITH FREQUENT PAUSES
- COMET MOVING AT 100 M/S THROUGH OUTER SPACE

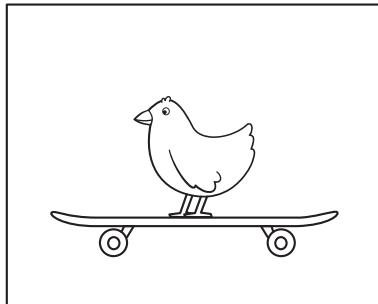
(THE COMET HAS BEEN TRAVELING AT THIS SPEED FOR DECADES)

SUPER IMPORTANT! MAKE SURE TO REMEMBER:

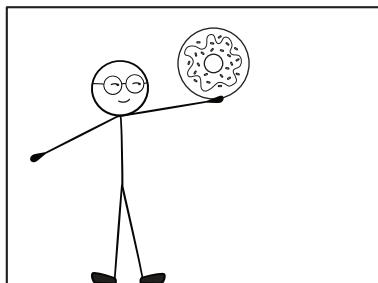
**A NET  
FORCE of  
ZERO means  
  
acceleration  
and  
velocity!**

## PRACTICE PROBLEMS – FORCES

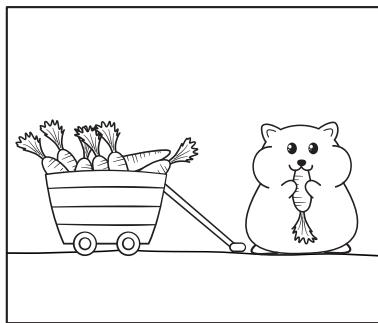
- ① A chicken sits on a skateboard that is not moving. What forces are acting on the chicken? Draw arrows representing the forces. Are they balanced (equal and opposite to each other) or unbalanced?



- ② Math Dad is holding a giant donut horizontally with one hand. The donut is not moving. What forces are acting on the donut?



- ③ When Superhamster pulls a cart filled with carrots, what force or forces opposes the motion of the pull?
- A. Gravity
  - B. Air resistance
  - C. Friction
  - D. Tension

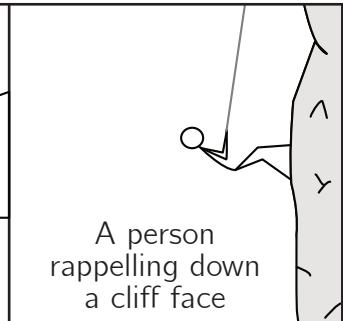
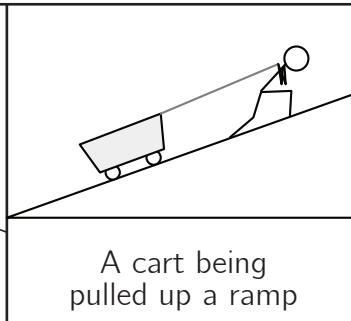
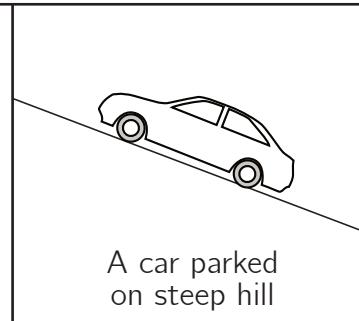
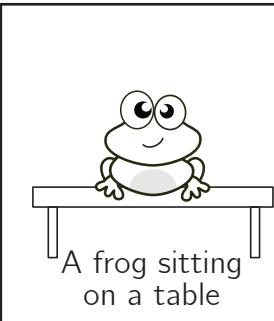


- ④ What is the unit of force in the International System of Units (SI)? What will one unit of this force do to 1 kg of mass?

- ⑤ Which statements about the normal force is true?
- A. It is a contact force.
  - B. It is a non-contact force.
  - C. It is always perpendicular to the surface that something is resting on.
  - D. It is always opposite the direction of gravity.
  - E. It is the most predictable force, which is why it is called the “normal” force.

# PRACTICE PROBLEMS – FORCES

- 6) Draw an arrow showing the direction of the normal force for each situation:



- 7) In the applied force column, two forces are shown acting on an object. Use that information to calculate the **net force** for each situation. Draw a box to represent the object and an arrow to show the net force.

APPLIED FORCE	NET FORCE

- 8) The NET FORCE will always be greater than the total of the individual forces.

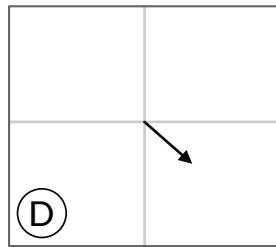
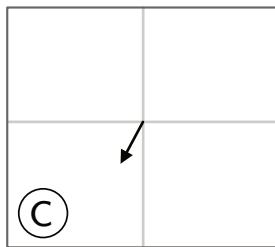
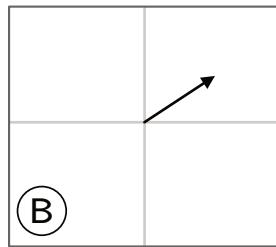
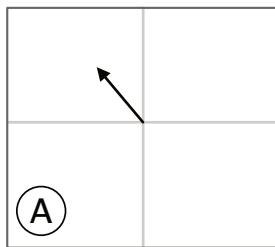
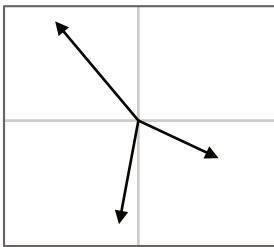
- A. True  
B. False

- 9) Which of the following forces require direct contact to be influencing the motion of an object?

- A. Gravity  
B. Friction  
C. Magnetism  
D. Normal Force

## Challenge

Three force vectors interacting on an object are shown below. Which of the vectors to the right show the **net force**?



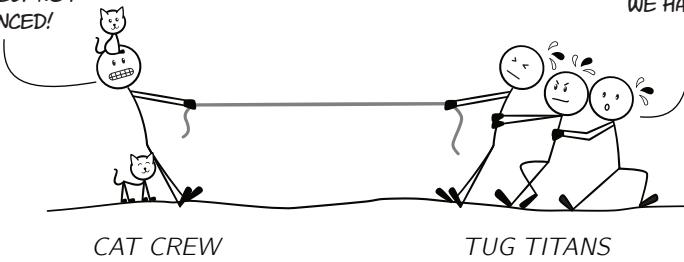
# FREE BODY DIAGRAMS

A free body diagram (FBD) uses arrows to represent the forces acting on an object.

The arrow shows the direction and strength of the force.

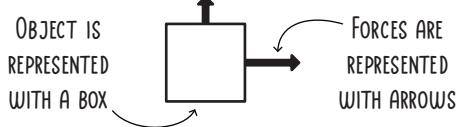
*Note: The arrows represent **forces** which may or may not match the **movement** of the object.*

THESE TEAMS ARE DEFINITELY NOT BALANCED!

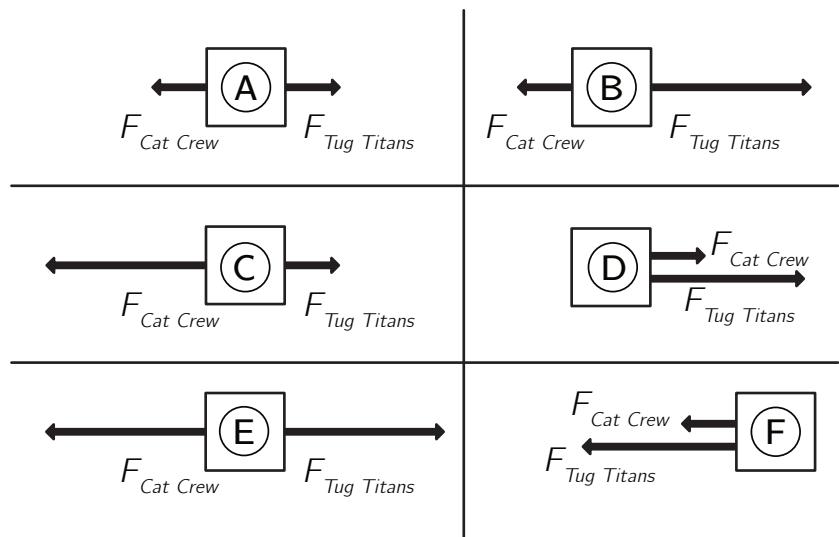


QUIT COMPLAINING.  
YOU HAVE 3 AND WE HAVE 3!

## ANATOMY OF A FREE BODY DIAGRAM:



Which free body diagram would best represent the forces of the two teams on the rope? Why is it the best choice?



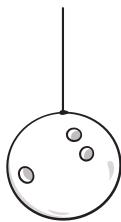
Draw and label an arrow for each force described below. (Note: the description may not include ALL of the forces acting on the object. Only draw arrows for the forces which are described.) Are the forces equal in size (balanced) or not?

A book rests on the table. Gravity pulls down and the normal force prevents the book from falling through the table.



- BALANCED  
 NOT BALANCED

A bowling ball is suspended from string and not moving. The tension in the string is equal to the force of gravity.



- BALANCED  
 NOT BALANCED

A person pushes a cart forward as they run faster and faster. The cart also experiences friction from the ground.



- BALANCED  
 NOT BALANCED

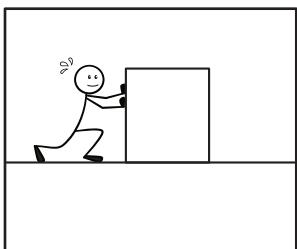
A kingfisher dives toward a lake. The bird feels some air resistance but accelerates downward.



- BALANCED  
 NOT BALANCED



Draw and label a free body diagram for each situation below. Is the net force zero? How do you know?



Pam pushes a box faster and faster. It slides across the ground, accelerating to the right.

Free body diagram for the box:

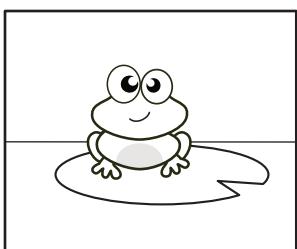



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A frog sits on a lily pad. It is holding completely still as it waits for an insect to come by.

Free body diagram for the frog:




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Two free body diagrams are drawn below. Invent situations that would match the diagrams! Then draw and/or describe them:




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## PRACTICE PROBLEMS – FREE BODY DIAGRAMS

- ① A cat is sitting at rest on a flat table. Draw a free-body diagram for the cat. How many forces are acting on the cat and what are they?
  
  
  
  
  
  
- ② A child is pushing a toy car on a horizontal surface with a constant speed. Draw a free-body diagram and identify the forces acting on the car.
  
  
  
  
  
  
- ③ A marmoset is relaxing by dangling from a branch by its tail. Draw a free-body diagram for the marmoset. Identify the forces acting on this small monkey.
  
  
  
  
  
  
- ④ A parachute is descending slowly towards the ground. Draw a free-body diagram for the parachute. What are the forces acting on it?
  
  
  
  
  
  
- ⑤ A hot air balloon is rising at a constant speed. Draw a free-body diagram for the balloon. What are the forces acting on it?
  
  
  
  
  
  
- ⑥ A soccer ball is in mid-air after being kicked. Draw a free-body diagram for the ball. How many forces are acting on it and what are they?



## BONUS CONTENT! EXTRA STRATEGIES FOR ADDING VECTORS/FORCES



We can add any two vectors by:

- Adding their coordinate points if they're on a grid.



- Forming a parallelogram out of them and then drawing the arrow from the origin to the furthest corner.



- Placing them in sequence so that one starts where the previous one ended. Works for more than two vectors and order doesn't matter!



WHAT IS THE NET FORCE OF THESE VECTORS?



- Use the pythagorean theorem (only if they are at a  $90^\circ$  or a right angle to each other)



### Pythagorean Theorem:

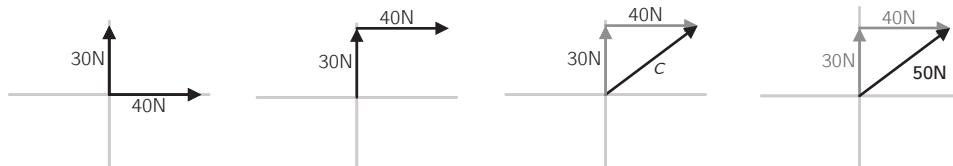
A right triangle with legs  $a$ ,  $b$ , and hypotenuse  $c$  satisfies the equation  $a^2 + b^2 = c^2$ .



### Another approach for finding net forces!

**Example:** Two dogs are pulling on a toy. Kaladin pulls east with a force of 40 N, while Lopen pulls north with a force of 30 N.

What is the net force as a result of their pulls?



The two vectors are at right angles to each other and can form a triangle. After the vectors are lined up end-to-end, the length between them is the hypotenuse (opposite the right angle) so we can call it  $c$ .

Using  $a^2 + b^2 = c^2$  we get:  $30^2 + 40^2 = c^2$  or  $2500 = c^2$

Take the square root of 2500 to get  $50 = c$ .

The net force on the toy is 50 newtons. The hypotenuse shows the direction of the force with slope  $\frac{3}{4}$  in the north-easterly direction.

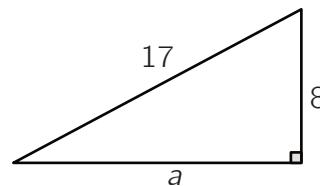
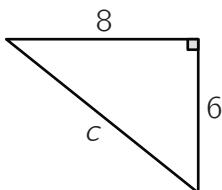
Careful, this only works with right triangles!



## BONUS CONTENT! EXTRA STRATEGIES FOR ADDING VECTORS/FORCES

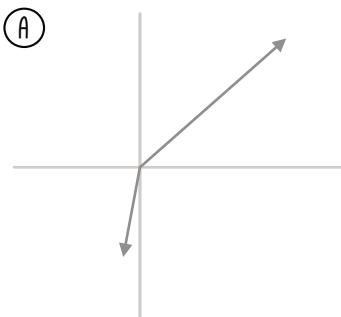


- 1 Use the Pythagorean Theorem to find the missing side of each triangle.

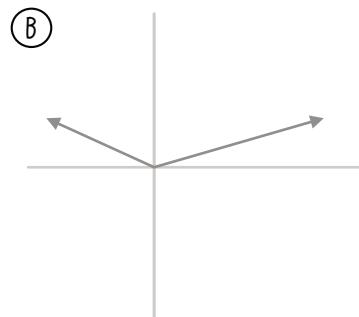


- 2 A ruler and protractor can be used to add vectors. Draw the net or resultant vector and then record the length & angle below.  
Use centimeters and degrees.

A. \_\_\_\_\_



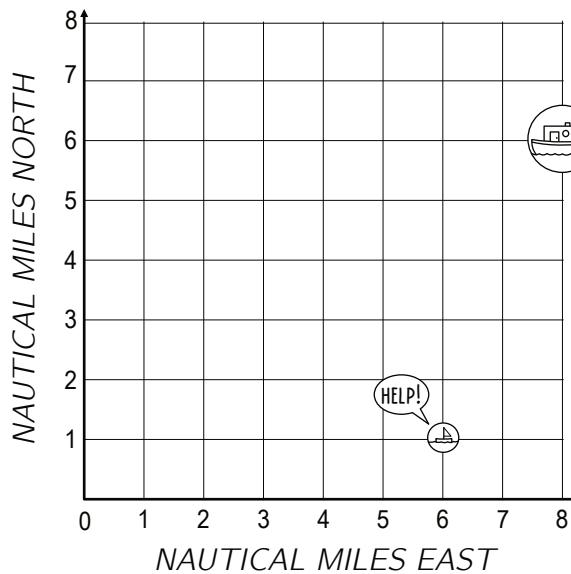
B. \_\_\_\_\_



- 3 Which method of adding vectors do you like best and why?

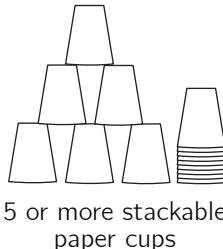
- Coordinate grid
- Parallelogram
- Pythagorean Theorem
- Ruler and Protractor

- 4 The coast guard boat got another distress call. What vector would get them to the next boat? How many miles and in which direction should they go?



# CUP STACK CHALLENGE

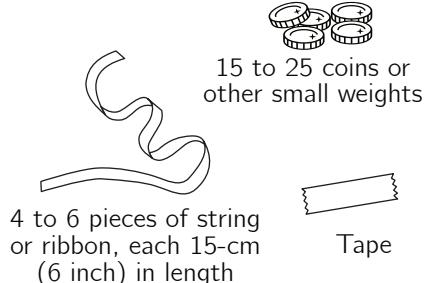
## MATERIALS



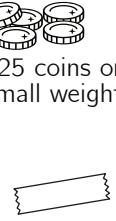
5 or more stackable paper cups



4 to 6 index cards or pieces of paper or cardboard



4 to 6 pieces of string or ribbon, each 15-cm (6 inch) in length



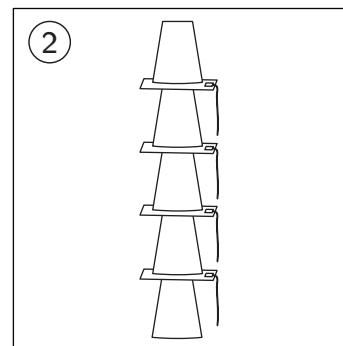
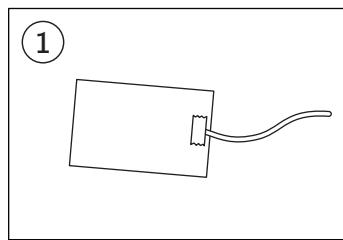
Tape

## GOALS

- To investigate the impact of different accelerations
- Experience an example of how mass can impact inertia (which we'll talk about more next week!)

## THE SET UP

- Use tape to add ribbon to each card on one side.
- Stack 5 cups so that each cup is resting on top of a card.



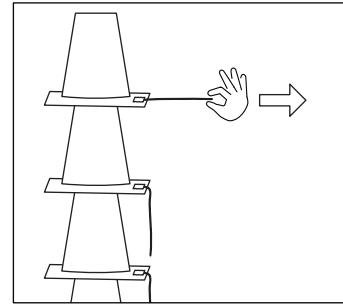
## EXPERIMENT ONE: FAST VS SLOW

The goal is to remove the cards and have the cups fall on top of each other to form a stack. Do you think this will be easier when pulling the cards out quickly or slowly? Make a prediction before trying it:

MY PREDICTION: \_\_\_\_\_

Start with the top card. Hold the string and pull. First try pulling slowly. Then set it up again and try pulling quickly. Do the cups stack or not?

THE RESULT: \_\_\_\_\_



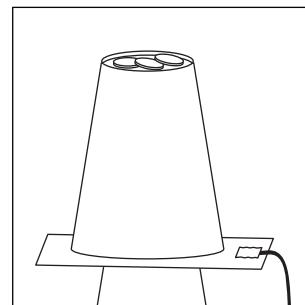
## EXPERIMENT TWO: HEAVY VS LIGHT CUPS

Make a "heavy cup" by placing 3 to 5 coins on top of each cup. Stack the heavier cups in the same way as before. Do you think the heavier cups will stack more easily or less easily than the single cups? Make a prediction before trying it:

MY PREDICTION: \_\_\_\_\_

Pull using whichever speed worked best for cup stacking in the first experiment.

THE RESULT: \_\_\_\_\_



# MOVEMENT - IDEAS THROUGH HISTORY

WE ARE WHAT WE REPEATEDLY DO. EXCELLENCE, THEN, IS NOT AN ACT, BUT A HABIT.

ALSO, THE EARTH CANNOT MOVE. THE SUN AND PLANETS CIRCLE US.

ARISTOTLE

BRILLIANT!

THAT IDEA IS LESS BRILLIANT.

THE EARTH MOVES AROUND THE SUN.

NO!!!! THAT IDEA MAKES US SO ANGRY!!

AND YET IT MOVES.



COPERNICUS



GALILEO

Big ideas:

-CENTRIC  
solar system

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Big ideas:

-CENTRIC  
solar system

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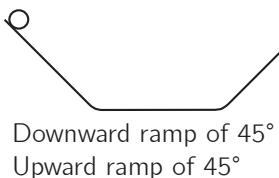
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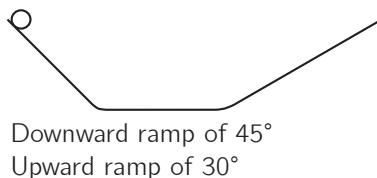
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## ROLLING DOWN A RAMP WITH LITTLE TO NO FRICTION

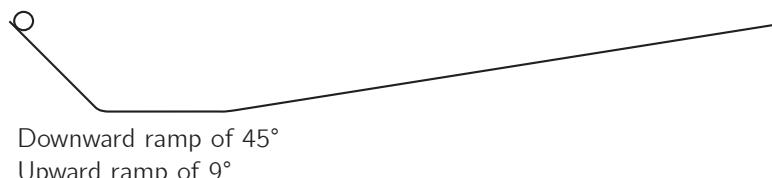
WHAT HEIGHT WILL THE BALL REACH IF IT ROLLS DOWN THESE RAMPS? MAKE A PREDICTION AND THEN DRAW THE RESULTS.



Downward ramp of 45°  
Upward ramp of 45°



Downward ramp of 45°  
Upward ramp of 30°



Downward ramp of 45°  
Upward ramp of 9°

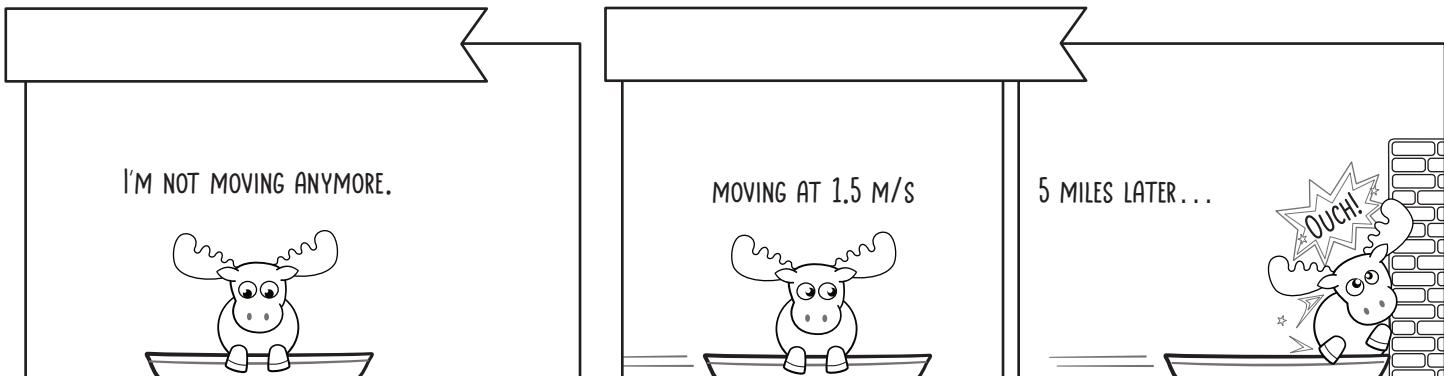


Downward ramp of 45°  
No upward ramp



## A MOVEMENT MISCONCEPTION

A sled receives a push that causes it to move forward across a flat surface of ice at 1.5 meters per second (about 3 miles per hour). The ice is 5 miles long and ***there is no friction or air resistance***. What will happen? One of the predictions below is accurate. The other is a misconception.



THE SLED WILL SLOW DOWN AND EVENTUALLY COME TO A STOP. FORCES ARE NEEDED TO KEEP OBJECTS MOVING.

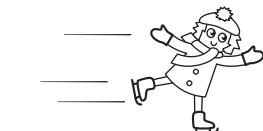
THE SLED WILL MOVE AT THE SAME SPEED UNTIL IT REACHES THE WALL. FORCES ARE NEEDED TO CHANGE THE MOTION OF A MOVING OBJECT.

## BALANCED FORCES =

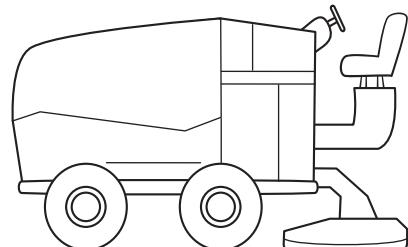


During a 3-second period, an ice skater is gliding across the ice at a ***constant speed***. An ice resurfacing machine (Zamboni) is also on the ice rink and it is *not moving*. Label the forces acting on each object and draw arrows to show the general direction and strength of each force. Are the forces **balanced** or **unbalanced**?

**ICE SKATER**  
CONSTANT SPEED FORWARD  
AT 2 METERS PER SECOND



**ZAMBONI**  
NOT MOVING



## PRACTICE PROBLEMS – THE LAW OF INERTIA

- 1 When a bus comes to a sudden stop, the passengers tend to lurch forward. Explain what causes this phenomenon:

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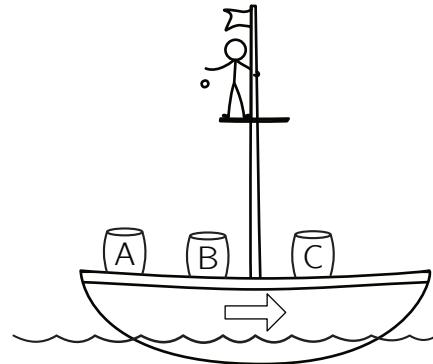
- 2 Gabi climbs 20 feet up the mast of a ship moving forward at 2 feet per second. She drops a ball from the top as pictured. There are 3 barrels on the ship labeled A, B, and C. Which barrel will the ball land in? Explain.

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- 3 In a game of tug-a-war between two teams of equally strong robots, which statement is true?

- A. The forces on the rope are unbalanced, leading to a clear winner.
- B. The forces on the rope are balanced, causing the rope to remain stationary.
- C. The forces on the rope are unbalanced, causing the rope to remain stationary.
- D. The forces on the rope are balanced, leading to a clear winner.

- 4 What would happen if a mischievous squirrel jumped onto a table that was covered by a slippery and almost friction-less tablecloth? (Assume there are no external forces acting on the tablecloth)

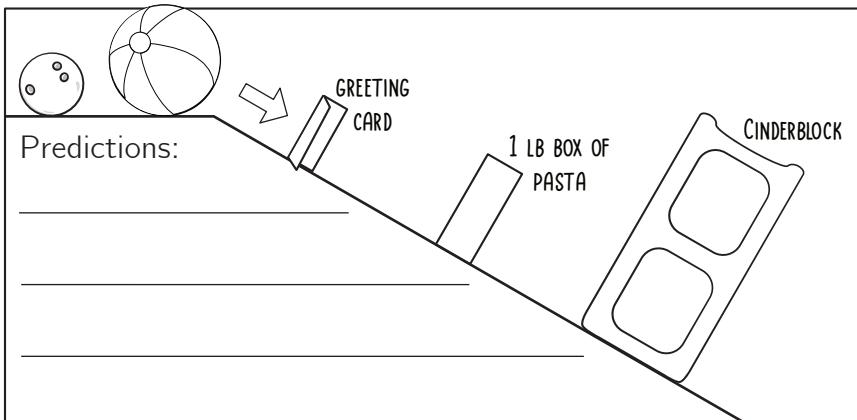
- A. The squirrel would be stuck in place, unable to move.
- B. The squirrel would slide to the end of the table in the same direction it jumped.
- C. The squirrel would slide a short distance and then come to a stop.
- D. The squirrel would start a perpetual motion machine.

- 5 Which of the following scenarios best represents Newton's first law of motion?

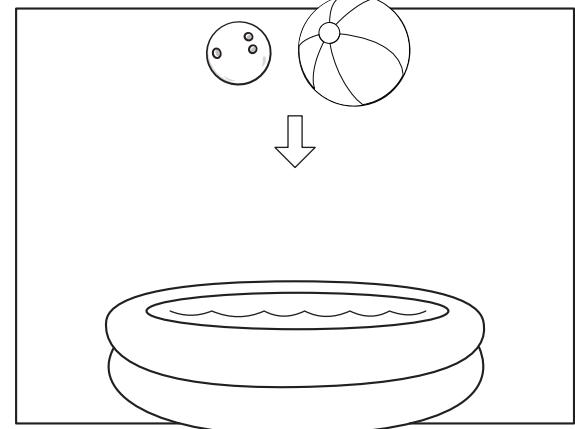
- A. A skateboarder speeding up when going downhill
- B. A cat struggling to jump off a slippery surface
- C. A book remaining motionless on a table until someone pushes it
- D. A ballerina spinning faster and faster during a pirouette

# INERTIA & MASS

## BEACH BALL VS BOWLING BALL



Predictions:

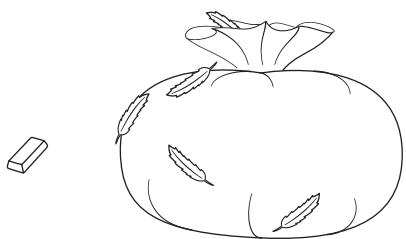


Beach ball results: \_\_\_\_\_

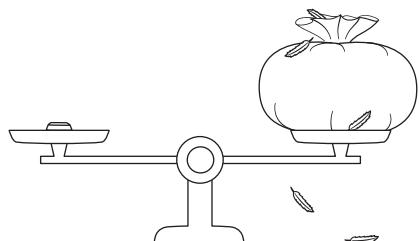
Bowling ball results: \_\_\_\_\_

## GOLD OR FEATHERS?

WHAT WEIGHS MORE, A POUND OF GOLD OR A 1 POUND BAG OF FEATHERS?



THEY'RE THE SAME! THEY EACH WEIGH 1 POUND.



A POUND ALWAYS WEIGHS A POUND — OR DOES IT?



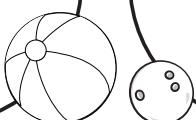
# MASS

WHAT IT IS & HOW IT'S MEASURED:

# WEIGHT

WHAT IT IS & HOW IT'S MEASURED:

VS



**Curiosity** is a car-sized rover on Mars. It has a mass of 899 kg. The gravitational strength on Mars is 3.7 N/kg. The gravitational strength on Earth is 9.8 N/kg. Calculate Curiosity's weight in newtons on Mars and Earth. On which planet is the rover heavier and by about how much?



### WHAT WOULD YOU WEIGH ON 4 DIFFERENT PLANETS?

First, find your mass! If you know your weight in pounds, convert it to kilograms by dividing by 2.205.

Mass:  
Gravity: 9.8 N/kg  
Weight:



**EARTH**

Mass:  
Gravity: 1.6 N/kg  
Weight:

**EARTH'S MOON** → 

Mass:  
Gravity: 3.7 N/kg  
Weight:

**MERCURY** 

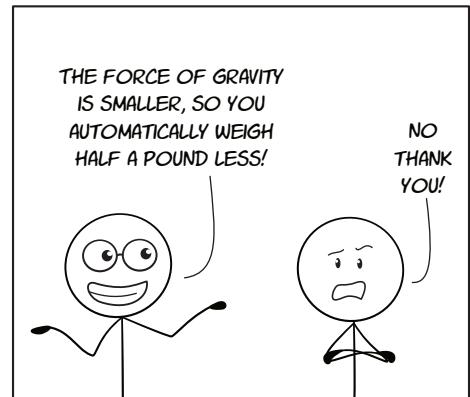
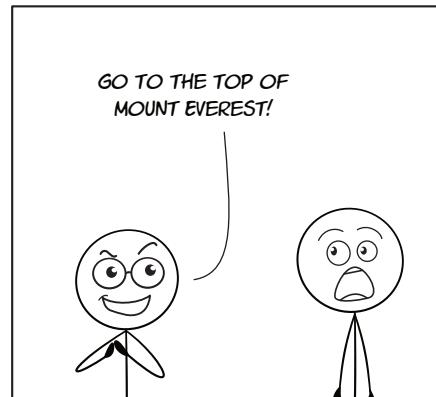
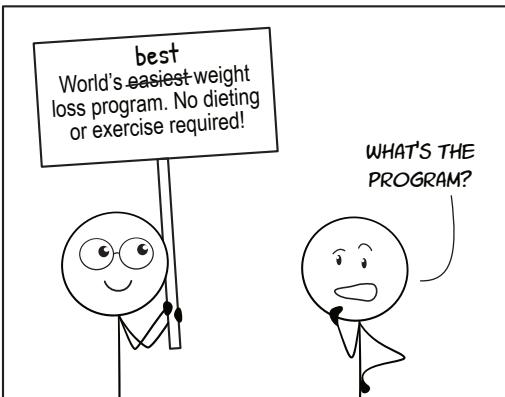
Mass:  
Gravity: 24.8 N/kg  
Weight:

**JUPITER**   
AUGHH!  
Should we tell them they can't land on Jupiter?  
They'll figure it out.

COMPLETE THE ARROWS SO THAT EACH SENTENCE IS TRUE:

↑ MASS = || INERTIA.      ↓ MASS = || INERTIA.

#### WEIGHTY MATTERS



# PRACTICE PROBLEMS – MASS VS WEIGHT

- 1** What changes depending on where you are in the universe?
- A. Mass
  - B. Weight
  - C. Both mass and weight change
  - D. Neither mass nor weight change with location
- 2** If you were to weigh yourself on the Moon, what would happen to your mass and weight compared to your mass and weight on Earth?
- A. Both mass and weight would decrease.
  - B. Both mass and weight would increase.
  - C. Mass would decrease, weight would stay the same.
  - D. Weight would decrease, mass would stay the same.
- 3** A sumo wrestler and a chicken are on ice skates on a friction-less ice skating rink. Who would require more force to start moving?
- A. The sumo wrestler, due to their greater mass.
  - B. The chicken, due to their lesser mass.
  - C. Both would require the same amount of force.
  - D. Neither could be moved, as they are on a frictionless surface.
- 4** Which of the following animals would have greatest inertia?
- A. A squirrel running along a fence
  - B. A sleeping rhinoceros
  - C. A cheetah sprinting across the savanna
  - D. A marmoset perched on a branch
- 5** Which has more inertia: a small pebble being thrown across a pond, or a giant boulder sitting on the shore? Explain why. Would the answer change if the boulder was rolling down a steep hill?

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- 6** Sam pushes on a heavy box, moving it across the floor. When she stops pushing, the box stops moving. Why? Does it violate the law of inertia? Explain.

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# INERTIA EXPERIMENTS

## PRO TIP FROM MATH DAD:

DON'T USE A FRAGILE OR BREAKABLE CUPS OR DISHES! CHOOSE ITEMS THAT ARE RESILIENT TO BEING KNOCKED OVER.

PLACE THEM IN A LOCATION WHERE IT WOULD BE OKAY IF THINGS ACCIDENTALLY TIPPED OVER. HAVE A TOWEL OR RAG HANDY TO CLEAN UP ANY MESSES!

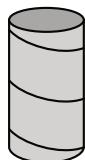
## GOALS

★ Better understanding of the concept of inertia.

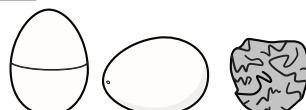
★ See that multiple trials or repeated experiments can improve our understanding

## EGG SPLASH

### MATERIALS



Toilet paper tube



1 OR MORE "LIGHT EGGS"  
An empty plastic egg, a blown egg, or an egg-shaped piece of crumpled paper, plastic, or foil



1 OR MORE "HEAVY EGGS"  
A plastic egg filled with dough or clay, a hard-boiled egg, or an egg-shaped bundle of coins or rocks wrapped in plastic, paper, or foil



Aluminum pie plate or a piece of cardboard



Cup that can fit an egg inside, about 2/3 full of water



Rag or towel to clean up any spilled water

In this experiment you will be attempting to land an egg in a cup. The egg is balanced over the cup, but to get it in you are only allowed to touch the pie pan. No touching the egg or toilet paper roll! BEFORE you try it, make a prediction. Which egg do you expect to be easier to land in the cup?

Your prediction! Select one of the predictions below or write your own:

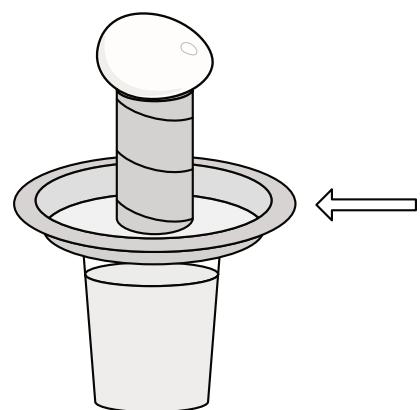
The light egg will land in the cup more often.

The heavy egg will land in the cup more often.

Other: \_\_\_\_\_

### Steps for the "Egg Splash:"

1. Place the pie pan right-side up on the top of the cup.
2. Stand the toilet paper roll in the center of the pie pan. Then balance either a "light egg" or a "heavy egg" on top.
3. Smack the pie plate with a swift motion from the side so that it leaves the top of the glass. Keep the speed and force as similar as you can each time!
4. Record whether the egg fell into the cup by filling in the table on the following page. Repeat the experiment 10 times with each type of egg.



## Egg-celent Data:

Mark a 0 for each attempt where the egg did not land in the cup and a 1 for each attempt where the egg landed in the cup (a “splash”).

Repeat the experiment 10 times for each type of egg and record the result for each attempt. Then add up the numbers in each column to record how many times the light and heavy eggs landed in the cup.

*“Tell me and I forget, teach me and I may remember, involve me and I learn.”*

- Benjamin Franklin

Light Egg	Heavy Egg

Total # of splashes  
out of 10 attempts:

--	--

Underline the thing(s) you kept the same in the egg splash. Circle the thing(s) you changed.

- Toilet paper tube to hold the egg
- Aluminum pie pan
- Amount of water in the cup
- Type of egg
- Speed and force of the “smack” on the pan
- The person performing the egg splash

Was there a difference in how the light egg and heavy egg behaved? If so, which egg fell into the cup most often? Why do you think this egg landed inside the cup more often?

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Andy tried the egg splash experiment once with the light egg and once with the heavy egg. Both eggs landed outside of the cup, so Andy says the weight of the egg makes no difference.

Do you agree with Andy’s conclusion? Why or why not?

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# TABLECLOTH PULL

## MATERIALS



A smooth cloth or scarf made of silk or satin with little or no ridge around the edge



A bath towel



A flat table or counter top



Two water bottles, each half-full of water, OR two unbreakable dishes or cups

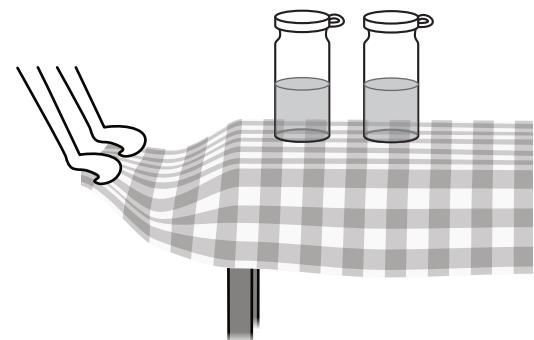


Can you pull a tablecloth out from under dishes without pulling the dishes off the table? Does the texture of the cloth make a difference?

### Steps:

1. Lay the silky-smooth cloth on the table so that about 50 cm (20 inches) of the cloth is on the table and the rest is dangling off the edge. Smooth out any wrinkles.
2. Practice pulling the smooth cloth off the table by gripping it firmly with both hands and pulling downward and outward quickly. Keep your hands below the edge of the table the whole time so that the cloth is not lifted up for any part of your pull.
3. Once you've practiced and can pull the cloth quickly, place the two water bottles on top of the cloth and pull.
4. If you pull quickly enough, the dishes will remain where they started, and the cloth will no longer be on the table.
5. Once you've successfully learned how to pull the "tablecloth" from under an object with the smooth cloth, try it three times and record your results. Then use the same technique and try it with a towel three times.

Do this activity in a safe location where objects falling off the table won't cause a mess. Be sure to have adult permission!



Record how often the objects stayed standing. Mark 0 if both objects fell over, 1 if one object tipped over, and 2 if both objects stayed upright and remained on the table.

SILKY CLOTH	BATH TOWEL
1 <sup>st</sup> attempt	
2 <sup>nd</sup> attempt	
3 <sup>rd</sup> attempt	
AVERAGE:	

## SILKY-SMOOTH CLOTH VS TOWEL EXPERIMENT:

Circle the things that you tried to keep the same in the silk vs towel experiment. Put a box around the thing that was changed:

HOW FAST THE CLOTH IS PULLED

THE OBJECTS ON THE TABLE

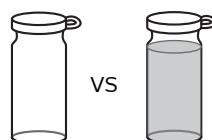
THE TEXTURE OF THE CLOTH

THE DIRECTION OF THE PULL

If you changed everything listed above, would you be able to tell which cloth worked better for the tablecloth pull?

## BONUS EXPERIMENT:

Does the weight of the objects matter? Try the demonstration with objects of different mass!



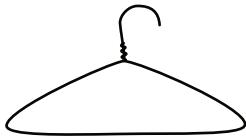
# INERTIA HAT

BONUS ACTIVITY!

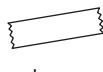
## MATERIALS



wire cutters and  
pliers (optional)



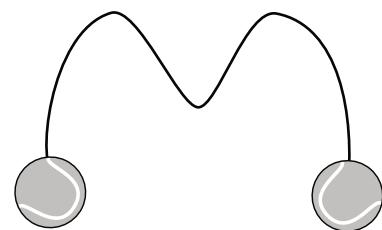
wire hanger



tape



2 wiffle balls, tennis  
balls or same-size  
pieces of modeling clay



Create a wire "hat" that can spin on your head. Then experiment with inertia.

### Steps:

1. Untwist and straighten a wire hanger OR, for easier bending, use wire cutters to trim off the hook. If using wire cutters, be careful with sharp ends!
2. Straighten the wire into a long straight strand. It may be helpful to use pliers when straightening.
3. Bend the wire into an M-shape as pictured. Try to make it as symmetric as possible.
4. Attach the balls (or modeling clay or any other two items of the same size and weight). Either puncture the balls or clay with the wire or use tape to secure the balls in place.
5. Place the center of the M-shaped wire on the palm of your hand to see if it stands up vertically. Bend the wires and make small adjustments until it stands vertically.
6. Place the "hat" on your head.
7. Demonstrate the law of inertia by changing how you move or how you apply force to the hat:

- a) Give one of the tennis balls a push and observe the hat. It may fall off the first few times you try, but with practice, you'll see it spin around like planets orbiting the Sun.

*Why does the hat keep spinning after the initial push?*

- 
- 
- 
- b) Can you spin in place and complete a full rotation with the hat staying in the same position?

Yes. I observed and/or did this.

No. This is not possible according to the laws of physics.

- c) Spin very slowly while balancing the hat so that the hat keeps the same position relative to your head. Then abruptly stop spinning. *What does the hat do? Why does it behave this way?*
- 
- 
-

## DIRECTLY OR INVERSELY RELATED?

Understanding how two quantities are related is an essential part of physics and science in general. Two important relationships that show up repeatedly are directly proportional and inversely proportional.

### DIRECTLY PROPORTIONAL VS INVERSELY PROPORTIONAL

$$\text{AREA} = (\text{BASE}) \cdot (\text{HEIGHT})$$

$$\begin{array}{c} \boxed{\text{Area} = 8} \\ 4 \end{array} \rightarrow \begin{array}{c} \boxed{\text{Area} = ?} \\ 12 \end{array}$$

If the **length** of the base is tripled, what happens to the area?

$$\begin{array}{c} \text{Area} = 12 \\ \boxed{6} \end{array} \rightarrow \begin{array}{c} \boxed{?} \\ 3 \end{array}$$

If **area** stays the **same**, what happens to the height when the base length is cut in half?

$$\text{WEEKLY EARNINGS} = (\text{HOURS WORKED}) \cdot (\text{PAY PER HOUR})$$



At this job, the number of hours worked per week (40) times hourly pay (\$10 per hour) results in weekly earnings of \$400.

If pay per hour doubles but hours worked stays the same, what happens to the earnings?

A person wants to reduce their hours from 40 to 10, but still earn the same total amount each week of \$400. How much do they need to earn per hour?

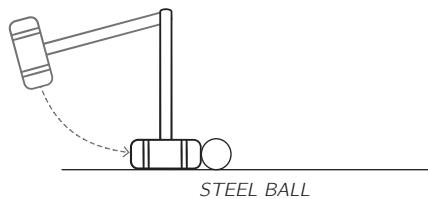
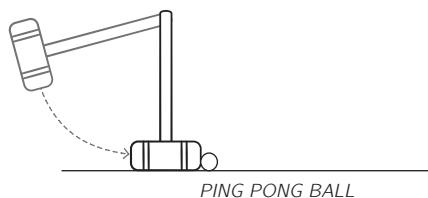
COMPLETE EACH SENTENCE. THEN CIRCLE WHETHER IT'S DIRECTLY OR INVERSELY PROPORTIONAL:

As test scores go down, grades go _____.	DIRECTLY	INVERSELY
For brighter flashlight settings, battery life _____.	DIRECTLY	INVERSELY
As driving speed increases, time spent traveling _____.	DIRECTLY	INVERSELY
As number of tacos ordered goes up, money spent _____.	DIRECTLY	INVERSELY
More workers helping will _____ the time to completion.	DIRECTLY	INVERSELY
Cooking a larger batch of cookies requires _____ flour.	DIRECTLY	INVERSELY

## EXPERIMENTS WITH MASS & FORCE

### EXPERIMENT ONE:

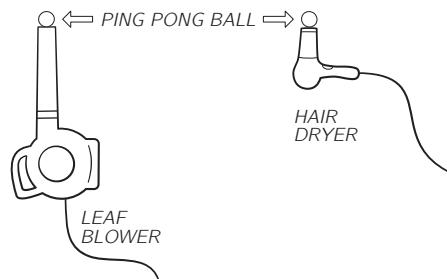
SAME FORCE, DIFFERENT MASS.



WHICH BALL WILL ACCELERATE MORE?

### EXPERIMENT TWO:

SAME MASS, DIFFERENT FORCE.



WHICH BALL WILL ACCELERATE MORE?

### EXPERIMENT THREE:

SAME ACCELERATION, DIFFERENT MASS



AN EMPTY SHOPPING CART ACCELERATING AT 0.25 METERS PER SECOND PER SECOND



A FULL SHOPPING CART ACCELERATING AT 0.25 METERS PER SECOND PER SECOND

WHICH REQUIRES MORE FORCE?

## NEWTON'S SECOND LAW OF MOTION

$$F = m \cdot a$$

If you know the 5 newtons of force is being applied to a 10,000 kg spaceship, can you calculate how quickly it will accelerate? What equation would you use?

WHAT UNITS SHOULD BE USED TO MEASURE THESE? DRAW LINES TO MATCH THEM TO THE BEST FIT:

Push

Weight

Acceleration

Mass

Force

NEWTONS

KILOGRAM

METERS PER SECOND PER SECOND

FILL IN THE BLANKS:

*scaling      directly      proportional      inversely*

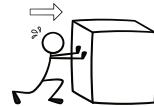
When two quantities are \_\_\_\_\_ proportional, changing or scaling one quantity leads to a corresponding \_\_\_\_\_ in the other. Anytime you have an equation where quantity A is a multiple of quantity B, A and B will be directly \_\_\_\_\_ to each other.

If two quantities are \_\_\_\_\_ proportional, then multiplying one quantity by a number requires us to divide the other by that same number.

In the equation  $F=ma$ , mass and acceleration are \_\_\_\_\_ proportional, and force and acceleration are \_\_\_\_\_ proportional to each other.

## PRACTICE PROBLEMS – NEWTON'S SECOND LAW

- ① How quickly will a 20 kg box accelerate if a net force of 40 N eastward is applied?



- ② How much force is needed to accelerate a mass of 100 kg at a rate of  $20 \text{ m/s}^2$ ?

- ③ A soccer ball is kicked with a force of 10 N and it accelerates at a rate of  $5 \text{ m/s}^2$ . What is the mass of the soccer ball?

- ④ When you double the force acting on an object, what happens to the acceleration?

- ⑤ When you triple the mass of an object, but apply the same net force, what happens to the acceleration?

- ⑥ A force of 15 N is needed to slide a bucket of 100 apples along a surface with an acceleration of  $0.3 \text{ m/s}^2$ . What force is needed to slide a bucket of 50 apples with that same acceleration?

- ⑦ To accelerate a rocket 5 times faster, how much more force is required?

- ⑧ A new model of dump truck supplies 3 times as much force and carries 2 times as much mass as the old dump truck. How will the acceleration of the new dump truck compare to the acceleration of the old dump truck?

## PRACTICE PROBLEMS – NEWTON'S SECOND LAW

- 9 Circle T or F to mark each statement as either True or False:

- T    F   Acceleration is a vector quantity.
- T    F   Mass is a vector quantity.
- T    F   Force is a vector quantity.
- T    F   If the acceleration stays the same, changing the mass will always change the force.

- 10 Fill in each blank below with either "directly" or "inversely" to make the statement true.

- The length of your shadow is \_\_\_\_\_ proportional to your height.
- Liters of gasoline consumed is \_\_\_\_\_ proportional to the distance driven.
- Time until arrival is \_\_\_\_\_ proportional to speed of travel.
- The number of candy bars purchased is \_\_\_\_\_ proportional to the total paid for candy.
- In the equation  $72 = x \cdot y$ , the variable  $x$  is \_\_\_\_\_ proportional to  $y$ .

- 11 MATCHING:

Each situation below represents a situation where forces are either unbalanced or balanced. Draw lines to connect each situation to the correct description of forces.

Tug of war - Unbeatable  
Science Kids winning

BALANCED

Tug of war - stalemate

UNBALANCED

Rock resting on the ground

A skater gliding at a uniform  
pace on ice with no friction

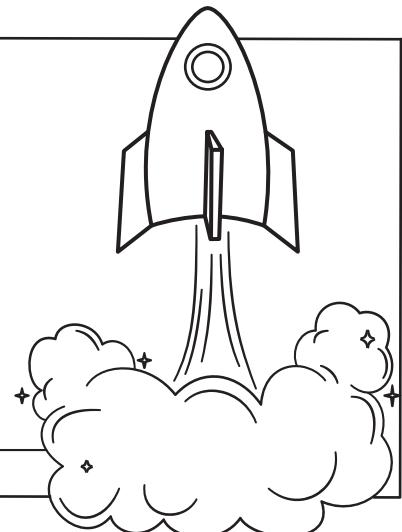
Rocket taking off

Dog sled team slowing  
down

- 12 A 100 kg satellite is going to be launched from a space station, but if its going to reach the correct orbit it needs to be launched with an acceleration of  $11 \text{ m/s}^2$ . How much force is needed to launch it?

## NEWTON'S THIRD LAW OF MOTION

FORCES BETWEEN TWO INTERACTING OBJECTS WILL ALWAYS OCCUR IN PAIRS THAT ARE \_\_\_\_\_ IN MAGNITUDE AND \_\_\_\_\_ IN DIRECTION



This is commonly stated "for every action, there is an equal and opposite reaction," but remember that while the FORCES involved will be equal and opposite, if the mass of the two objects is different, their resulting MOMENTUM or ACCELERATION will be very different!



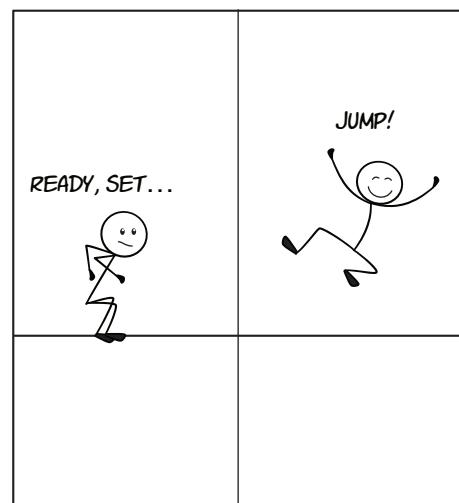
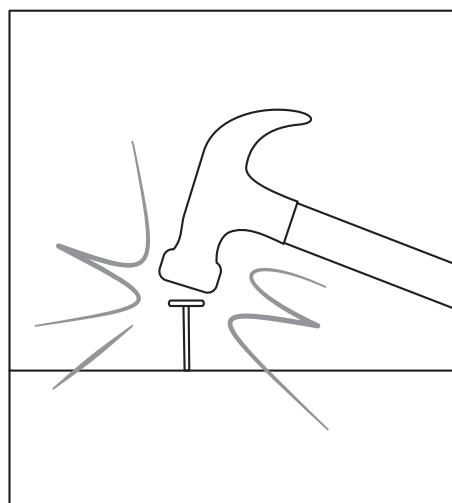
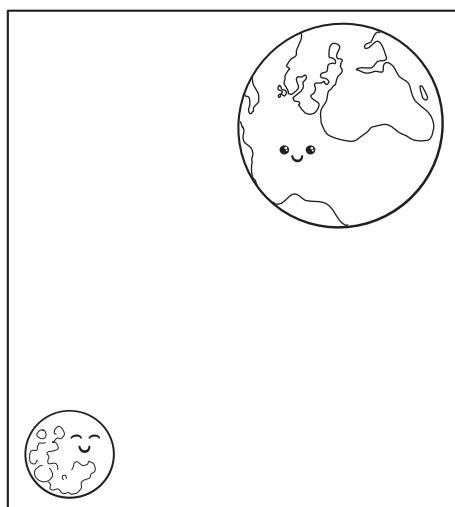
ESSENTIAL CONCEPT

FORCES RESULT FROM INTERACTIONS BETWEEN OBJECTS.  
BY DEFINITION, A FORCE WILL ALWAYS INVOLVE AT LEAST TWO OBJECTS!

What holds the Moon in orbit around the Earth? \_\_\_\_\_

Does the Moon also exert a force on the Earth? \_\_\_\_\_

DRAW ARROWS TO SHOW THE STRENGTH AND DIRECTIONS OF THE FORCES BETWEEN EACH PAIR OF OBJECTS.



# LET'S TEST IT!



Scales for measuring a person's weight use pounds or kilograms.

$$1 \text{ kg} = 2.2 \text{ lb} = 9.8 \text{ N}$$

TWO BATHROOM SCALES ARE HELD VERTICALLY BACK-TO-BACK. A PERSON IS PUSHING ON ONE. THE OTHER IS STATIONARY AGAINST A DOOR.



If the person pushes with 80 newtons of force, what will the scales show?

Will they have identical or non-identical readings?

---



---

## IDENTIFY THE FORCE PAIRS IN EACH SCENARIO:

*Ignore friction and the normal force - just consider gravity and the force of the push (applied force)*



A PERSON JUMPS FORWARD FROM SOLID PAVEMENT.



PERSON JUMPS FORWARD WITH THE SAME FORCE AS BEFORE, BUT THIS TIME STANDING ON A SKATEBOARD.

SKATEBOARD JUMP EXPLAINED:

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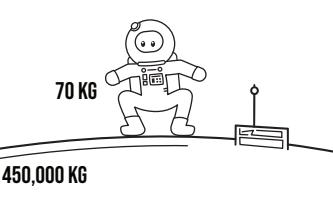


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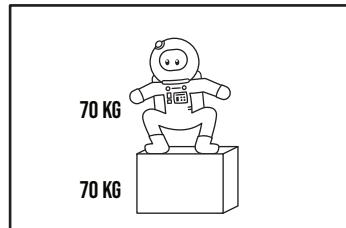
## JUMPING IN OUTER SPACE! PREDICT THE FORCE & ACCELERATION IN EACH SCENARIO:

*The same force or push is applied by the astronaut with each of the three jumps.*

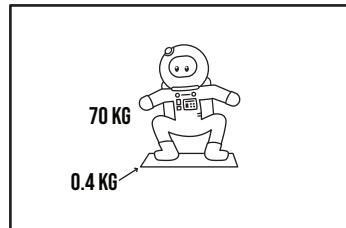
Which object experiences more force or acceleration?  
Circle the correct answer for each situation.



JUMP FROM ROOF OF  
LARGE SPACE STATION



JUMP FROM BOX  
WITH EQUAL MASS



JUMP FROM A PIECE  
OF THIN ALUMINUM

WHICH EXPERIENCES  
GREATER FORCE?

ASTRONAUT	SPACE STATION	SAME
-----------	---------------	------

WHICH EXPERIENCES  
GREATER ACCELERATION?

ASTRONAUT	SPACE STATION	SAME
-----------	---------------	------

ASTRONAUT	BOX	SAME
-----------	-----	------

ASTRONAUT	ALUMINUM	SAME
-----------	----------	------

ASTRONAUT	BOX	SAME
-----------	-----	------

ASTRONAUT	ALUMINUM	SAME
-----------	----------	------

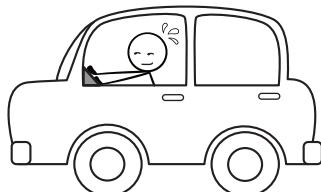
## WOULD IT MOVE?

Consider each situation and use what you know about Newton's Laws of Motion to predict the motion.

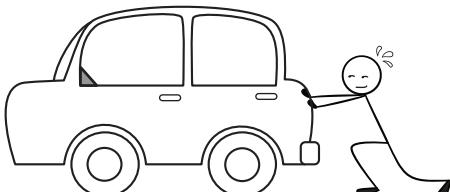


Maria is super strong and can push with more than 500 newtons of force!

PUSHING WITH 500 N FROM INSIDE THE CAR.



PUSHING WITH 500 N FROM OUTSIDE THE CAR.

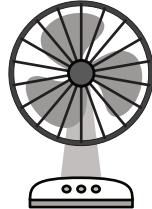


Both cars are in neutral gear. 230 newtons of force could propel them forward if applied correctly.

RECORD WHAT YOU PREDICT WOULD HAPPEN:

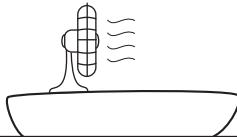
\_\_\_\_\_

\_\_\_\_\_

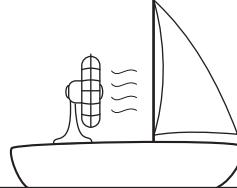


The curved blades of a fan rotate, pushing air forward.

A POWERFUL FAN ON A BOAT



A POWERFUL FAN ON SAILBOAT



RECORD WHAT YOU PREDICT WOULD HAPPEN:

\_\_\_\_\_

\_\_\_\_\_

MAKE NOTES BELOW! DRAW ONE OR MORE OF THE FREE BODY DIAGRAMS!



## PRACTICE PROBLEMS – ACTIONS AND REACTIONS

1 A balloon is inflated and then released without tying the opening causing the balloon to fly around the room. Explain this behavior with Newton's third law?

2 Two stationary people of equal mass on slippery ice (no friction) push off from each other. Will both move at the same speed in opposite directions?

- A. Yes
- B. Yes, but only if both push with equal effort
- C. No
- D. No, unless their mass changes

3 When a cannon fires a cannonball, both the cannonball and the cannon push off each other in forces of equal magnitude. Why does the cannonball accelerate so much faster than the cannon?



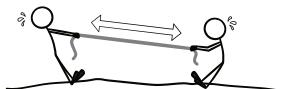
4 The Earth exerts a pull on you equal to your weight. Do you exert an equal pull on the Earth?

5 A male ice skater and a female ice skater push off of each other. The male has a mass of 100 kg, and the female has a mass of 50 kg. If the male skater accelerates to the right at  $2 \text{ m/s}^2$ , how quickly does the female skater accelerate?

6 A chair exerts a force of 25 N downwards to the floor it stands on. A book weighing 2 N is placed on the chair. What is the force that the floor exerts upwards on the chair?

7 Circle T or F to mark each statement as either True or False:

- T    F In a tug-of-war, neither contestant can ever win because any force exerted will be counteracted by an equal but opposite force.
- T    F When a person jumps on the ground they exert a force on the ground but the ground doesn't exert a force on them.
- T    F Actions and reactions always result in motion.
- T    F When a bug and a windshield collide, the bug hits the windshield with as much force as the windshield hits the bug.



# RACING BALLOONS

## MATERIALS



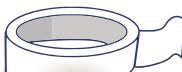
2 to 4  
Balloons



10 or more meters  
(32+ feet) of thin  
thread or fishing line



Clip or clothespin  
(optional)



Tape

10 or more meters  
(32+ feet) of rough  
yarn or twine



2 straws

## GOALS

★ Learn more about the force of friction

★ Conduct a scientific experiment and describe what you learned

Note: This experiment is best performed with assistance from 2 or more people.

First, make a prediction! Two balloons attached to straws will be put on different lines or “strings” of material. What do you expect to happen when they are inflated and then released?

Will the balloon/straws move along the string? If yes, in which direction? Which balloon will move more, the one on thread or twine?



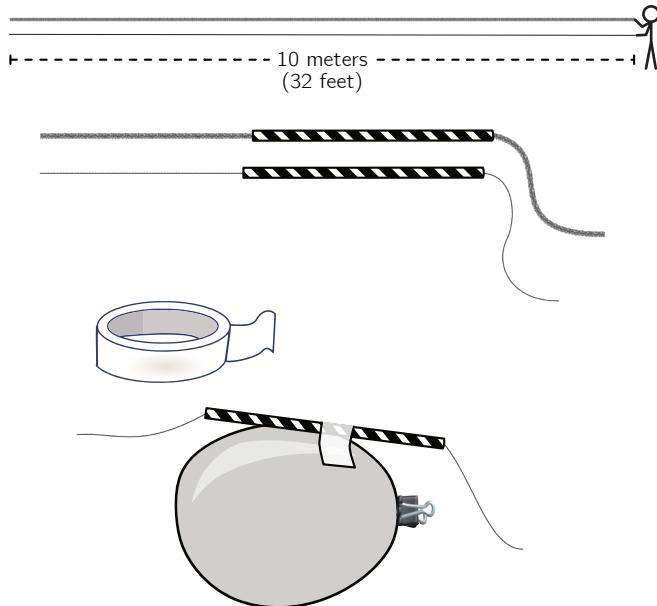
My prediction: \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

## Steps:

1. Find a location where the thread and twine can be laid out parallel to each other and stretch at least 8 to 10 meters (26 to 32 feet) in straight lines.
2. Secure the ends of the thread and twine to a stationary object or have a volunteer hold both ends so that they do not move. If tying the thread and twine, be careful to secure them safely so that you don't accidentally pull over any objects.
3. At the other ends of the lines, put one straw over the thread and another over the twine.
4. Blow up two balloons so they are inflated to a similar size, but don't tie the end. Instead, hold the balloon closed with your hands or a clip.
5. Tape each balloon to a straw with the mouth of the balloon pointing parallel to the thread/twine.
6. Check to be sure that both the thread and twine are straight.
7. Release the balloons!
8. Measure how far the balloons traveled. Repeat the experiment 5 times and record your results.



## TIPS FOR SUCCESS:

- Make sure the string is completely straight.
- Balloon should be blown up fully BEFORE it is taped to the straw.
- Make sure the end of the balloon is parallel to the string.

# VARIABLE

## INDEPENDENT

What is changed or controlled



## DEPENDENT

What is measured



NUMBER OF HOLES

HOW FAST THE BOAT SINKS

Any factor, condition, or trait that can exist in different amounts or types.

In the racing balloons experiment, the instructions said to keep all variables as identical as possible except for the thickness and texture of the strings. Why do we want to change just one variable? What would happen if we changed 3 or more?

---

---

What was the **independent variable** in this experiment?

---

What was the **dependent variable** in this experiment?

---

Enter the distances you observed for each racing balloon and then describe your results. Did changing the string material change how far the balloon traveled?

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## RACING BALLOONS DATA

Record the distance each balloon traveled

	THREAD or FISHING LINE	TWINE or THICK YARN
1 <sup>st</sup> attempt		
2 <sup>nd</sup> attempt		
3 <sup>rd</sup> attempt		
4 <sup>th</sup> attempt		
5 <sup>th</sup> attempt		

AVERAGE DISTANCE TRAVELED	

How would you *explain* these results? What does this experiment tell us about the force of friction?

---

---

---

## ADDITIONAL VARIATIONS TO EXPLORE:

⇒ Change the angle of the string!

Does the balloon move faster if it's going downhill? What about uphill? Can you find the maximum slope where it will still travel to the end of the thread/fishing line?

⇒ Try adding a payload!

Can your balloon still propel the straw forward if the mass is increased? Use tape to attach a small weight such as coins to the straw. What effect does increased mass have on the motion of the racing balloons?

# Down to Earth

## UNDERSTANDING THE FORCE OF GRAVITY

BEFORE 1638 - MANY SIMILAR IDEAS ABOUT GRAVITY EXIST IN VARIOUS CULTURES.



1638 - GALILEO SHAKES THINGS UP.



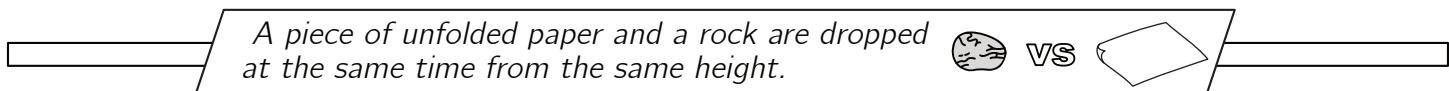
1687: NEWTON DESCRIBES UNIVERSAL GRAVITATION.



1915: EINSTEIN ADDS A NEW DIMENSION - LITERALLY.



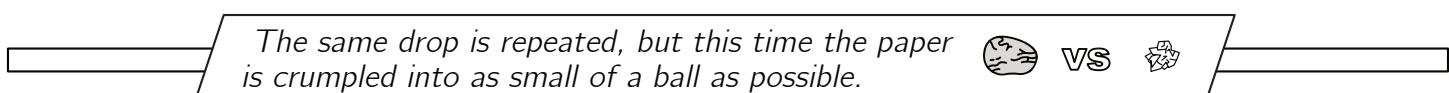
PREDICT AND RECORD THE OUTCOME:



Which will land first, paper or rock?

PREDICTION: \_\_\_\_\_

OUTCOME: \_\_\_\_\_



Which will land first, paper or rock?

PREDICTION: \_\_\_\_\_

OUTCOME: \_\_\_\_\_

PAPER, ROCK... HEY!  
WHAT ABOUT ME?



# Free Fall

The height  $h$  that an object falls after  $t$  seconds is given by the height formula:  $h = \frac{1}{2}gt^2$ .

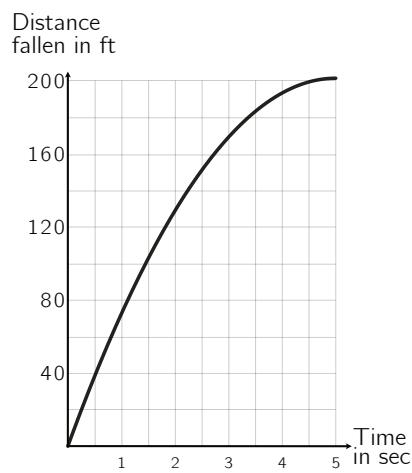
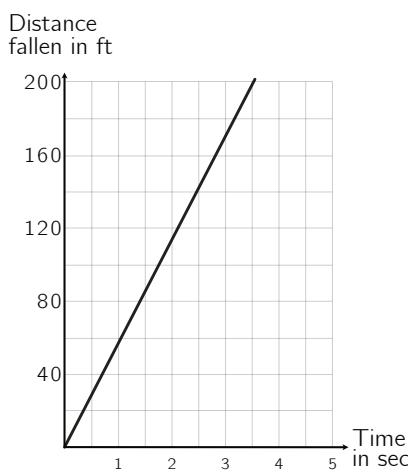
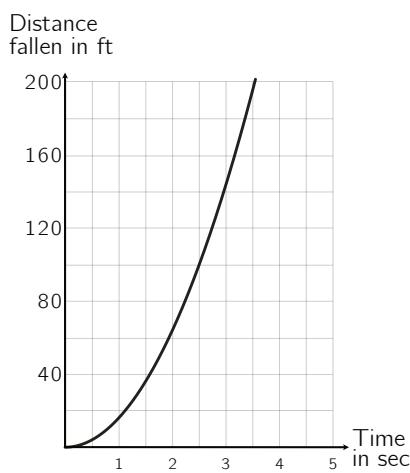
The gravitational constant,  $g$ , can be either  $32 \text{ ft/s}^2$  or  $9.8 \text{ m/s}^2$ .

Example: If an object falls for 5 seconds, it will fall a total distance of  $h = \frac{1}{2} \cdot 32 \cdot 5^2 = 400 \text{ ft}$ .

Use the height formula to find the total distance that an object falls for each of the remaining values in the table below:

Total time (in s)	0	1	2	3	4	5
Total distance (in ft)						400

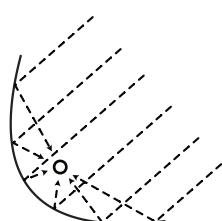
Which of the graphs matches the data in the table?



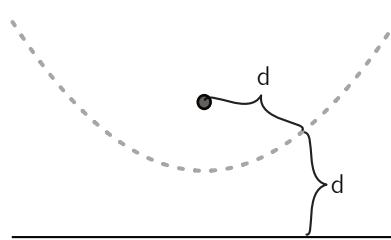
The curve to describe the position of a constantly accelerating object has a mathematical shape called a parabola. Parabolas are used to make satellite dishes, microphones, and automobile headlights. They are one of the most important curves in mathematics!

Are these FACT or FICTION? Write your verdict below each statement:

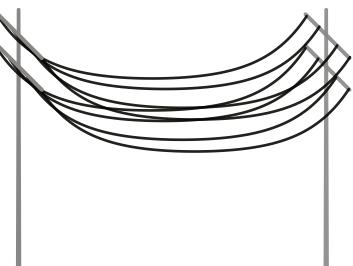
Parabolas have the property that all incoming rays entering parallel to its axis of symmetry will be redirected to the same point (the focus).



A parabola is formed whenever the points that are the exact same distance from a line and a point are plotted.



Power lines (and other cables) make a parabola shape as they dangle.



# Terminal Velocity

An object has reached **terminal velocity** once the upward force of friction is equal but opposite to the downward force of gravity. An object's terminal velocity depends on its shape and on its mass.

WHICH WOULD FALL FASTEST AND WHY?

Golf Ball

Radius: 2 cm



Mass: 1.6 oz

Steel Ball

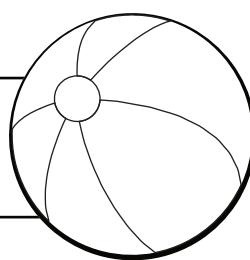
Radius: 2 cm



Mass: 18.9 oz

Beach Ball

Radius: 43 cm



Mass: 1.6 oz

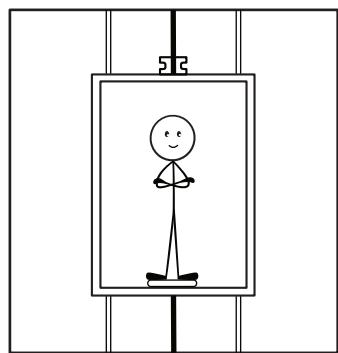
vs

Draw a free body diagram for a rock that has been dropped from a plane:

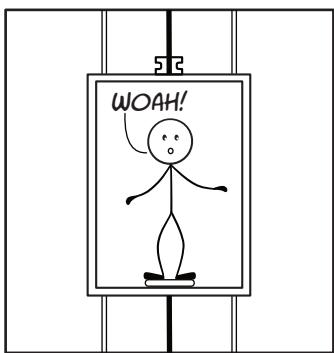
1 second after being dropped

15 second after being dropped

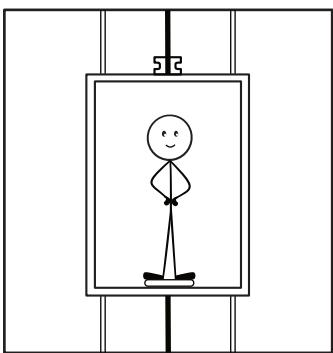
A person who weighs 150 lb (68 kg) is standing on a scale in an elevator. The elevator is stationary in the beginning. Then it accelerates, traveling up to the 20<sup>th</sup> floor where it slows to a stop. In the situations illustrated below, will the scale show readings that are higher, lower, or the same? Circle your prediction and then draw or color what weight you expect the scale would display:



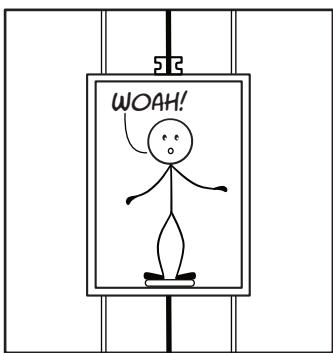
ELEVATOR IS STATIONARY AT GROUND FLOOR



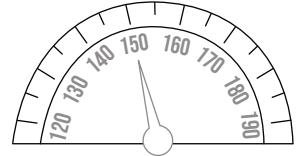
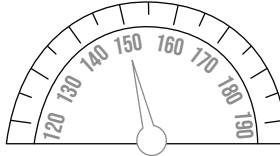
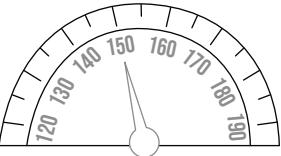
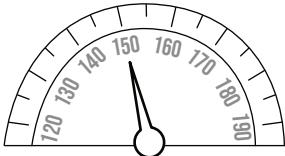
ELEVATOR SPEEDING UP OR ACCELERATING UPWARD



ELEVATOR MOVING AT CONSTANT SPEED TOWARD THE 20<sup>TH</sup> FLOOR



ELEVATOR SLOWING DOWN AS IT REACHES THE 20<sup>TH</sup> FLOOR



LOWER SAME HIGHER

LOWER SAME HIGHER

LOWER SAME HIGHER

## PRACTICE PROBLEMS – GRAVITY AND FREEFALL

Use the formula for fall distance:  $h = 16t^2$  to find how far an object has fallen over time.

- 1 An object is dropped from a height of 16 feet. Fill out the table of values below with the total distance an object falls over each time interval.

Total time falling (in s)	0	0.25	0.5	0.75	1
Total distance (in ft)					

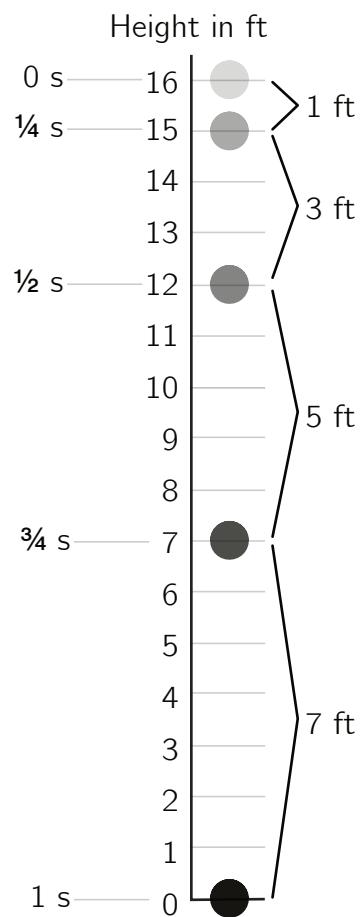
- 2 What do you notice about the numbers in the second row of the table? (Hint: They have a special mathematical property.)

- 3 How long would it take for the object to fall 81 ft?

- 4 Explain what terminal velocity is and what causes it.

- 5 Do two objects with identical mass have the same terminal velocity? Explain.

- 6 Is terminal velocity the same on Earth and the Moon? Explain.



# PRACTICE PROBLEMS – GRAVITY AND FREEFALL

5

An object dropped from a height of 256 ft will hit the ground in 4 seconds as pictured to the left.

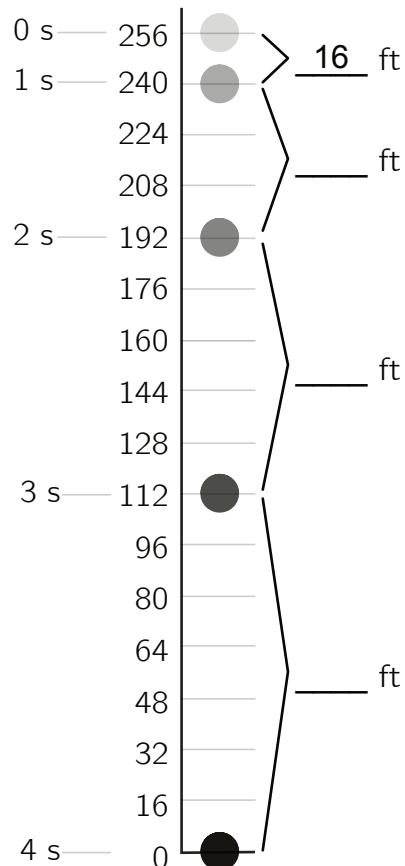
Fill in the table below to record the total distance fallen at each interval.

Next, fill in the blanks to identify how far the object fell in each 1-second interval.

Total time falling (in s)	0	1	2	3	4
Total distance (in ft)					

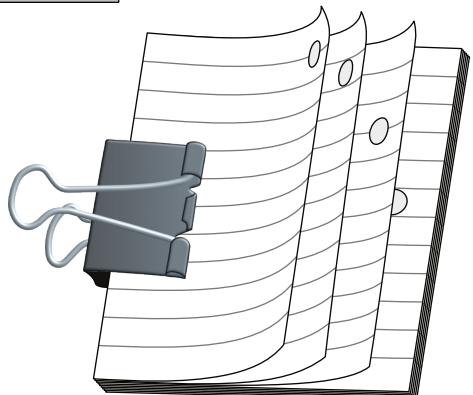
When you change the length of the time interval, the distance traveled on each time interval will keep the same ratio of 1:3:5:7:9...

Height in ft



## BONUS ACTIVITY: FLIP BOOK PHYSICS

1. Cut a stack of 3"x5" index cards in half. Try to be precise.
2. Make a stack of the index cards with their right edges aligned.
3. Make a series of images showing a ball fall and bounce over time. Each successive frame of your cartoon will appear on the next card.
4. Use a binder clip to hold the pages in place so that the right-hand edges are aligned.
5. Flip through your book from front to back and watch your cartoon unfold.



Does your bouncing ball cartoon look realistic? Did you use the 1:3:5:7:9 spacing progression that is guaranteed with free fall?

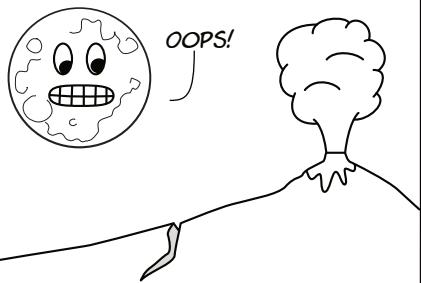
# NEWTON'S LAW OF UNIVERSAL GRAVITATION

EVERY OBJECT IN THE UNIVERSE \_\_\_\_\_ ON EVERY OTHER OBJECT. THIS FORCE IS \_\_\_\_\_  
PROPORTIONAL TO EACH MASS AND \_\_\_\_\_ PROPORTIONAL TO THE SQUARE OF THE DISTANCE.

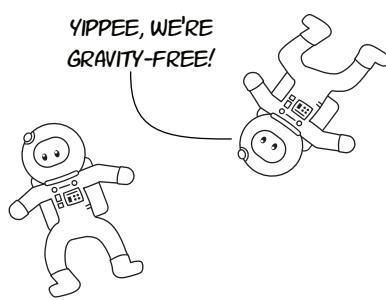
$$F = G \frac{m_1 m_2}{d^2}$$

## FACT OR FICTION? Write your verdict below each statement:

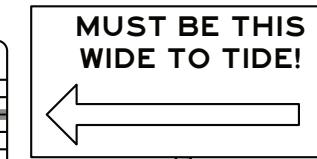
Earthquakes and volcanic eruptions are more likely during a full moon.



There is no gravity in outer space.

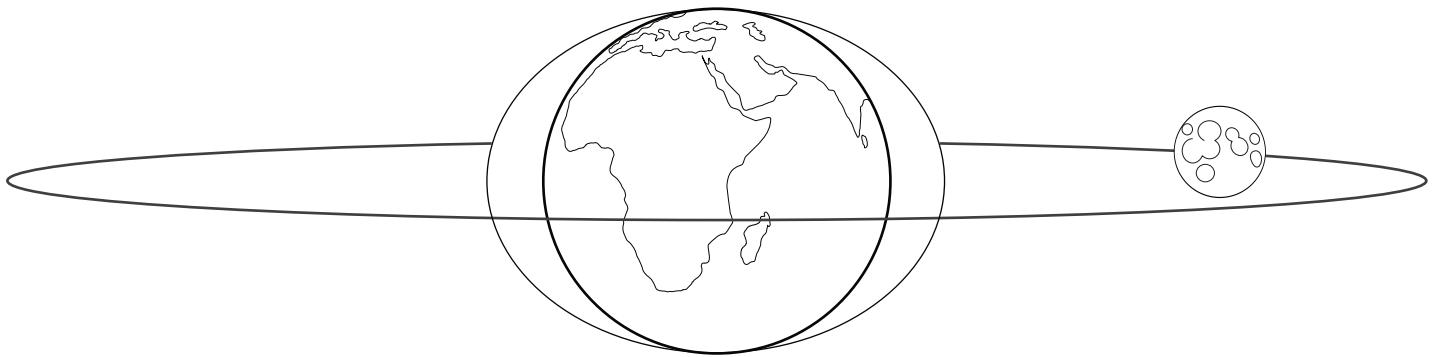


Tides occur in oceans but not in ponds.



EXPLAIN WHY EACH STATEMENT WAS FACT OR FICTION:

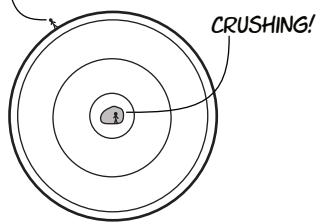
# TIDES AND ORBITS



## FACT OR FICTION? Write your verdict below each statement:

The force of gravity inside the Earth would be >1,000x stronger than on the surface.

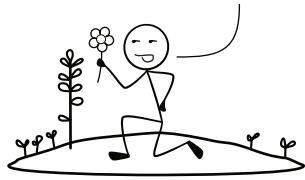
HOW DOES IT FEEL IN THE CORE CAVE?



"Pluck a flower on Earth, and you move the furthest star."

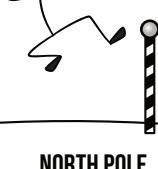
- Paul Dirac

GARDENING TODAY?



The force of gravity is stronger at the equator than at the North Pole.

I CAN JUMP HIGHER HERE!



NORTH POLE

NOW THINGS ARE HOTTER AND HEAVIER!



EQUATOR

EXPLAIN WHY EACH STATEMENT WAS FACT OR FICTION:

## PRACTICE PROBLEMS – SPACE STATION PHYSICS

- 1 An astronaut is floating motionless in space holding onto a tool when she realizes that her ship has drifted slightly away from her. She has no tether and is at risk of being stranded in outer space. Thinking quickly, the astronaut throws the tool with all her might, launching the tool away from the ship. Would this return the astronaut to the ship? Why or why not?
- 2 An elephant is sitting on a seesaw with a mouse on the other end. Which statement is correct?  
A. The elephant will experience more gravitational force than the mouse.  
B. The mouse will experience more gravitational force than the elephant.  
C. Both the elephant and the mouse will experience equal gravitational force.  
D. Neither the elephant nor the mouse will experience any gravitational force.
- 3 If the Earth were three times as massive but the same size, how would your weight on Earth change?
- 4 If the Earth had the same mass but three times the radius, how would your weight on Earth change?
- 5 If object B has twice the weight of object A, why do both objects fall at the same rate?
- 6 Circle T or F to mark each statement as either True or False:  
T    F If you drop a feather and a hammer in a vacuum (where there is no air resistance), they will hit the ground at the same time.  
T    F In space, astronauts experience zero gravity because there is no gravity in space.  
T    F You have the same mass on Mars as on Earth.  
T    F You have the same weight on Mars as on Earth.  
T    F The force of gravity becomes stronger as objects get farther from each other.

# HOW TO WRITE A LAB REPORT

There are many different styles and formats for sharing science results. Some are published in academic journals as text and images, but results could also be presented as a posters, talks, or in video format! While the format is flexible, a good report will contain these sections:

## 1. Introduction.

The introduction explains the objectives (goals) of the experiment and any relevant background. You can write an introduction by answering some of these questions about your topic:

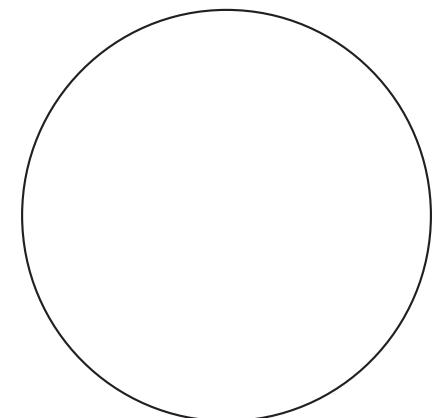
- Why is this an important experiment? What makes this an interesting question? Why should people care about it?
- What is your hypothesis? What is the goal of this study?



## 2. Materials and Methods.

This section explains the exact steps of the experiment. It should be clear enough so that others could duplicate the experiment.

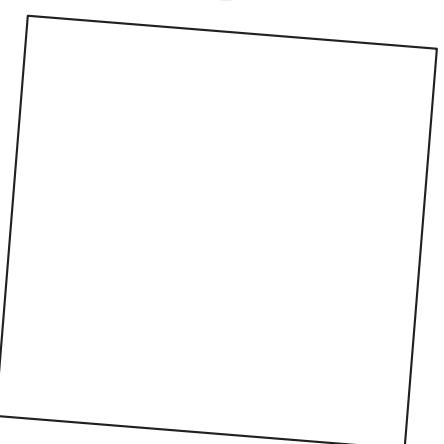
- How was the experiment set up? What supplies, tools, or materials were used?
- How was the experiment carried out? Include specific details and steps.



## 3. Results.

The results section shares the outcomes of the experiment.

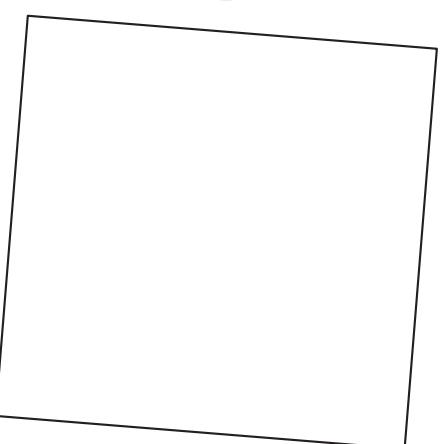
- What data did you gather? Present your results in a well-organized table, list, chart, or graph.



## 4. Analysis and Discussion.

This section explores the results and talks about the data.

- Were the results expected or unexpected?
- Is the data consistent or a hot mess? Is the data valid or did something interfere with the results?



## 5. Conclusions.

Wrap it up by sharing what was learned from the experiment.

- What does the data mean? What did you learn?
- Did the experiment raise new questions or is there something you wish had been done differently? Are there any steps that should be taken for further study?

In the next few pages you'll find 3 options for an experiment where you could present your results as a lab report. Choose at least one. Then share your results and conclusions with a family member, friend, or classmate! Which lab(s) will you choose?

- WATER ROCKET LAB
- FALL TIME VS HEIGHT LAB
- HORIZONTAL MOTION AND GRAVITY LAB

# WATER ROCKET LAB

## MATERIALS



Water rocket kit consisting of a stand with fins, a plastic bottle, tubing and cork/bung, and a bicycle pump



Eye protection



Phone or camera



Materials to make a cone such as paper, scissors, tape, and a plastic bottle (optional)

## GOALS

- ★ Explore Newton's third law of motion
- ★ Design and conduct an experiment
- ★ Write a lab report

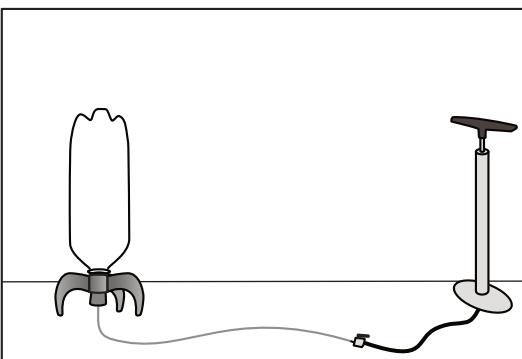
A water rocket is a type of model rocket that uses water and pressurized air to launch a plastic bottle up into the air. Like all rockets, water rockets operate on the principle of Newton's third law of motion: for every action, there is an equal and opposite reaction.

**Safety First!** Always wear safety goggles during an experiment or activity that involves projectiles. Be aware of wind conditions. Do not launch rockets if the weather is windy.

## Steps:

1. Find a large, open area outside that is about the size of a soccer or football field. This area is your "launch site." It should be free of trees, buildings, or any other items where the bottle could get stuck.
2. Add water to the bottle until it is approximately 1/4 full.
3. Place the bung or cork firmly into the bottle's opening. Attach the tubing to the bicycle pump. Ensure the cork and pump are both secure and will not easily release or leak.
4. Invert the rocket and check to be sure that it is stable.
5. Put on eye protection such as safety goggles or sunglasses.
6. If using a phone to estimate height and time in the air, start filming.
7. Pump air into the bottle. As you pump, the pressure will build up inside the bottle. Eventually, the pressure will become great enough to push the water and cork out, propelling the bottle high into the air.

IF CONDITIONS ARE WINDY,   
 DO NOT LAUNCH ROCKETS!



## Suggested Experiments:

### 1: What Water Level Works Best?

What amount of water will send the rocket the highest? Make a prediction (hypothesis) and then change the amount of water in the rocket and record how it affects the height and time in the air. Try three different water levels (for example, 1/4 full, 1/2 full, 3/4 full). For best results, try each launch 3 times and use a phone to record the results. Then use the tips on the opposite page to approximate the height.

### 2. How Does Rocket Shape Impact the Flight?

Make a cone to change the shape of the top of the rocket. The cone should be able to fit over or attach to the bottle so that the rocket can be launched multiple times with or without the cone. One style of cone can be made by using a similar-sized plastic bottle with a lid and carefully cutting the end off. Another type can be made using paper and tape. For best results, launch each type of rocket ("no cone" vs "cone") multiple times and use a phone to approximate the height.

## HOW TO USE TIME TO MEASURE DISTANCE!

Use a phone or camera to record the total time the rocket is in the air. Measure the number of seconds from the moment it launches to the moment it lands.

Acceleration due to gravity is  $9.8 \text{ m/s}^2$  (or  $32 \text{ ft/s}^2$ ), so you can calculate the maximum height reached by the rocket using the formula:

$$h = \frac{1}{2}gt^2$$

For the variable  $t$ , it is important to use the fall time, which is  $\frac{1}{2}$  of the **hang time** or  $\frac{1}{2}$  of the total time the rocket is in the air. Use 9.8 for the value of  $g$  if you want to calculate the height in meters and 32 if you want the height to be in feet.

**Note:** the fall of the empty bottle is impacted by air resistance which is not included in the above formula. Because air resistance slows the fall, the actual height will be lower than the calculated height.

But for purposes of *comparing* the heights, this estimation is still useful! It can be used to determine which rocket flew higher.

### LAB REPORT CHECKLIST:

- KEEP ALL VARIABLES AS SIMILAR AS POSSIBLE EXCEPT FOR THE ONE YOU ARE CHANGING (ROCKET SHAPE OR WATER LEVEL)
- DO MULTIPLE ROCKET LAUNCHES AND CAREFULLY RECORD YOUR RESULTS!
- PRESENT YOUR FINDINGS AND DISCUSS WHAT THEY MEAN. WHAT DID YOU LEARN?



**Tip:** some water rocket kits have a special release valve so the same amount of air pressure is created in each rocket launch.

When using a rubber cork or bung, the amount of pressure will vary!

To reduce this variability as much as possible, have the same person push the bung into the bottle each time.

FOR NOTES AND DOODLES



# HANG TIME LAB

## MATERIALS



A tennis ball



Stopwatch or  
camera for timing



A ball launcher (often  
found in pet stores)

## GOALS

- ★ Use physics to calculate the height of an object
- ★ Design and conduct an experiment
- ★ Write a lab report

Gravity causes all objects to fall at the same speed unless air resistance slows the object down. For light objects (such as a feather), air resistance will slow the fall dramatically. But if air resistance is small, we can calculate how far an object fell just by timing how long it was in the air!

This formula relates height and time using the gravitational constant ( $g$ ):  $h = \frac{1}{2}gt^2$

The gravitational constant  
can be measured in m or ft

$$g = 9.8 \text{ m/s}^2$$
$$g = 32 \text{ ft/s}^2$$

## Example.

If an object falls for 4 seconds, then  $t = 4 \text{ s}$ , so the height fallen is

$$h = \frac{1}{2}(9.8 \text{ m/s}^2) \cdot (4 \text{ s})^2 \quad \text{or} \quad h = \frac{1}{2}(32 \text{ ft/s}^2) \cdot (4 \text{ s})^2$$
$$= 78.4 \text{ m} \quad \quad \quad = 256 \text{ ft}$$

Before any measurements, make an educated guess. How high do you think you can throw a ball?

## Steps:

1. Go outside to an open area and throw a tennis ball as high as you can while another person records the time it takes to hit the ground. Throw the ball several times to get an average height. Be smart and be safe! The total time the ball is in the air is called the **hang time**.
2. Divide your best throw hang time in half to get the time  $t$ . Remember, the height formula uses the **fall time** which is one half of the **hang time**.
3. Substitute the time in seconds into the height formula. If your original estimation was in feet, use  $32 \text{ ft/s}^2$  for  $g$ . If your estimation was in meters, use  $9.8 \text{ m/s}^2$ .
4. Calculate your height!
5. Next, make a prediction for how high you can throw using a ball launcher. Repeat steps 1-4 with the launcher. Then compare your results to your predictions.
6. In your lab report, discuss the design of the ball launcher and how that affected the height the ball reached.

$$h = \frac{1}{2}gt^2$$



## Extensions:

1. How high could you throw a ball on the Moon where  $g = 1.62 \text{ m/s}^2$  or  $5.31 \text{ ft/s}^2$ ?
2. Adapt the process above to calculate how high you can jump. Then measure your actual maximum jump height and compare it with your calculation.
3. Height vs Distance: What angle of throw gives the longest hang time?

# HORIZONTAL MOTION VS GRAVITY LAB

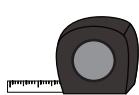
## MATERIALS



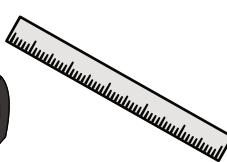
Two identical coins



Camera for timing



Measuring tape



Ruler

## GOALS

★ Strengthen analysis and reasoning skills

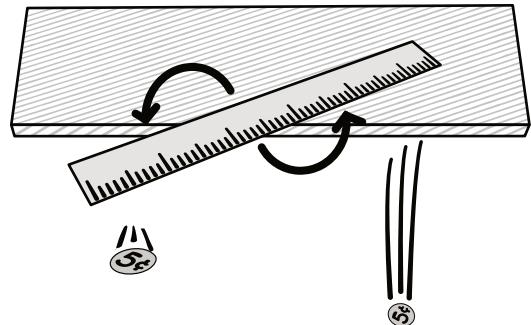
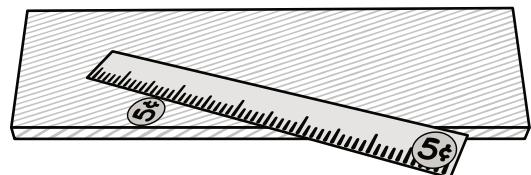
★ Design and conduct an experiment

★ Write a lab report

*Does horizontal motion change how quickly something will fall? Set up an experiment to find out!*

### Steps:

1. Place a ruler diagonally along the edge of a table so that one end dangles over the edge. Place one coin on the end of the ruler and the other along the edge of a table.
2. Rotate the ruler about its center quickly so that it knocks one coin off the table.
3. The coin that was on the ruler should fall straight down while the coin that was on the edge of the table should fly out horizontally and fall some distance away from the table.
4. After a few practice runs to make sure you know how fast to rotate the ruler, use a camera to record 5 different videos of steps 1 through 3. If one penny is out of frame, throw out that recording and try again
5. Record the data in the table provided. You will likely need to move the video files to a computer to get the exact times. Most phone cameras default to 30 frames per second, so a difference of 3 frames is about 0.1 second.



Record the fall times and then calculate the average by adding the values in each column and dividing by the number of samples. (In the case of this table, divide the sum of each column by by 5)



AVERAGE:

Time for vertically dropped penny <i>V</i>	Time for horizontally launched penny <i>H</i>	Difference in time <i>V-H</i>
<b>AVERAGE:</b>		

Use the height equation to calculate fall distance in meters ( $g = 9.8 \text{ m/s}^2$ ) or in feet ( $g = 32 \text{ ft/s}^2$ ). Calculate the height using the average fall times for both the vertically dropped (V) and horizontally launched (H) pennies.

CALCULATED HEIGHT FOR V PENNY: \_\_\_\_\_

CALCULATED HEIGHT FOR H PENNY: \_\_\_\_\_

$$h = \frac{1}{2}gt^2$$

The height equation!

Measure the height of your surface with a tape measurer and convert it to either meters or feet so that it matches the units used above:

MEASURED HEIGHT: \_\_\_\_\_

Is the fall distance you calculated close to the actual height of your surface? If not, then why? What do you think went wrong?

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Does your data show a difference in the average fall times between the two coins?

If the two coins fall at the same rate, what would you expect the average difference in fall times between the two coins to be? Explain.

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Here is a famous physics question: Will a bullet that is fired from a gun hit the ground before, after, or at the same time as a bullet that is dropped from the same height? What do you predict and why?

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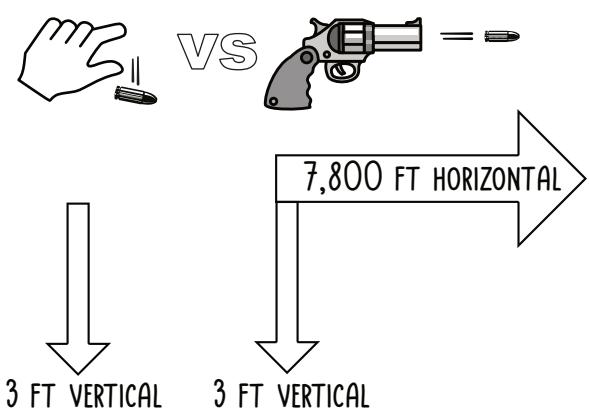
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# ASSESSMENT

BE SURE TO HAVE A PENCIL AND SCRATCH PAPER!

- 1 Name the number for each of Newton's laws below.

Law of Reaction: \_\_\_\_\_

Law of Inertia: \_\_\_\_\_

Law of Acceleration: \_\_\_\_\_

- 2 Which laws of motion are involved in the statement "An object will always move with a changing velocity while it is acted upon by an unbalanced force."

- A. Newton's 1<sup>st</sup> Law
- B. Newton's 2<sup>nd</sup> Law
- C. Newton's 3<sup>rd</sup> Law
- D. The statement is actually false.

- 3 A full grocery cart is harder to slow down than an empty cart. Which law of motion explains the reason why?

- A. Newton's 1<sup>st</sup> Law
- B. Newton's 2<sup>nd</sup> Law
- C. Newton's 3<sup>rd</sup> Law
- D. None of Newton's laws are relevant to the motion of grocery carts.

- 4 A 40 kg go-kart is propelled by a constant force of 60 N. What is the go-kart's acceleration?

- A. 2400 m/s<sup>2</sup>
- B. 24 m/s<sup>2</sup>
- C. 1.5 m/s<sup>2</sup>
- D. 0.67 m/s<sup>2</sup>

- 5 An ice skater is gliding straight across the ice until they collide with the wall of the skating rink. Which description below is an example of Newton's 1<sup>st</sup> law?

- A. The skater is coasting at a constant velocity.
- B. The skater's velocity changes quickly as she collides with the wall.
- C. The skater collides with the wall and the wall pushes back.

- 6 Which has more inertia?

- A. A 30 kg child sitting in a moving car
- B. A 50 kg child standing on the sidewalk.
- C. A 40 kg child standing on ice.

- 7 Circle T or F to mark each statement True or False.

T    F When a net force acts upon an object, the object will accelerate in the direction of the net force.

T    F Whenever two people push off from each other, they both experience the same acceleration.

T    F The laws of motion do not apply in orbit around a planet.

T    F An object with mass has inertia.

T    F Fast objects have more inertia than slow objects.

T    F Inertia is the tendency to resist motion.

T    F The weight of an object would be less on the Moon than on the Earth.

T    F The weight of an object is equal to the force of gravity acting upon the object.

T    F If an object is moving to the right, then the forces acting upon it are NOT balanced.

- 8 Which law of motion explains why we need to wear seat belts?

- A. Newton's 1<sup>st</sup> Law
- B. Newton's 2<sup>nd</sup> Law
- C. Newton's 3<sup>rd</sup> Law
- D. Newton's 4<sup>th</sup> Law

- 9 Bob installs a new engine in his car to give it more power. The new engine doubles the weight of the car, but it supplies 6 times as much force. How does the acceleration of the car compare to the way it used to be?

- A. New acceleration is 3 times the old.
- B. New acceleration is 12 times the old.
- C. New acceleration is 1/3 times the old.
- D. New acceleration is 8 times the old.

- (10)** A ramp is sloped so that a ball with a mass of 3 kg rolls down with an acceleration of  $2 \text{ m/s}^2$ . What is the net force acting upon the ball along the slope of the ramp?

- A.  $1/6 \text{ N}$
- B.  $2/3 \text{ N}$
- C.  $3/2 \text{ N}$
- D.  $6 \text{ N}$

- (11)** What is the mass of an object if a force of  $12 \text{ N}$  causes it to accelerate at  $3 \text{ m/s}^2$ ?

- (12)** What is the acceleration of a  $20 \text{ kg}$  object if a force of  $10 \text{ N}$  is applied to it?

- (13)** Circle number 1, 2, or 3 to indicate which of Newton's laws is being described.

- 1 2 3 A car slows down when its brakes are applied.
- 1 2 3 An oar pushes water backwards and the water pushes the boat forward.
- 1 2 3 A full grocery cart is harder to push than an empty cart.
- 1 2 3 For every force, there is an equal and opposite force.
- 1 2 3 The bus brakes hard and the passengers continue moving forward.

- (14)** A ball is launched deep in outer space. The amount of force needed to keep it going equals

- A. zero, since no force is necessary to keep it moving
- B. the same amount of force it was launched with.
- C. an increasing amount of force
- D. about half the force with which it was launched

- (15)** Gravity on Earth is 6 times as strong as gravity on the moon. An object with a mass of  $12 \text{ kg}$  on Earth will have how much mass on the Moon?

- A.  $0 \text{ kg}$
- B.  $2 \text{ kg}$
- C.  $6 \text{ kg}$
- D.  $12 \text{ kg}$

- (16)** In a tug-of-war between you and a friend, what is the "equal and opposite force" to the force of your hand pulling on the rope described by Newton's 3rd Law?

- A. The force of your friend pulling in the opposite direction
- B. The force of friction as your feet pushing on the ground.
- C. The force of the rope pulling on your hand
- D. The force of your arm pulling on your hand

### PIPE FLOW MATCHING - UNIT 2

	E			5
	A	3	D	
		B		2
1	4			C

Use Newton's 2<sup>nd</sup> law to rank the acceleration of objects A-E below from slowest to fastest. Record your answer in the grid by joining the answers with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

Acceleration rightward

1. Slowest

Forces



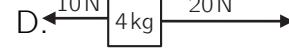
2. Slow



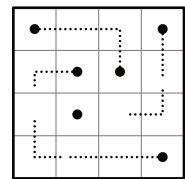
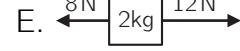
3. Medium



4. Fast



5. Fastest



# Unit 3: Work, Machines, & More

In this unit, we'll learn more about how physics impacts daily life by exploring energy, work, power, rotational motion, and simple machines.

## CENTRIPETAL FORCE



$$F_c = \frac{mv^2}{r}$$

The inward force causing circular motion

## WORK



$$W=F\cdot d$$

Energy transferred when force causes displacement

## LEVER



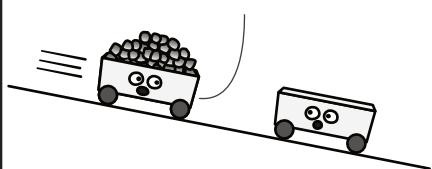
BAR

FULCRUM

One of the six classic simple machines

## MOMENTUM

LOOK OUT! I HAVE LOTS OF MASS AND VELOCITY!



$$\vec{p}=m\vec{v}$$

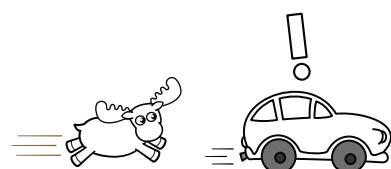
The product of mass and velocity

## PULLEY



One of the six classic simple machines

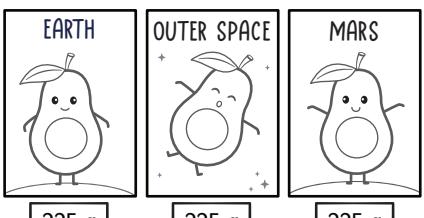
## KINETIC ENERGY



$$KE=\frac{1}{2}mv^2$$

Energy due to motion

## MASS



$kg$  or  $g$  The amount of matter in an object or particle

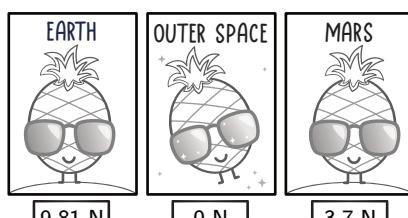
## NEWTON



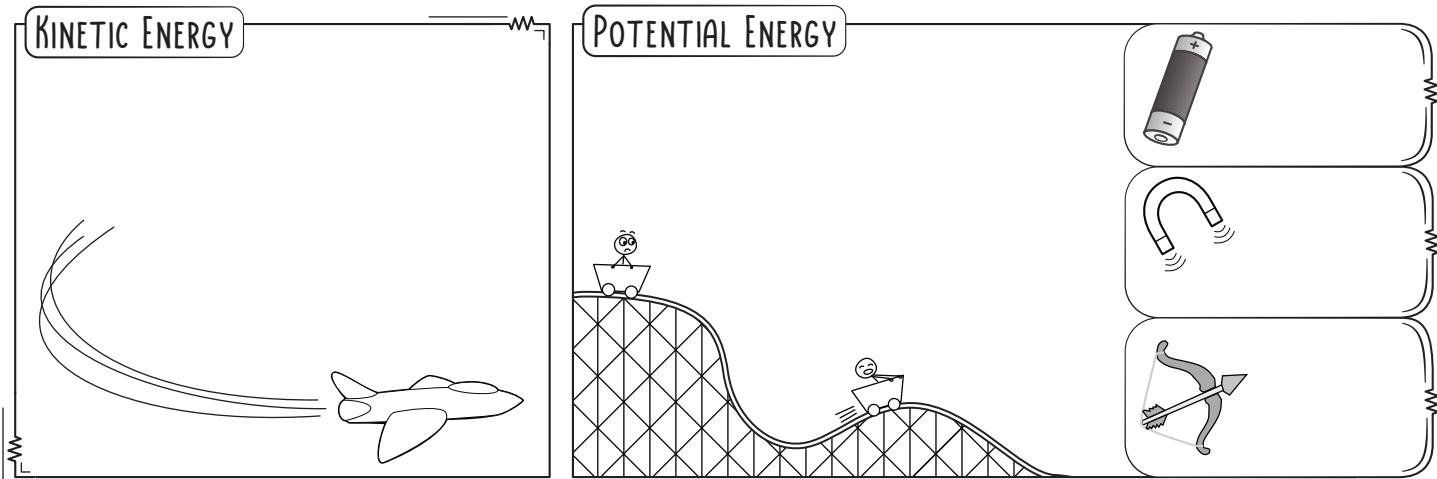
$$1\text{ m/s}^2$$

$1\text{ kg}\cdot\text{m/s}^2$  The force that gives 1 kg an acceleration of  $1\text{ m/s}^2$

## WEIGHT



$W=m\cdot g$  The force acting on an object due to gravity



FILL IN THE BLANKS:

*stored      energy      joules      mass      velocity      potential      height*

Kinetic \_\_\_\_\_ depends on both the \_\_\_\_\_ and \_\_\_\_\_ of an object.

Potential energy is \_\_\_\_\_ energy, and there are many different types! Gravitational \_\_\_\_\_ energy is calculated using mass, \_\_\_\_\_, and gravitational acceleration ( $9.8 \text{ m/s}^2$  on Earth). Both PE and KE are measured in \_\_\_\_\_.

Where have you seen PE and KE? List (or draw) three examples of each.

Kinetic Energy: \_\_\_\_\_

1.

2.

3.

Potential Energy: \_\_\_\_\_

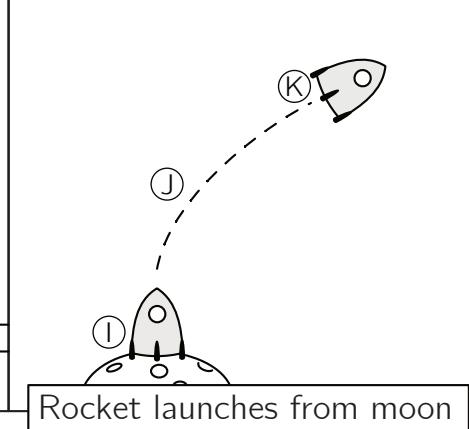
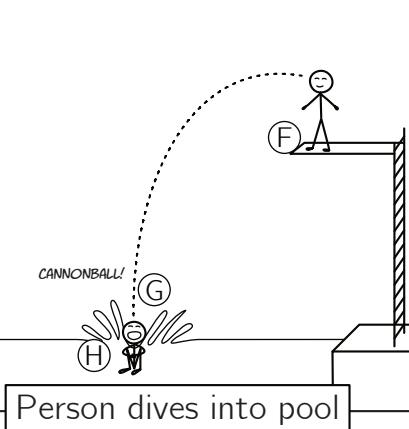
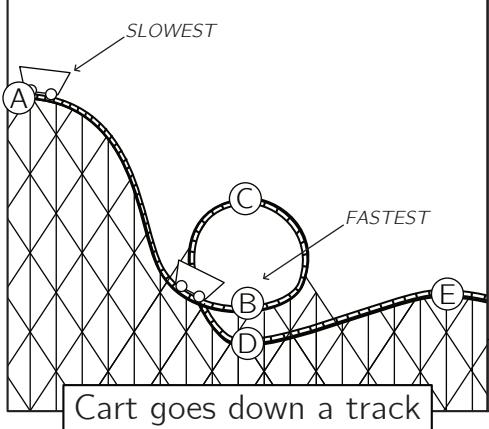
1.

2.

3.

## WHERE IS THE ENERGY?

IDENTIFY WHERE THE MOST POTENTIAL, KINETIC, AND TOTAL ENERGY IN EACH SCENARIO.



Maximum PE: \_\_\_\_\_

Maximum PE: \_\_\_\_\_

Maximum PE: \_\_\_\_\_

Maximum KE: \_\_\_\_\_

Maximum KE: \_\_\_\_\_

Maximum KE: \_\_\_\_\_

Maximum Total E: \_\_\_\_\_

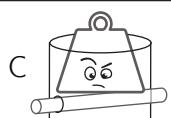
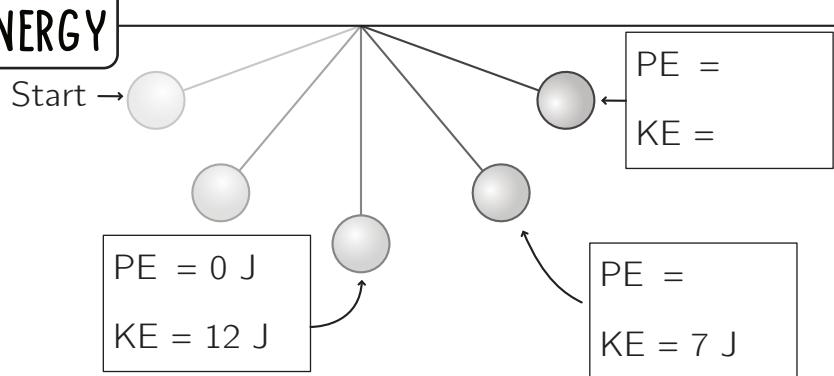
Maximum Total E: \_\_\_\_\_

Maximum Total E: \_\_\_\_\_

## LAW OF CONSERVATION OF ENERGY

Energy can *change* forms but is not *created* or *destroyed*.

$$PE_1 + KE_1 = PE_2 + KE_2$$

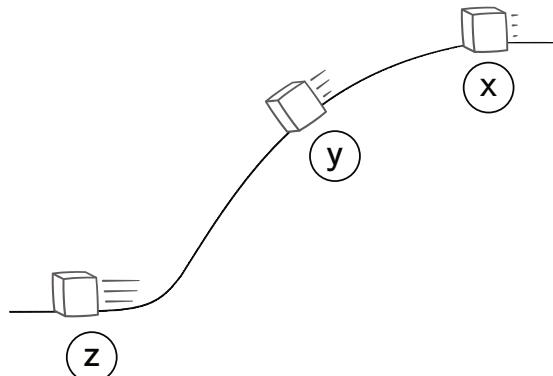


A weight is dropped from different heights onto an empty aluminum can. One weight is just above the can (A). Another is twice as high (B), and another is at the top of the tube (C). Which weight will squish the can the most and why?

## PRACTICE PROBLEMS – KINETIC VS POTENTIAL ENERGY

- ① A box sits nearly motionless at the top of a frictionless hill. Then it slides down the hill picking up speed and moves quickly along the flat surface at the bottom.

▷ What type of energy or energies does the box have at the top of the ramp? (x)



▷ What type of energies does it have at point y?

▷ What type of energies does it have at point z?

▷ At which point will the box have the most energy?

- ② What equation would you use to calculate potential energy?

- A.  $PE = mgh$
- B.  $KE = \frac{1}{2}mv^2$
- C.  $F = ma$
- D.  $W = mg$

- ③ Could the equation for PE be written as height · weight (Wh) instead of  $mgh$ ? Why or why not?

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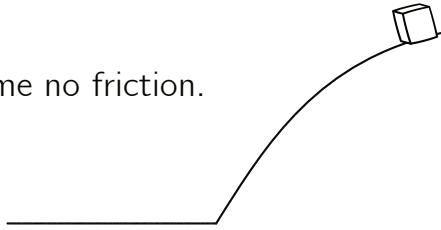
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- ④ What information is needed to calculate kinetic energy?

- A. Mass and velocity
- B. Mass, velocity, and height
- C. Mass, height, and the gravitational constant
- D. Height, velocity, and the gravitational constant

## PRACTICE PROBLEMS – KINETIC VS POTENTIAL ENERGY

- 5) There is a 15 kg box sliding down a hill that is 50 meters high.
- If the box starts from rest at the top of the hill, what is its potential energy at the top of the hill?

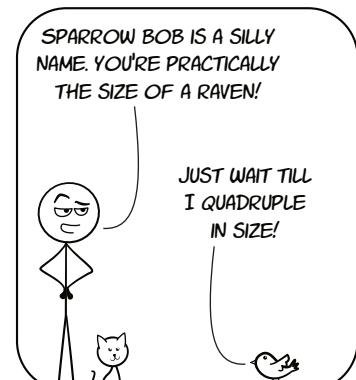


- What is its kinetic energy at the bottom? Assume no friction.

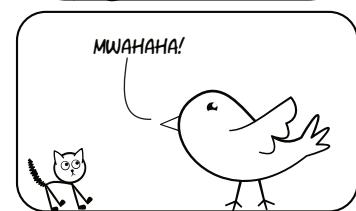
- 6) A baseball with a mass of 0.145 kg is thrown at a speed of 40 m/s. What is the kinetic energy of the baseball?

- 7) Sparrow Bob has a mass of 1 kg and is flying with a kinetic energy of 2 joules, giving a total KE of 2 joules.

- What would the kinetic energy be if Sparrow Bob quadrupled his mass to 4 kg but kept the same velocity?



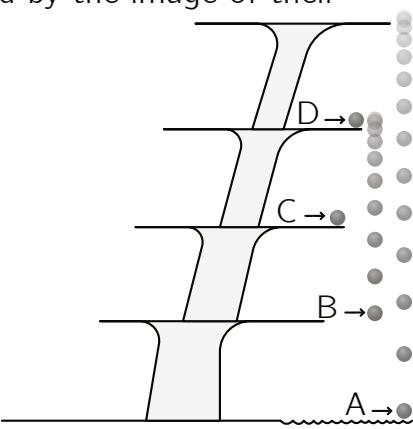
- What would the kinetic energy be if Sparrow Bob kept his original mass of 1 kg but quadrupled his velocity?



- What would the kinetic energy be if Sparrow Bob cut his original mass in half but doubled his original velocity?

- 8) Use the high-dive picture to order the balls based on their **potential energy** from least to greatest at the exact moment in time captured by the image of their positions. Observe that:

- Ball A is about to hit the water.
- Ball B is at about the level of the first platform.
- Ball C is not moving.
- Ball D is not moving.



# WORK

List 3 to 5 examples of things you consider to be work!

Look at the examples you listed. In physics, **work** occurs when a **force** causes **displacement**. Which examples are also considered work according to physics? Identify the force and displacement for each.

BOB TRIES TO LIFT A SUPER HEAVY BOX  
BUT IT DOESN'T MOVE.

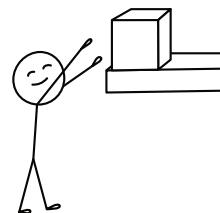


Did Bob do work? Y N

What provided the force?

---

BOB LIFTS A DIFFERENT BOX ONTO A SHELF.

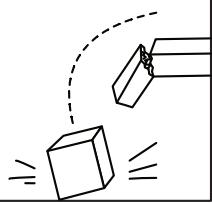


Did Bob do work? Y N

What provided the force?

---

THE SHELF BREAKS AND THE BOX FALLS ON  
THE FLOOR

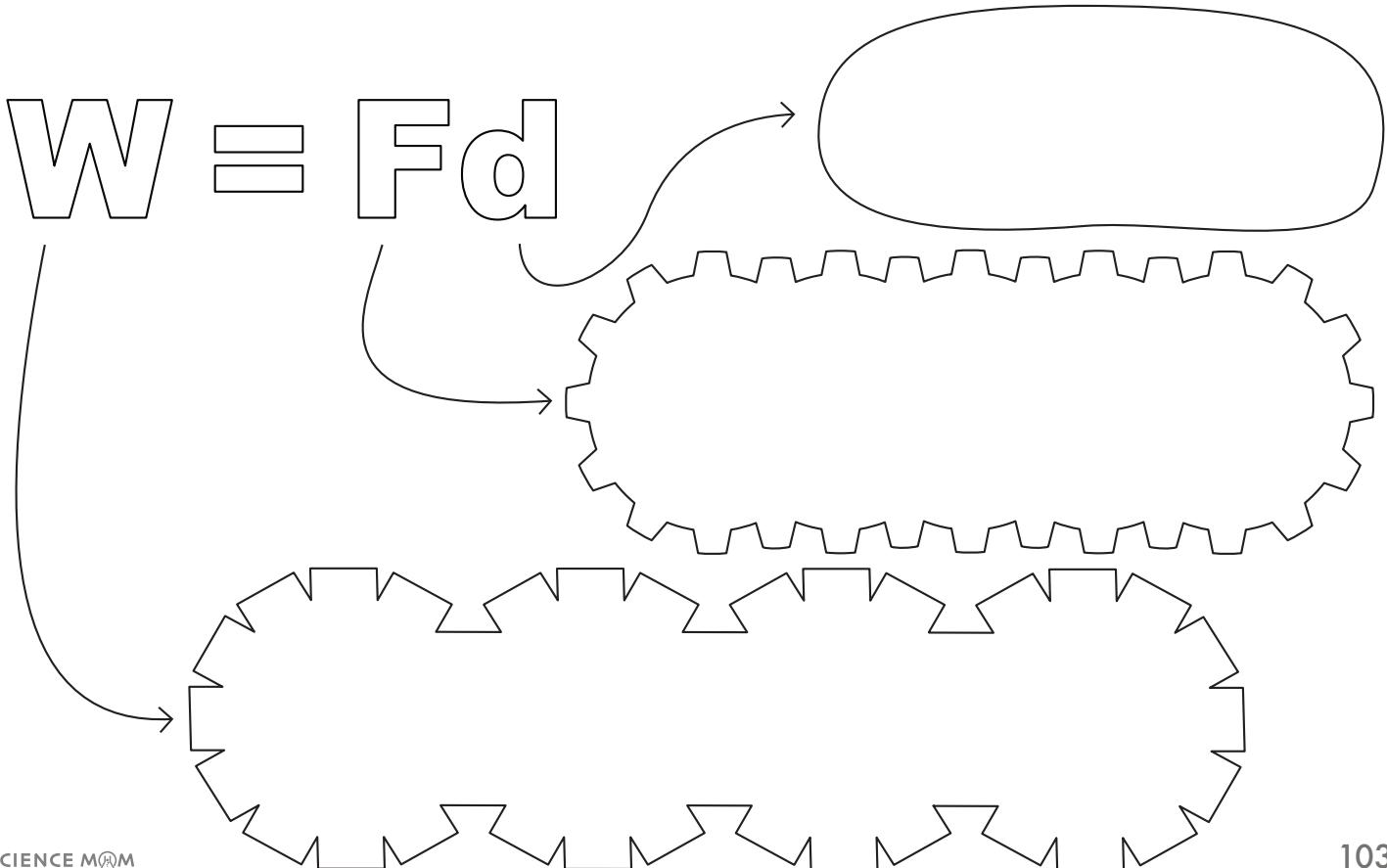


Did work happen? Y N

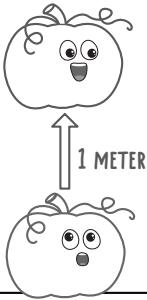
What provided the force?

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$$W = Fd$$



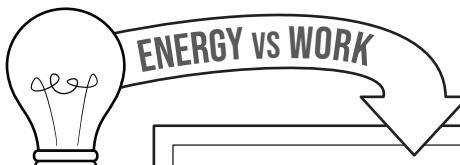
## JOULE



USED TO  
MEASURE  
ENERGY AND  
WORK!

$$J = \frac{kg \cdot m^2}{s^2}$$

The work done by a force of 1 newton thru 1 meter

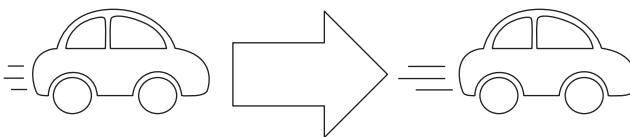


**Energy** is the capacity to perform work or to cause change. **Work** is the transfer of energy from one object to another.

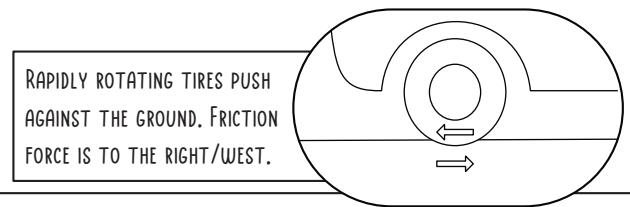
In essence, energy is what an object **has**, and work is what an object **does** with that energy.

When work is done on an object, energy is transferred to or from that object.

## ACCELERATING - is it work?



THE CAR SPEEDS UP, TRAVELING TO THE RIGHT (WEST).



RAPIDLY ROTATING TIRES PUSH AGAINST THE GROUND. FRICTION FORCE IS TO THE RIGHT/WEST.

What is the direction of the displacement?

- East
- West

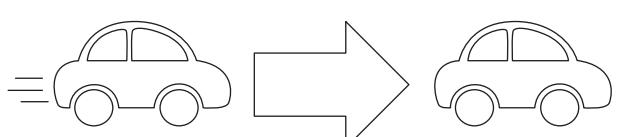
What is the direction of the main force (friction)?

- East
- West

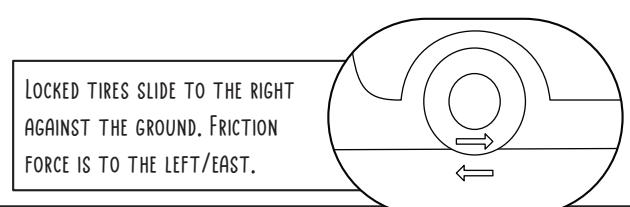
Is the kinetic energy of the car increasing or decreasing?

- Increasing
- Decreasing

## BRAKING - is it work?



THE CAR BRAKES HARD, STILL TRAVELING TO THE RIGHT (WEST).



LOCKED TIRES SLIDE TO THE RIGHT AGAINST THE GROUND. FRICTION FORCE IS TO THE LEFT/EAST.

What is the direction of the displacement?

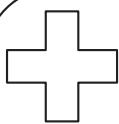
- East
- West

What is the direction of the main force (friction)?

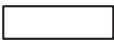
- East
- West

Is the kinetic energy of the car increasing or decreasing?

- Increasing
- Decreasing

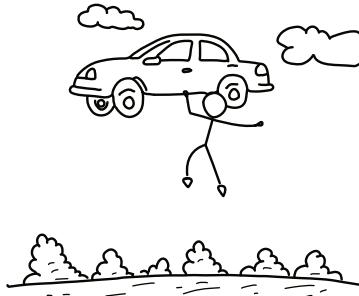


POSITIVE WORK



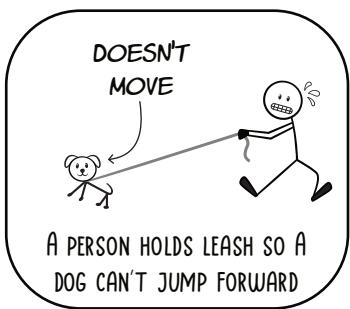
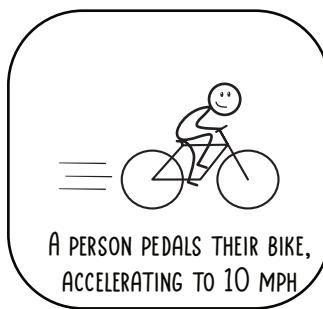
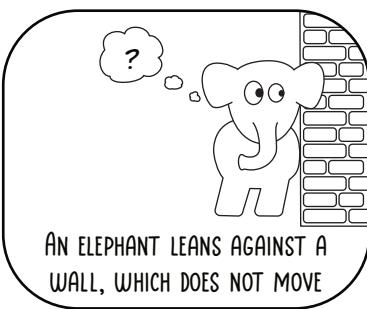
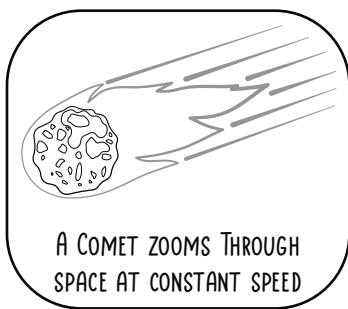
NEGATIVE WORK

## PRACTICE PROBLEMS – WORK

- 1 If you push a shopping cart with a force of 10 newtons for a distance of 5 meters, how much work did you do?
- 2 If an engineer knows a train engine can do 10,000 J of work and the force it can apply is 500 N, how could they calculate the displacement (how far this engine can move the train)?
- 3 A superhero pushes a car (weight = 10,000 newtons) straight up into the air for a distance of 20 meters. How much work does the superhero do on the car?
- 4 If a teacher pushes a desk across the room with a force of 100 newtons and does 500 joules of work, how far did the desk move?
- 5 An elevator lifts 4 people a distance of 20 meters. If the elevator did 28,000 joules of work, how much did the 4 people weigh?
- 6 A hockey puck is moving at constant speed across a frictionless ice rink. Is work being done on the hockey puck?

# WORK & POWER

Draw lines to match the following situations with whether work happened or not.



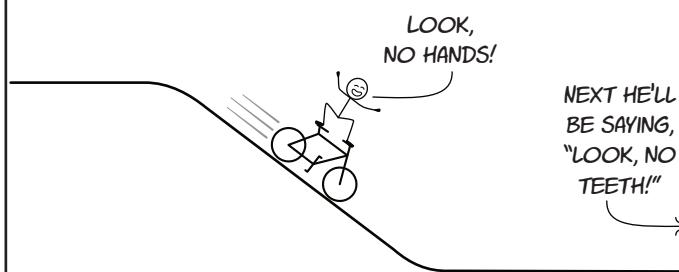
**NO WORK HAPPENED**

**WORK WAS DONE!**

Bonus: indicate whether it was positive or negative work!

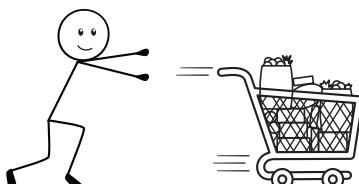
## WORK-ENERGY THEOREM

Force and motion are linked together in an important way: THE WORK DONE ON AN OBJECT IS EQUAL TO THE CHANGE IN ITS KINETIC ENERGY. This is known as the work-energy theorem:  $\Delta KE = F \cdot d = \text{Work}$



If Diego knew his total mass and his speed at the bottom of the hill, could he calculate the height of the hill?

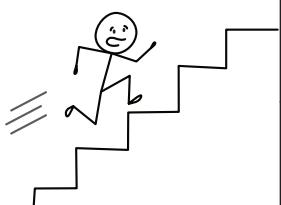
Tala pushes a stationary cart with a mass of 15 kg. It reaches a speed of 2 m/s and covers a distance of 2 m. Where did the energy to move the cart come from? How much force did Tala apply?



## WHO DID MORE WORK?



WALKING UP STAIRS



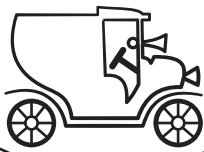
SPRINTING UP STAIRS

$$P = \frac{W}{t}$$

WHAT ARE THE UNITS?

## CLUNKER CAR versus RACE CAR

Weight: 2,200 lbs  
Can go from 0-60 mph  
in 32 seconds.



Weight: 4,500 lbs  
Can go from 0-60 mph  
in 2 seconds.



Both cars are able to travel 96 kph (60 mph). Which car has more power and why?

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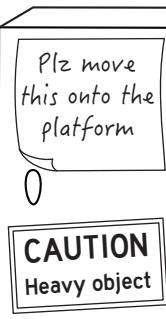


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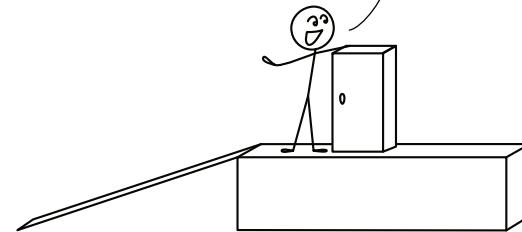


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## Moving Day



ACCORDING TO PHYSICS, IT'S THE SAME AMOUNT OF WORK FOR YOU TO LIFT THE SAFE UP ONTO THIS PLATFORM AS IT WAS FOR ME!



BUT YOU HAD A RAMP!

## PRACTICE PROBLEMS – WORK AND POWER

WE'VE SEEN A LOT OF USEFUL EQUATIONS IN PHYSICS SO FAR! FOR EACH OF THESE PRACTICE PROBLEMS, FIRST ASK WHAT YOU WANT TO KNOW. WHAT VARIABLE ARE YOU TRYING TO SOLVE FOR? THEN SELECT THE MOST USEFUL EQUATION AND USE IT TO FIND WHAT YOU'RE LOOKING FOR.

- 1 Mike pushes a lawn mower 15 meters across his yard. The force he applies is 50 newtons. How much work does Mike do?

- 2 A 10-kilogram box is moved across the floor with a force of 30 newtons. In total, 150 joules of work was done. How far did the box move?

- 3 Maria uses 1000 joules of energy to move a box 20 meters. How much force does she apply?

- 4 Tom does 300 joules of work to return his grocery cart in 20 seconds. What is his power output?

- 5 A 1000 kg car accelerates from 0 to 30 m/s over a distance of 200 m. What force was applied to the car to achieve this speed?

- 6 An electric motor lifts a 200 kg load to a height of 10 m in 5 seconds. How much power is used by the motor? (Use  $g = 9.8 \text{ m/s}^2$ )

### USEFUL EQUATIONS:

$$W=Fd$$

$$F = W/d$$

$$D = W/F$$

$$P=W/t$$

$$PE = mgh$$

$$KE = \frac{1}{2}mv^2$$

$$PE_1+KE_1 = PE_2+KE_2$$

$$\Delta KE = Fd$$

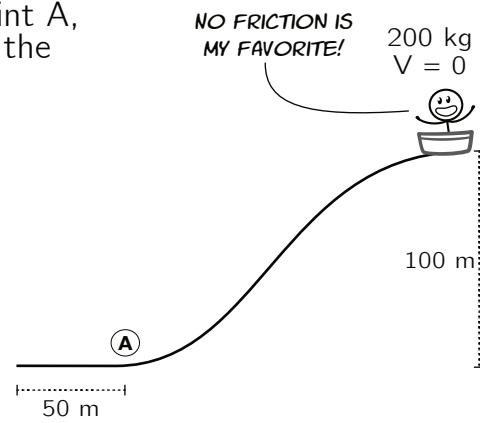
$$g = 9.8 \text{ m/s}^2$$

# PRACTICE PROBLEMS – WORK AND POWER

## Challenge

Crazy Nancy went sledding down a frictionless hill! At point A, she encountered friction which, after 50 meters, stopped the sled. Can you calculate the force of the friction?

*Hint: remember the conservation of energy.*



# DOUBLE BOUNCE DEMO

## MATERIALS



Basketball (or other big ball with lots of bounce)

A flat hard surface that is outdoors such as a sidewalk or parking lot



Smaller ball with good bounce such as a tennis ball

A tall reference object such as a wall, tree, or streetlight



Optional: Camera



Optional: glue gun or tape and a hair band

## GOALS

★ Observe the transfer of momentum

★ Conduct an experiment

### Prepare and Make Predictions:

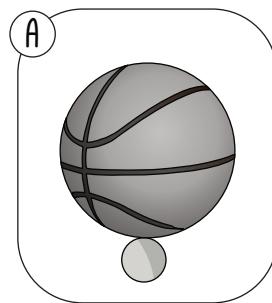
1. Measure the bounce height of each ball by dropping them from chest height on a flat and firm surface. Be sure to *drop* the ball. Don't throw it or push it down! Use a tall reference object such as the side of a building, streetlight, or tree to estimate the height of each bounce. Drop each ball at least 3 times. Then record the typical bounce height in the table on the following page. If desired, use a camera to record a video and use that to get a more accurate idea of the height.
2. Make a prediction for what you expect to happen when the balls are dropped together in a "double bounce" orientation. Will they bounce higher or lower than when bounced individually? Which arrangement will produce the highest bounce and why?
3. (Optional) Make a small "nest" on the top of the large ball by laying down a circle of hot glue or taping or gluing a hair tie to the ball. (This will help the balls to stay lined up one on top of the other)
4. Have another person use a camera to film the "double bounce" step. (optional)

### Conduct the Experiment:

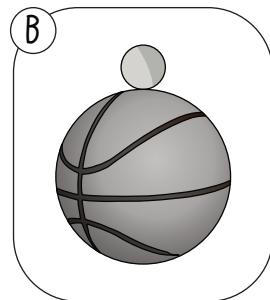
1. Hold the small ball atop the large ball at chest level. Release them both at the same time so they fall together for a "double bounce." Step back quickly as soon as you drop them! If the balls are not lined up straight, the top ball can bounce unpredictably. If the small ball rolled off the large ball before bouncing, then the bounce was not successful. Set them up and try again.
2. Next reverse the orientation by placing the large ball on top of the small ball. Drop them at the same time and step back quickly.
3. Record your results!

Note: this experiment should be performed outside.

DOUBLE BOUNCE: WHEN 2 BALLS ARE STACKED ON TOP OF EACH OTHER AND DROPPED AT THE SAME TIME.



WHICH  
WILL  
BOUNCE  
HIGHER?

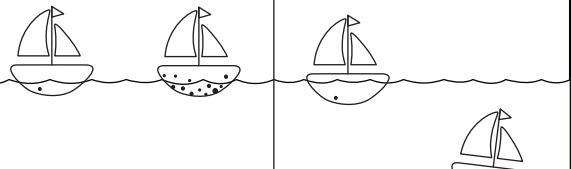


## TYPICAL BOUNCE HEIGHT & PREDICTIONS

Record the typical height of each ball's bounce and then make predictions for what you expect to observe with a double bounce. If using feet or meters to measure height, calculate the average height of each ball's bounce. If using a reference object to measure height, use descriptive measurements such as "the lowest branch of the tree" or "the first tape mark on the pole."

TYPICAL HEIGHT OF A BOUNCE WHEN DROPPED AT CHEST-HEIGHT	
Larger ball	
Smaller ball	

	PREDICTIONS FOR DOUBLE BOUNCE	RESULTS FOR DOUBLE BOUNCE
 Small on top of large		
 Large on top of small		

<b>INDEPENDENT</b> What is changed or controlled  	<b>DEPENDENT</b> What is measured  	REMEMBER: For best results, keep all factors as identical as possible except for the independent variable!  What was the <b>independent variable</b> in this experiment? _____
NUMBER OF HOLES IN BOAT	HOW FAST BOAT SINKS	What was the <b>dependent variable</b> in this experiment? _____

Describe the results! Use the words velocity and mass in your description.

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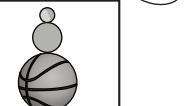
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### ADDITIONAL VARIATIONS TO EXPLORE:

→ Try a triple bounce!  
What if you stack 3 balls?



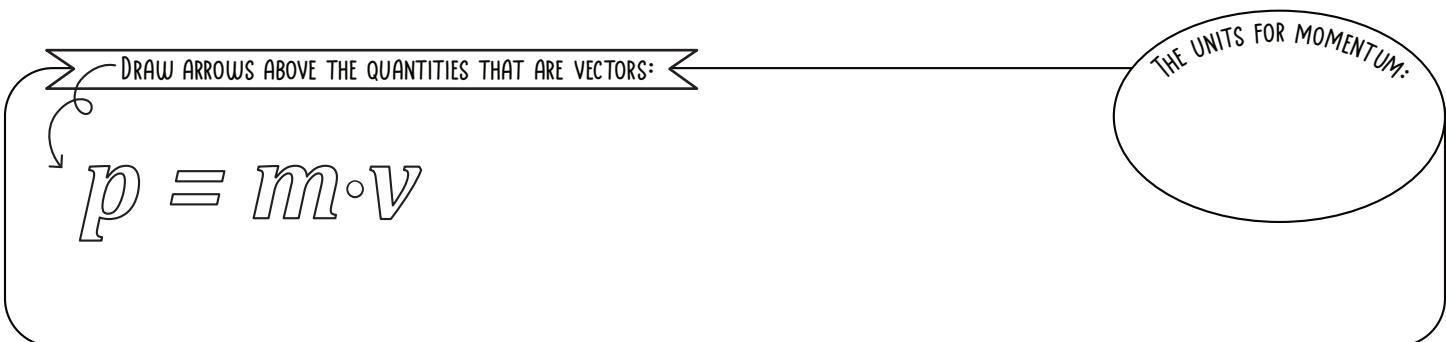
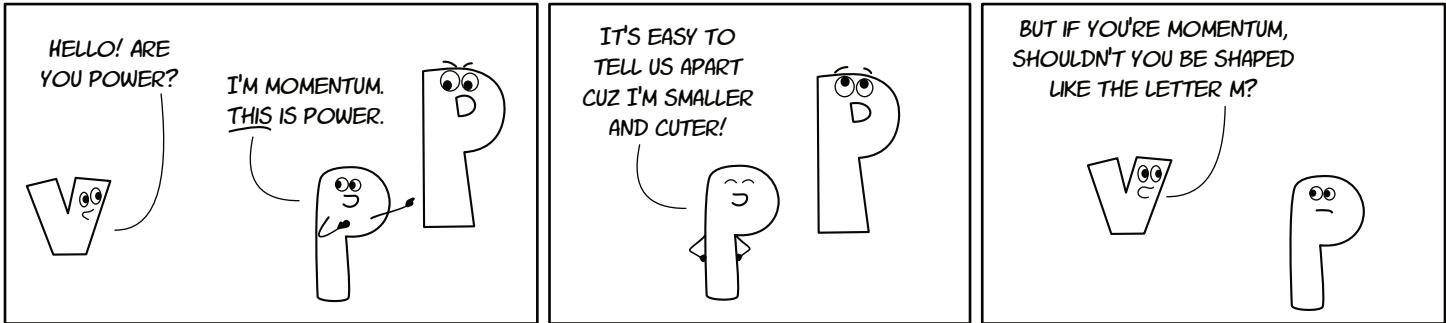
→ Try it on a different surface!  
A trampoline, water, or grass?



→ Try it with identical spheres!  
What would you expect with two balls of equal size?



# MOMENTUM & COLLISIONS



Which vehicle has more momentum and why?

A 1,000 kg car traveling 11.2 mph (5 m/s)



vs

A 150 kg motorcycle at 56 mph (25 m/s)




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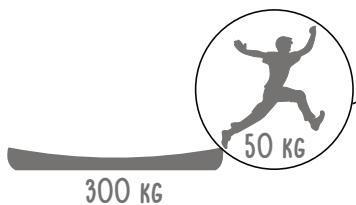
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ANOTHER WAY OF LOOKING AT NEWTON'S 3<sup>RD</sup> LAW:

THE CONSERVATION OF MOMENTUM!

WHAT WILL HAPPEN TO A 300 KG BOAT WHEN A 50 KG PERSON JUMPS FORWARD WITH A VELOCITY OF 2 METERS PER SECOND?



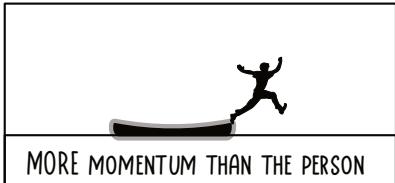


Calculate the momentum of the jumping person:

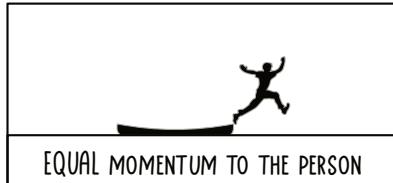
300 KG

50 KG

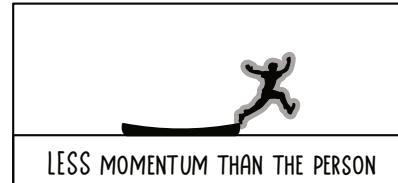
According to the conservation of momentum, the boat will have (circle the correct answer):



MORE MOMENTUM THAN THE PERSON



EQUAL MOMENTUM TO THE PERSON



LESS MOMENTUM THAN THE PERSON

For the boat, what values are known, and what are unknown? Fill in the known values for the equation below and then solve for the missing value.

$$p = m \cdot v$$

velocity =

mass =

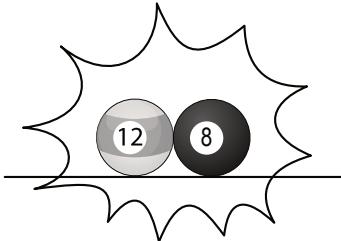
momentum =

### A collision on the pool table:

The mass of each billiard ball is 0.2 kg. Velocities are shown below. Calculate the total momentum and then predict the momentum and velocity of the balls after the collision. Assume no friction.

**BEFORE COLLISION:**

$$v = 4 \text{ m/s} \quad v = 0 \text{ m/s}$$



**AFTER COLLISION:**



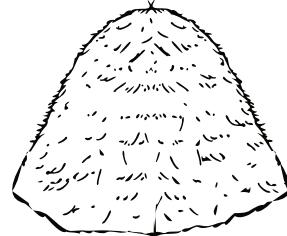
# HOW TO CHANGE MOMENTUM

To change momentum, you need to apply a force over time. We call this exerting an **impulse**.

$$\Delta p = F t$$

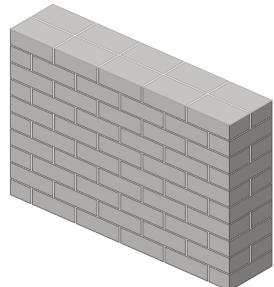
A car with failed brakes is headed for a dangerous hill! Their only option for stopping is to drive into either a haystack or a brick wall. Colliding with either object will bring the car to a stop. The driver of the car weighs 80 kg and is traveling 20 m/s.

- ◆ How much momentum will the driver lose in the crash?



A collision with the brick wall will last for 0.1 s but a collision with the haystack lasts for 0.8 s.

- ◆ How much force would the driver experience hitting each object?

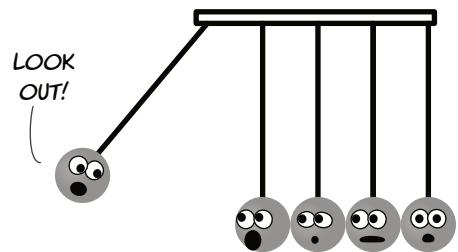


A **collision** happens when objects exert forces on each other over a short time period. Collisions are defined by the exchange of momentum and energy.

## ELASTIC COLLISIONS (bouncy)

- Both momentum and kinetic energy (the energy of motion) are conserved.
- Total momentum and the total kinetic energy before the collision is the same (or nearly the same) as after the collision.

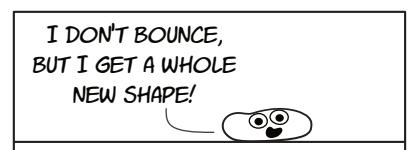
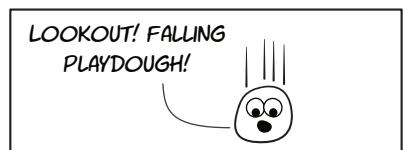
Ex. Billiard balls colliding, bouncy ball, a steel ball dropping on an anvil



## INELASTIC COLLISIONS (sticky)

- Momentum is conserved, but kinetic energy is not.
- The total kinetic energy after the collision is less than before the collision, because energy gets converted into other forms, like heat or sound.

Ex. A football lineman tackling a running back, ripe fruit falling from a tree, a car accident



## PRACTICE PROBLEMS – MOMENTUM AND COLLISIONS

- 1 Two ice skaters push off from each other on a frozen lake. If one skater is twice as heavy as the other, how do their speeds compare after the push-off?
- 2 What is the difference between an elastic and inelastic collision?
- 3 If a 3 kg toy car moving at 2 m/s collides with a stationary 2 kg toy car, what will the total momentum of the system be after the collision? Assume no external forces are acting on the system.
- 4 A stationary rocket explodes into two pieces. One piece has a mass of 20 kg and moves to the right at 10 m/s. What is the velocity of the second piece, which has a mass of 30 kg?
- 5 Kyle has a mass of 50 kg and is running a rate of 5 m/s when he collides with a wall. If he puts his arms out to slow himself, the collision will last for 0.5 seconds. If he forgets to put out his arms, the collision lasts 0.1 seconds. How much force does Kyle experience in each scenario?

# CENTER OF MASS

FILL IN THE BLANKS:

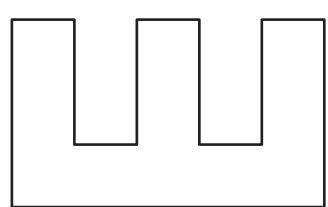
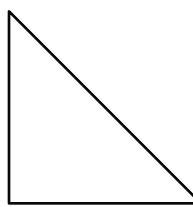
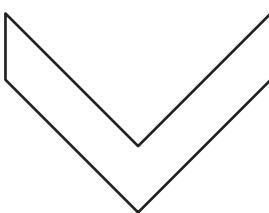
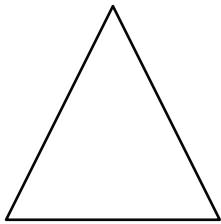
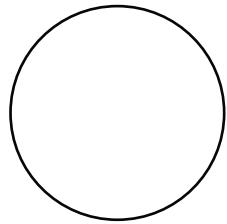
concentrated position center balance gravity

The center of mass of an object is the average \_\_\_\_\_ of the object's mass. It's the point where the entire mass of an object can be considered to be \_\_\_\_\_.

For a symmetrical object, it's the geometric \_\_\_\_\_. If \_\_\_\_\_ or an applied force acts on this point, the object will move in a straight line. For 2-dimensional objects, the center of mass is the \_\_\_\_\_ point.



Mark the center of mass of each shape below (using your intuition to estimate).



## TRY THESE CHALLENGES!

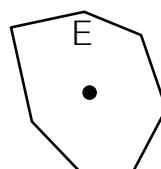
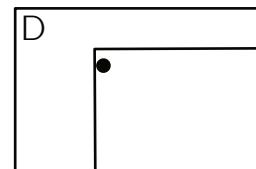
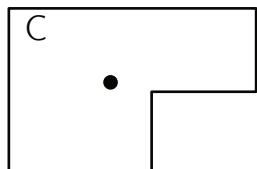
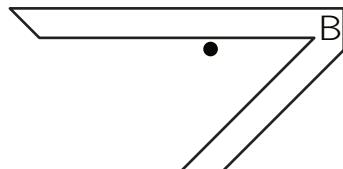
Stand with your heels and back touching the wall. Can you bend over and touch your toes?

Stand with your left shoulder and foot against a wall. Can you lift your right foot?

Sit in a straight-back armless chair with your back against the back of the chair and your feet flat on the floor. Fold your arms. Keeping your feet flat and your back straight, can you stand up?

## WHAT HAPPENED?

The center of mass is marked for each shape. Which shapes would fall over and why?



# CENTRIPETAL FORCE

Swing a bucket of water fast enough in a circle so that the water doesn't spill. (It can help to tie a string to the bucket to make the circle bigger.)

What keeps the bucket in its circular path?



What keeps the water in the bucket?

## Centripetal Force

- Keeps an object moving in a circular path
- The net force is directed towards the center of rotation

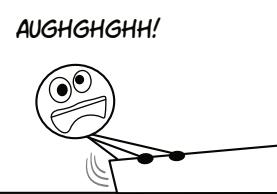
IF THE FORCE IS TOWARD THE CENTER, THEN WHY DO I FEEL PUSHED TO THE OUTSIDE?!



THAT WOULD BE CENTRIFUGAL "FORCE." IT'S AN APPARENT OR FICTIONAL FORCE.

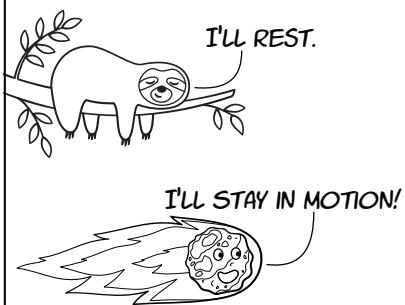


YOUR MASS ACTUALLY WANTS TO TRAVEL IN A STRAIGHT LINE BUT THE CART IS PREVENTING IT FROM DOING SO. HOPE THAT HELPS!

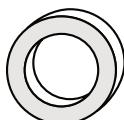


## Remember the Law of Inertia?

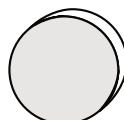
*There's inertia for rotation too! Rotating objects want to keep rotating, and non-rotating objects resist being rotated.*



## Rotational Inertia:



vs

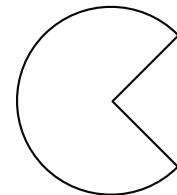
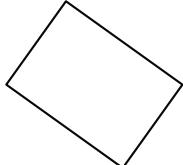
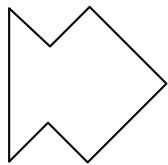


A solid cylinder races down a ramp against a cylinder that shares the same mass but has all the mass near its outer edge. Which cylinder will win? Explain.

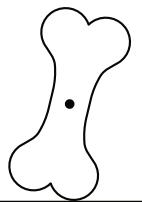
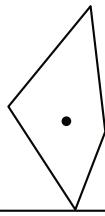
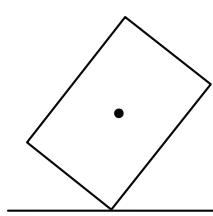


## PRACTICE PROBLEMS – CENTER OF MASS

- ① You are swinging a tennis ball attached to a string in a circular path. Which force, centripetal or centrifugal, is keeping the ball in circular motion?
- ② If you swing it faster, does the force increase, decrease, or stay the same?
- ③ What would happen to the motion of the Earth if the Sun disappeared?
- ④ A person on a spinning merry-go-round is holding a ball. If they let go of the ball, what will happen to the ball?
- ⑤ Estimate the center of mass for each 2D shape below.

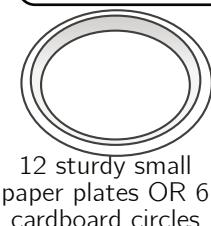


- ⑥ Several 2D shapes are displayed below with their center of mass marked. Determine whether the shape will tip to the left or right when released.



# RACING WHEELS

## MATERIALS

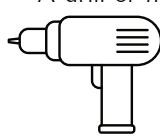


12 sturdy small paper plates OR 6 cardboard circles



3 pencils

A drill or nail



Pennies, nuts or other small weights



Tape or a glue gun

An index card and ruler (optional)



A table, board or ramp

## GOALS

- ★ Learn about how the moment of inertia affects acceleration.
- ★ Design and conduct an experiment.
- ★ Learn about wheel and axles, one of the basic simple machines

## Steps:

1. With the help of an adult, mark the exact center of each paper plate. This can be done with the help of an index card or other rectangular piece of paper. Fold the card in half and line the corners up with the edge of the plate or cardboard circle. Then make marks on either edge of the fold. Remove the card and use a ruler to draw a straight line. Rotate the plate and repeat. The resulting X will mark the center.
2. Use a drill or a sharp object such as a nail to make a hole in the center. With a drill, you could do this for all of the plates at the same time.
3. Use two paper plates back-to-back for each wheel unless you found very sturdy plates or are using cardboard circles. Push a pencil through two wheel pairs to make an axle for your racing wheels.
4. Create 3 racers using the same size plates or cardboard circles. Then add weight using glue and coins, nuts, or any other small heavy objects. One racer should be free of coins. The second should have coins close to the axle. The third should have coins placed near the outer edge of the plate. **Make sure that the weighted wheels each have the same number of total coins.**
5. Which set of wheels do you think will be faster? Make a prediction and be sure to include a sentence or two about why you think this set will be the fastest:

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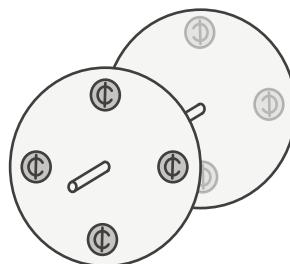
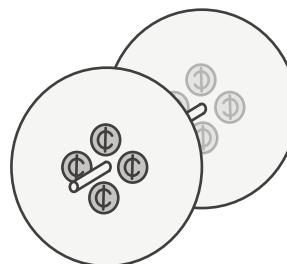
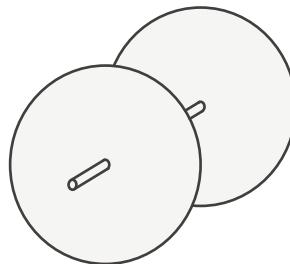
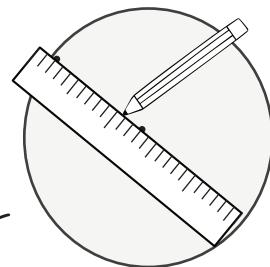
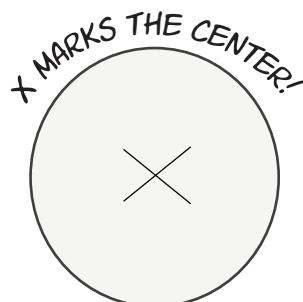
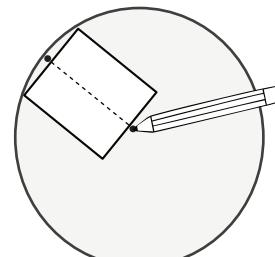
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- Set up a table or board on an incline so that it makes a ramp.
- Roll the wheels down the ramp and record which is the fastest.

## RACING WHEELS DATA

If racing the wheels individually, record the time of each wheel with a stopwatch. Race each wheel down the same ramp 5 times and take the average time for each wheel. If racing the wheels at the same time, be sure to release them at the same moment. Then record which one reaches the bottom first. Repeat 5 times to see if the results are reproducible.

Were the results what you predicted? Why do you think you saw what you observed?

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	NO WEIGHT	INSIDE WEIGHT	OUTSIDE WEIGHT
1 <sup>st</sup> attempt			
2 <sup>nd</sup> attempt			
3 <sup>rd</sup> attempt			
4 <sup>th</sup> attempt			
5 <sup>th</sup> attempt			

AVERAGE RESULT		
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## Variations for further exploration:

- Try to make the fastest set of wheels.
- Try to make the slowest set of wheels.
- Distribute the weight unevenly on a set of wheels.
- Change the slope of the ramp.
- Add more pencils between the wheels at different locations.
- Add more wheels to a single axle

GIVE SOMEONE ADVICE FOR MAKING THE FASTEST AND THE SLOWEST SETS OF RACING WHEELS:

To make the fastest wheels: \_\_\_\_\_

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To make the slowest wheels: \_\_\_\_\_

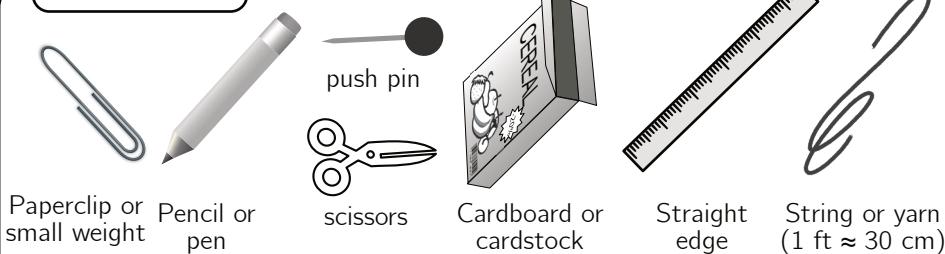
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# CENTER OF MASS

## MATERIALS



## GOALS

- ★ Identify the center of mass of a 2D shape.
- ★ Make predictions and carry out a procedure to verify the accuracy of the prediction.

### 2D Center of Mass

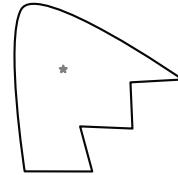
In this activity, you'll create 2-dimensional cardboard cutouts and locate their center of mass.

#### Steps.

1. Cut a variety of shapes out of rigid cardboard such as a breakfast cereal box. Aim for a width of at least 6 inches.
2. Make a guess for where the center of mass will be for each shape, and mark your guess with a star.
3. Tie the paperclip to one end of the string to act as a weight, and tie the other end to the push pin.
4. Along the outer edge of a shape, poke a hole through the shape with the push pin so that the string hangs down.
5. Nudge the shape to make sure that it can spin freely on the pin so that gravity will pull the shape downward without resistance. The string should be hanging straight down, pulled down by the paperclip.
6. Use the straight edge and pencil to trace straight down along the string in a straight line.
7. Pick a second point along the outer edge where you can poke a hole and repeat steps 4, 5, and 6. Ideally, this point will be away from the line you drew in step 5.
8. Now you should have two lines drawn. The center of mass is the point where the two lines cross.

Repeat this process for each of the different shapes.

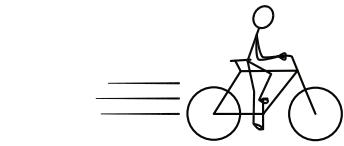
How did you do on your guess for the center of mass of each shape?



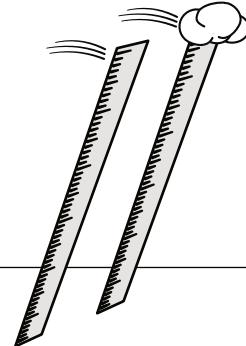
Try balancing each shape on your finger using the center of mass you calculated. Then try again using the center of mass you guessed. Which works better?

What do you think would happen if you repeated steps 4 through 6 again and drew a third line on the shape?

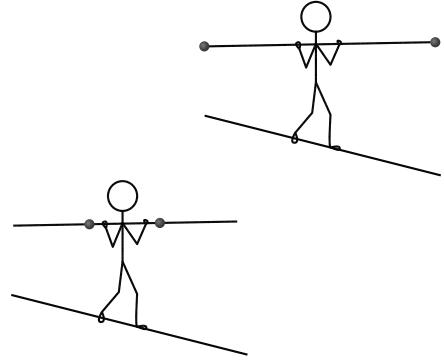
# ROTATIONAL MOTION



Is it easier to balance on a bike when riding a bike slowly or quickly?



Which will tip over faster: a ruler or a ruler with a weight of clay at the end?



Which pole will help the tightrope walker balance better?

Torque - the measure of force that can cause an object to rotate about an axis.

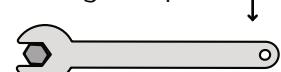
## TORQUE DEPENDS ON 3 THINGS.

1. the angle at which the force is applied -

Weak torque:



Strong torque:

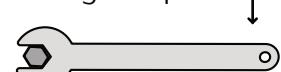


2. the force applied -

Weak torque:



Strong torque:

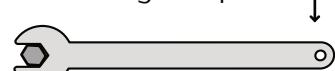


3. the distance from the axis -

Weak torque:



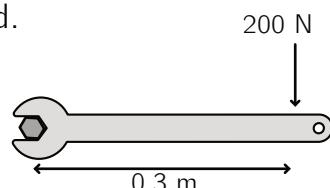
Strong torque:



Torque is measured in newton-meters (N·m).

$$\text{Torque} = (\text{arm length}) \cdot (\text{perpendicular force}) = rF$$

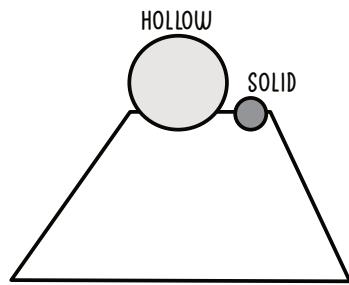
Calculate the torque on the bolt using the distance and force indicated.



If you want to open a heavy door, would it be easier to push near the hinges or at the handle? Why?

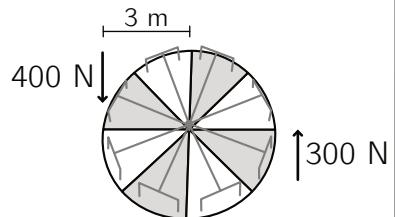
## PRACTICE PROBLEMS – ROTATIONS AND TORQUE

- 1** A solid and hollow sphere have the same mass, but the mass of the hollow sphere is located further from the axis of rotation. Which sphere will be more difficult to rotate (have greater rotational inertia)? Explain why.

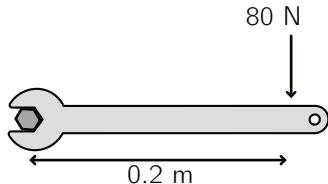


- 2** A wrench is being used to loosen a rusty bolt. Would it require more or less force to loosen the bolt if you hold the wrench closer to the bolt? Explain your answer in terms of torque.

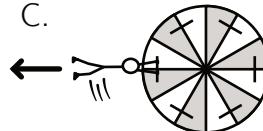
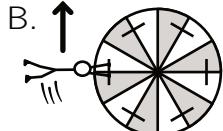
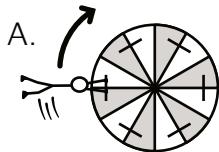
- 3** Two kids are spinning a merry-go-round as pictured. How much torque is created by their pushes?



- 4** Find the torque on the bolt in the diagram below.

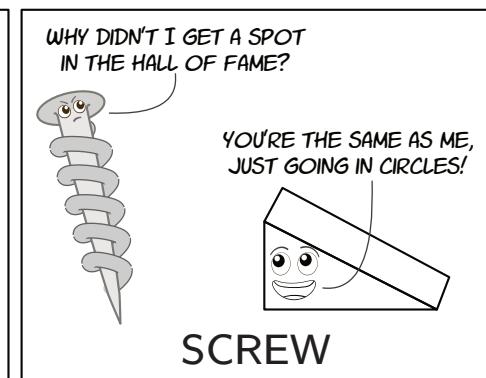
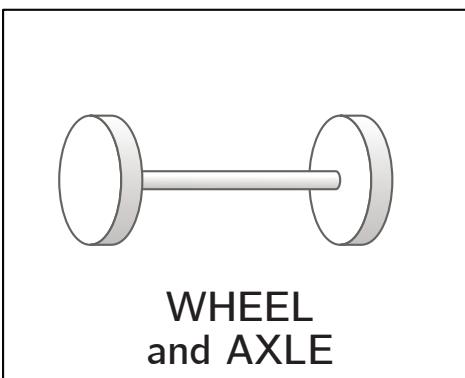
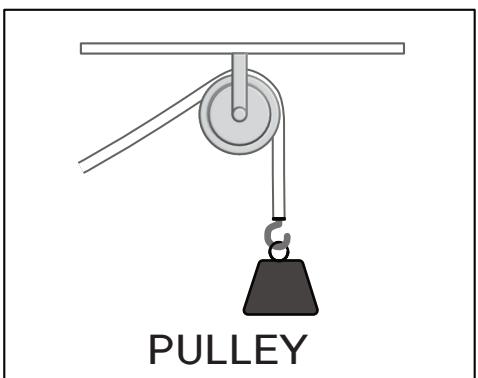
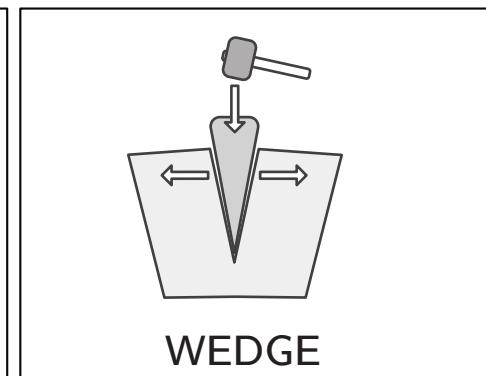
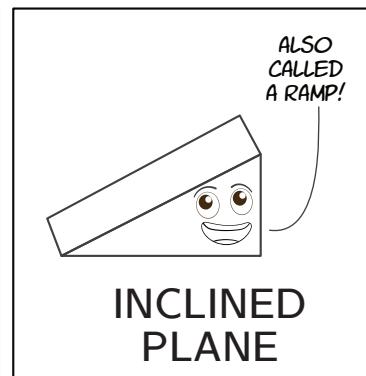
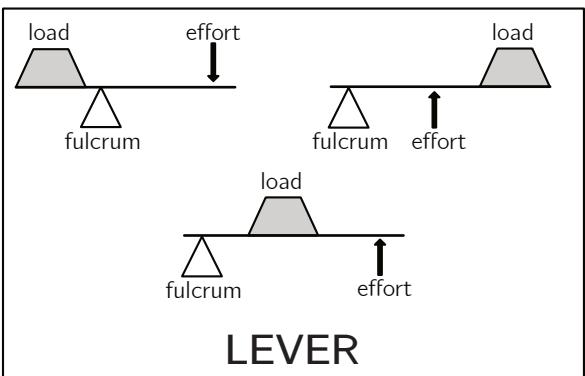


- 5** Rose is hanging on for dear life onto a rapidly rotating merry-go-round. Fortunately, the merry-go-round is surrounded by a large gymnastics pit filled with foam blocks. If Rose lets go from the position shown below, what will her path of travel look like? Explain.



# SIMPLE MACHINES

Simple machines are devices that change the direction or magnitude of a force to make work easier. They use leverage to change the force or distance involved. When these simple machines are combined they form complex or compound machines. Renaissance scientists identified six simple machines:



Match the following devices with the simple machine that performs their primary function:



**INCLINED  
PLANE**

**LEVER**

**PULLEY**

**SCREW**

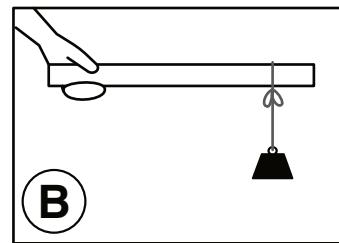
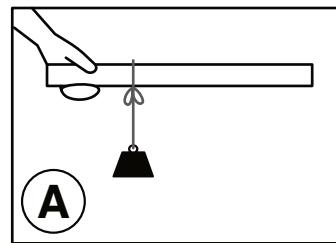
**WEDGE**

**WHEEL  
AND AXLE**

Holding a ruler with a weight hanging from it will feel different depending on whether the weight is hanging close to the hand (A) or further away (B).

Mark which things are the same and which are different when considering situations A and B:

	SAME	DIFFERENT
MASS OF RULER AND WEIGHT		
FORCE ACTING ON HAND		
HOW 'EASY' IT IS TO KEEP THE RULER FROM TWISTING OR DIPPING DOWN		
THE DISTANCE FROM THE HAND TO THE STRING HOLDING THE WEIGHT		

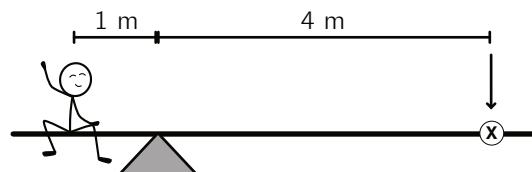


### TORQUE: LEVER ARM · FORCE



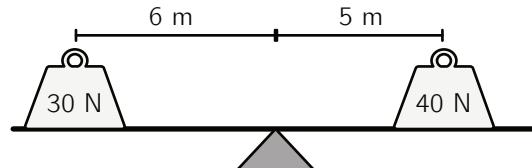
Lever arm: the shortest distance between the axis of rotation and the applied force.

Bob sits on one end of an seesaw. His weight of 90 lbs (400 N) is 1 meter from the fulcrum. Calculate the torque created by Bob's weight. (Assume the lever is weightless.)

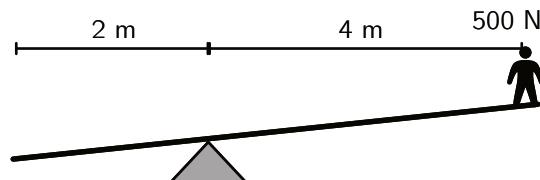


How much force or weight would be needed to keep the fulcrum balanced? The balancing weight needs to be located 4 m to the right of the fulcrum (point x).

Two weights are placed on opposite sides of a seesaw as pictured. Will the seesaw tip down to the left or right? Explain.



How much weight can the pry bar lift (assuming no mass to the bar)?

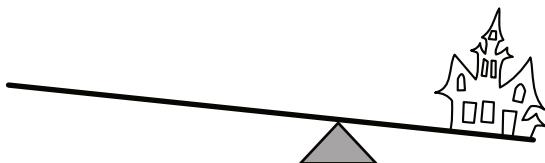


## PRACTICE PROBLEMS – SIMPLE MACHINES

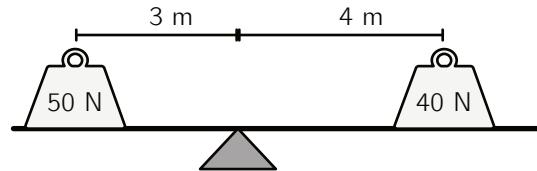
- 1 A lever is being used to lift a rock that weighs 300 N. The rock is 0.5m from the fulcrum, and the other arm of the lever is 1.5m long. How much force needs to be applied to the other end of the lever to lift the rock?



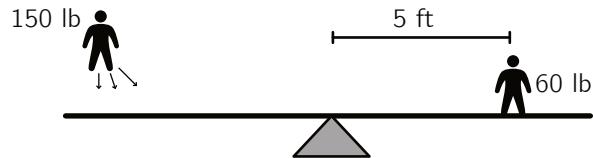
- 2 A house weighs 10,000 kg. A fulcrum is placed 10 m from the house. How long does the other side of the lever need to be for a 100 kg person to lift the house?



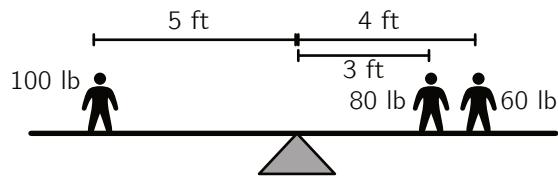
- 3 A 40 N weight is 4 m to the right of the fulcrum of a lever, and a 50 N weight is 3 m from the fulcrum on the left arm of the lever. Which side of the lever will descend?



- 4 A 150 lb parent wants to sit on a seesaw with their 60 lb child. The child is 5 feet from the fulcrum. Where should the parent sit to balance the seesaw?

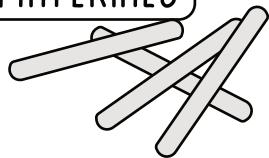


- 5 Three people are sitting on a seesaw. On the left side, a 100 lb person is 5 ft to the left of the fulcrum, while an 80 lb child is 3 ft to the left of the fulcrum and a 60 lb child is 4 ft to the right. To which side will the seesaw tip?



# TENSEGRITY TABLE

## MATERIALS



Popsicle sticks  
(at least a dozen)



Glue gun



A drill



About 60 cm (2 ft)  
of yarn or string

## GOALS

- ★ Create a structure that is supported entirely by tension.
- ★ Diagnose and troubleshoot engineering difficulties.

A tensegrity table is a unique and fascinating structure that utilizes the principles of tension and compression to create a "floating" tabletop. The term "tensegrity" is derived from the words "tension" and "integrity," reflecting the balance of forces that hold the structure together. In a tensegrity table, rigid components (like popsicle sticks) are held in place by tensioned elements (such as strings), which create an equilibrium that results in a stable, yet visually striking, piece of furniture.

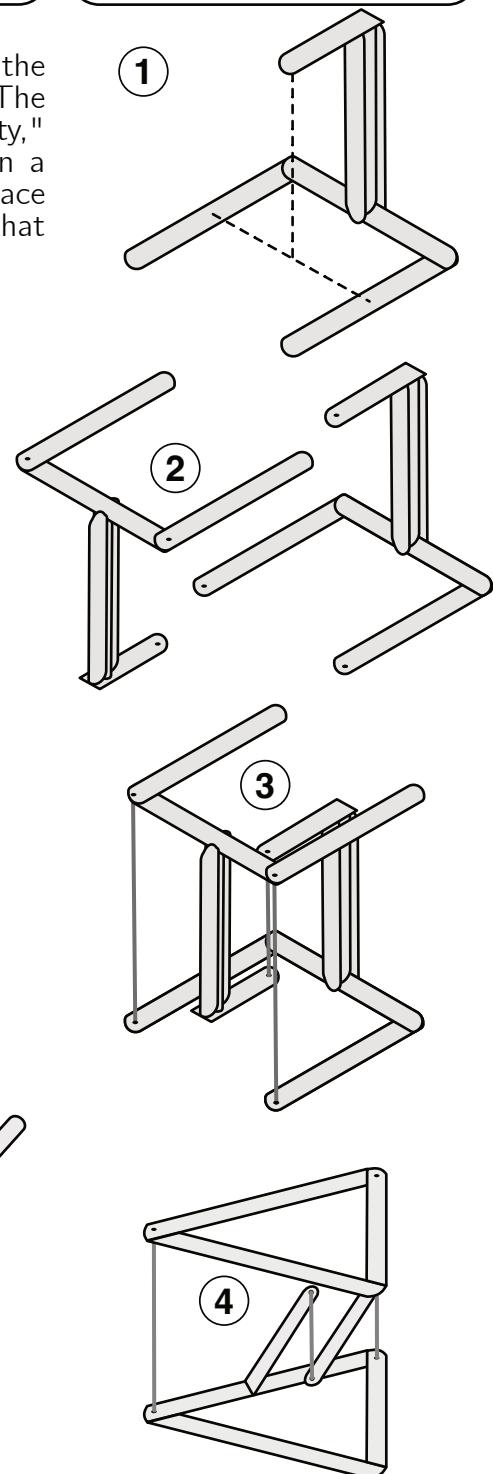
### Variant 1 - Steps. (It can be very helpful to watch a sample video.)

1. Glue a U-shape of three popsicle sticks that will act as a base.
2. Add a vertical support to the bottom of the U-shape. Use plenty of glue. It might help to cut or flatten the popsicle sticks.
3. Break a stick so that it is about 60% of its original length. Then glue this arm to the top of the vertical support so that it stretches to the center of the U. It should look like ①.
4. Repeat steps 1-3 to get a second component with a U base.
5. Drill holes in the arm of each piece that your string will pass through. For one piece, make two more holes that will be at the tips of the U, while for the other piece, make two holes at both sides of the base of the U as pictured in ②.
6. With a partner run the string through the corresponding pieces so that each string is tight as in ③. You can tie knots or use glue to keep the string in place. You will likely need to make adjustments to get the strings to the right length.

### Variant 2 - Steps.

1. Glue three popsicle sticks into a triangle that will act as a base.
2. Make a second triangle for the other piece.
3. Cut or grind down the edge of two popsicle sticks so that they have a straight edge that will extend as an arm at an angle (as though you were extending the base into a tetrahedron).
4. For one piece, attach the arm at a corner. For the other piece, attach the arm along the center of an edge.
5. Invert one piece and attach the strings as in ④.

Explain in your own words, how does a tensegrity table support the top surface in the air?



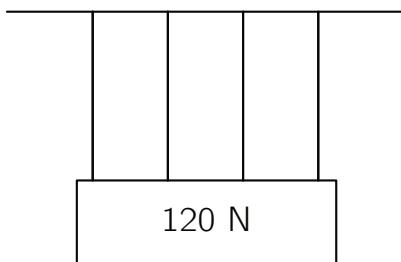
# PULLEY

FILL IN THE BLANKS  
USING THESE WORDS:

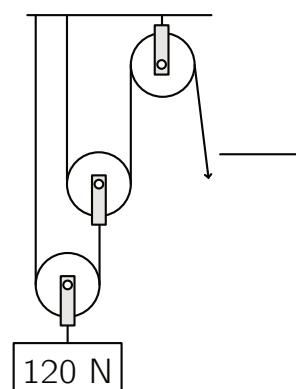
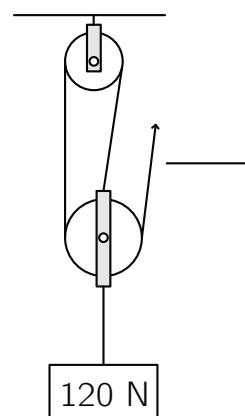
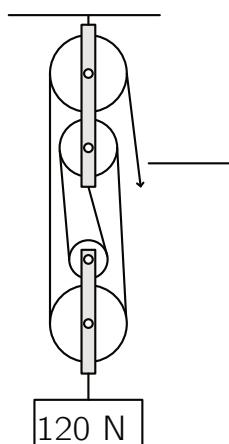
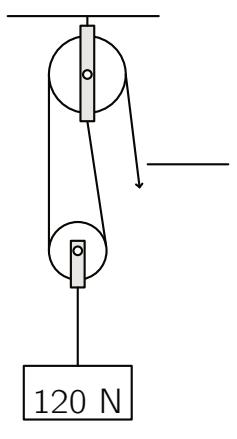
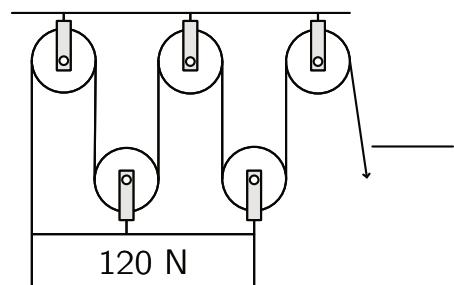
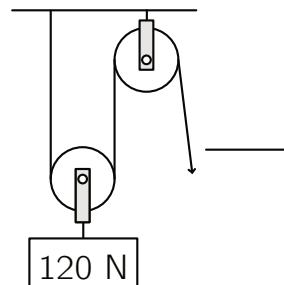
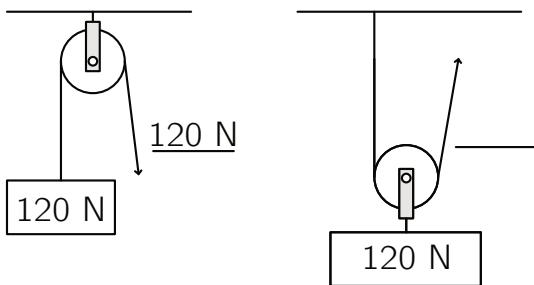


A pulley is a simple machine that consists of a \_\_\_\_\_ with a groove along its edge, designed for a rope or \_\_\_\_\_ to move within it. It is used to change the \_\_\_\_\_ of an applied force or to significantly decrease the amount of \_\_\_\_\_ required to lift or move a load. When \_\_\_\_\_ pulleys are used together in a system, you can lift \_\_\_\_\_ loads with much less effort. In a balanced pulley system, the force downward is equal to the force upward.

A box with a weight of 120 N is attached to the ceiling with 4 cables as pictured below. Identify and label the forces applied by each rope.



A 120 N weight is suspended. Calculate the force needed to keep the weight stationary. (Assume there is no friction.)



## PRACTICE PROBLEMS – PULLEYS & MECHANICAL ADVANTAGE

Select each action below that changes the effectiveness of a frictionless pulley.

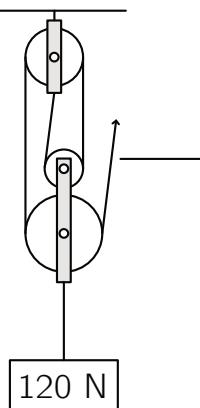
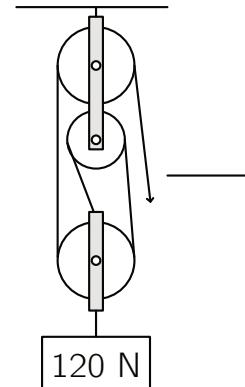
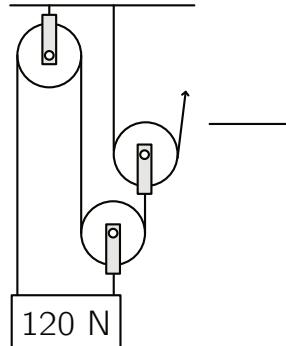
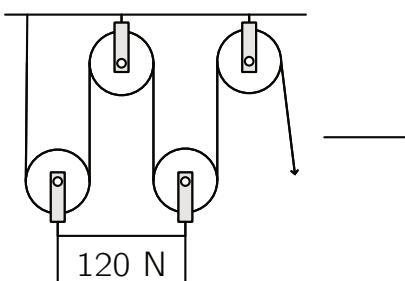
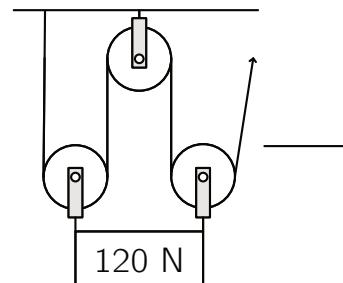
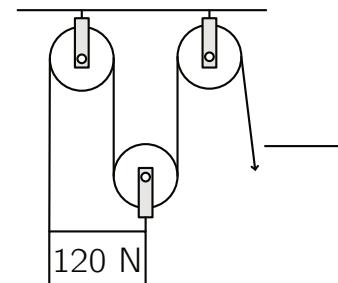
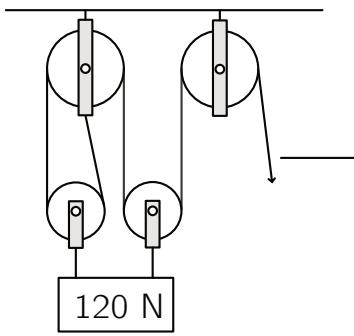
- 1 A. Shorten the string.  
B. Lengthen the string.  
C. Pull at an angle instead of straight down.  
D. Add more pulleys to the system.



- 2 A certain simple machine has a mechanical advantage of 8. How much force of effort is required to lift a weight of 120 N?

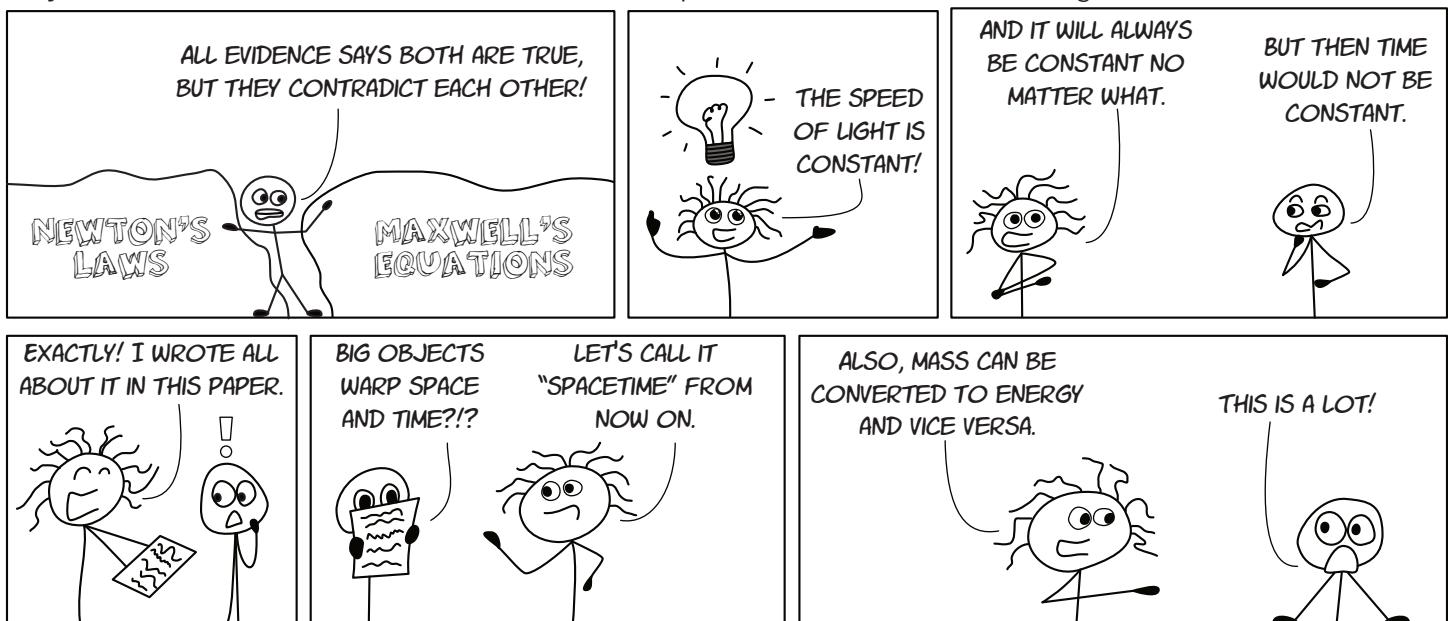
- 3 Most physics textbooks make a distinction between **ideal** mechanical advantage and **actual** mechanical advantage when it comes to simple machines. Explain the difference between these two ideas. Which idea is more useful?

- 4 A 120 N weight is suspended. Calculate the force needed to keep the weight stationary. (Assume there is no friction.)



# RELATIVITY

Physicists were stuck between a rock and a hard place... until Einstein had a lightbulb moment:



Motion is **RELATIVE** AND SO ARE TIME AND DISTANCE!\*

\*at super fast speeds

TIME DILATION

LENGTH CONTRACTION

There was a young lady named Bright  
Whose speed was far faster than light;  
She set out one day  
In a relative way  
And returned on the previous night.

- Reginald Buller

There once was a young man named Fisk,  
Whose fencing was extremely brisk,  
So fast was his action,  
The Lorentz contraction,  
Foreshortened his foil to a disk.

-James Coleman

## SPECIAL RELATIVITY:

1. THE LAWS OF PHYSICS ARE THE SAME IN ALL UNIFORMLY MOVING FRAMES OF REFERENCE.
2. THE SPEED OF LIGHT IS A CONSTANT FOR ALL OBSERVERS INDEPENDENT OF THE RELATIVE MOTION OF THE SOURCE.



### WHY SO FAMOUS?

**1**  $E=mc^2$  explains mass/energy conversion: fusion in the sun and fission in nuclear reactors and atomic bombs.

**2** General relativity predicts gravitational lensing, black holes, gravitational waves and time dilation! An understanding of time dilation is needed for GPS satellites to work properly.

Draw a comic that includes something about relativity. It could be black holes, the speed of light, time dilation, distance contraction, or some other aspect!

**COMIC**

How would you describe relativity to a friend who had never heard of it before?

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What part of relativity do you find most surprising?

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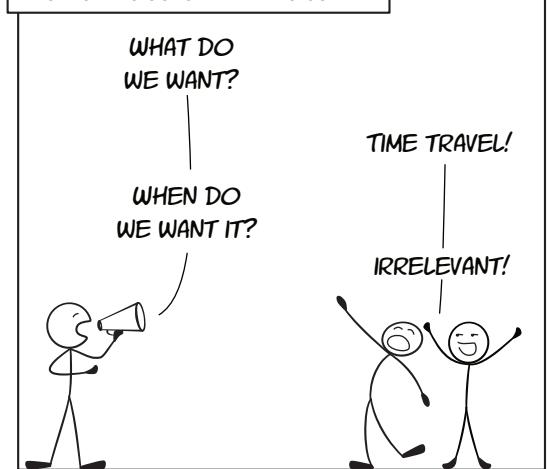


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### PROTESTERS OUTSIDE A PHYSICS LAB:



## PRACTICE PROBLEMS – RELATIVITY

① What is the principle of relativity?

② Who is most associated with the development of the theory of relativity?

- A. Isaac Newton
- B. Galileo Galilei
- C. Marie Curie
- D. Albert Einstein

③ What does the principle of constant speed of light state?

- A. Light can change speed depending on the medium it travels through.
- B. The speed of light in a vacuum is always the same, regardless of the observer's speed or direction.
- C. Light always travels faster than sound.
- D. Light speed can be broken by advanced spaceships.

④ What does  $E = mc^2$  represent in the theory of relativity?

- A. It represents the formula for calculating speed.
- B. It shows how energy (E) is interchangeable with mass (m), with "c" being the speed of light.
- C. It is the equation for calculating the force of gravity.
- D. It is the equation that explains time travel.

⑤ What is a key prediction made by general relativity?

- A. The possibility of time travel
- B. The existence of black holes and gravitational waves
- C. The possibility of travel at light speed
- D. The existence of other dimensions

⑥ If you were gliding on a hover train with no windows, could you sense the difference between uniform motion and rest? Between accelerated motion and rest? Explain how you could make such a distinction using a bowl filled with water.

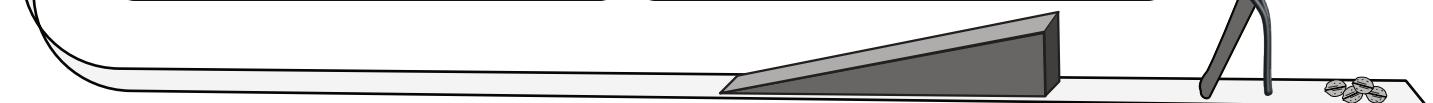
# RUBE GOLDBERG MACHINE CHALLENGE

## MATERIALS

Whatever you have laying around the house. Examples include wood scraps, marbles, string, pencils, dominoes, fans, PVC pipe, magnets, duct tape, cups or bowls, toy cars, cardboard boxes

## GOALS

- ★ Assemble simple machines to carry out a complicated task.
- ★ Diagnose and troubleshoot engineering difficulties.



In this activity, you'll be making a Rube Goldberg machine, which is an intricate and elaborate device designed to accomplish a simple task through a series of complex steps. These machines operate on the principle of chain reactions, where one action triggers another, subsequently leading to the completion of the intended task. Rube Goldberg machines derive their name from Rube Goldberg, a renowned cartoonist known for his illustrations of these contraptions.

For example, a Rube Goldberg machine might accomplish the goal of crushing the shells of walnuts by first starting a fan. The fan blows over a domino which starts a chain reaction where more dominoes are knocked over until the final domino nudges a ball down a ramp. The ball rolls up another ramp and collides with the head of a mallet, tipping it over onto the walnuts.

Design and build your own Rube Goldberg machine utilizing materials readily available at home. Try to make the machine as imaginative and intricate as possible, with the objective of achieving a simple task in a highly convoluted manner.

Upon completing the construction of your Rube Goldberg machine, please address the following reflection questions:

1. What was the primary task your Rube Goldberg machine aimed to achieve?
2. Elaborate on the individual steps of your machine. Which step presented the greatest challenge, and why?
3. How did you address and resolve difficulties encountered during the construction process?
4. If given the opportunity to reconstruct the machine, what modifications or improvements would you make?
5. Which simple machines played a role in your Rube Goldberg machine?

Please note that there is no definitive approach to constructing a Rube Goldberg machine. The primary focus should be on fostering creativity and enjoying the process.

# ASSESSMENT

BE SURE TO HAVE A PENCIL AND SCRATCH PAPER!

- 1 Which units below use the units  $\text{kg} \cdot \text{m}^2/\text{s}^2$ ?

- A. Watts
- B. Joules
- C. N•m
- D. Ampere

- 2 Which quantities below use the units  $\text{kg} \cdot \text{m}^2/\text{s}^2$ ?

- A. Momentum
- B. Energy
- C. Torque
- D. Work

- 3 The SI-unit of power is the

- A. Newton
- B. Joule
- C. Watt
- D. Meter

- 4 What is the potential energy of a 2 kg book sitting on a 2 m bookshelf?

- A. 0 J
- B. 4 J
- C. 24.6 J
- D. 39.2 J

- 5 What is the kinetic energy of a 2 kg book sitting on a 2 m bookshelf?

- A. 0 J
- B. 4 J
- C. 24.6 J
- D. 39.2 J

- 6 What is the momentum of a 6 kg ball rolling east at a rate of 3 m/s.

- A. 2  $\text{kg} \cdot \text{m/s}$  east
- B. 9  $\text{kg} \cdot \text{m/s}$  east
- C. 18  $\text{kg} \cdot \text{m/s}$  east
- D. 36  $\text{kg} \cdot \text{m/s}$  east

- 7 What is the angular speed of the second hand on a clock that is 6 cm long?

- A. 1/60 rotation/s
- B. 1 rotation/s
- C. 60 rotation/s
- D. 3600 rotation/s

- 8 The mechanical advantage of a machine can be calculated by:

- A. Multiplying the input force by the output force
- B. Dividing the input force by the output force
- C. Dividing the output force by the input force
- D. Subtracting the input force from the output force

Circle T or F to mark each statement as either True or False:

- 9 T      F Energy is the ability to do work or cause change.

- 10 T      F Kinetic energy is the energy of an object due to its position or shape.

- 11 T      F The amount of potential energy an object has depends on its height and mass, not its speed.

- 12 T      F Power is defined as the rate at which work is done or energy is transferred.

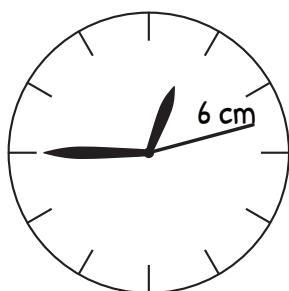
- 13 T      F Momentum is a measure of how difficult it is to stop a moving object and it depends only on the object's mass.

- 14 T      F The distribution of mass will affect an objects rotational inertia.

- 15 T      F Pulleys have a greater mechanical advantage than levers.

- 16 T      F Simple machines are able to lift heavy objects by doing less work.

- 17 T      F Power and energy are the same thing.

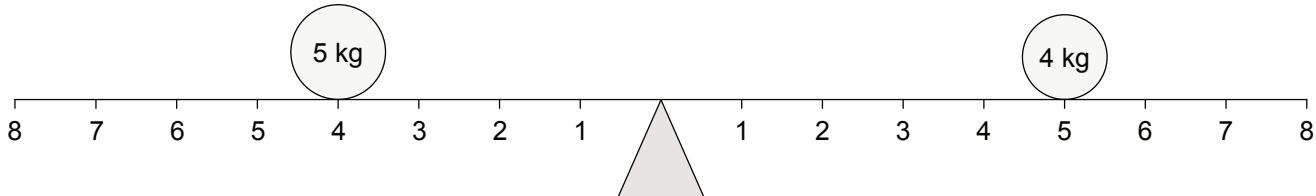


- (18)** Which of the following statements about energy conservation in a closed system is TRUE?
- Energy can be created and destroyed.
  - The total amount of energy in the system changes over time.
  - Energy can change forms, but the total energy remains constant.
  - Energy is always lost as heat.

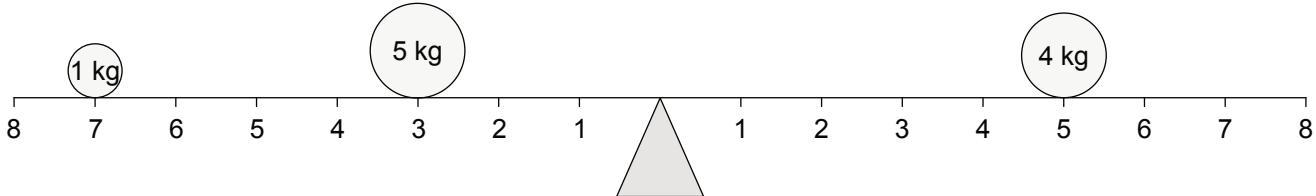
- (19)** If an object is lifted to a greater height, what happens to its potential energy?
- It decreases.
  - It increases.
  - It remains the same.
  - It changes into kinetic energy.

- (20)** 50 N of force are applied perpendicular to a wrench that is 30 cm long. How much torque is applied to the bolt?
- 15 N•m
  - 150 N•m
  - 166.7 N•m
  - 1500 N•m
- 

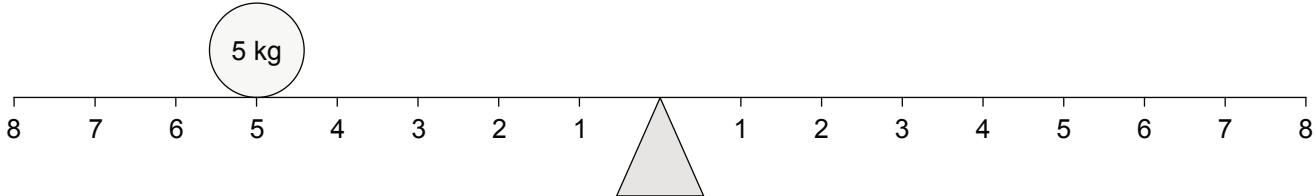
- (22)** Weights are placed on a seesaw as pictured. Which direction will the seesaw tip?



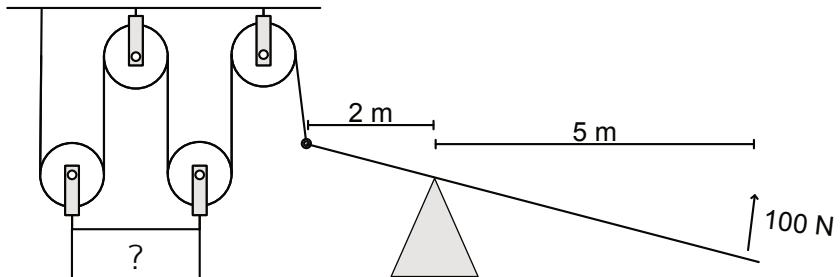
- (23)** Weights are placed on a seesaw as pictured. Which direction will the seesaw tip?



- (24)** Place weights with mass 2 kg, 3 kg, and 4 kg on the seesaw below so that it balances.



- (25)** A lever is hooked up to a pulley as pictured. Assume the lever and string are weightless. How much weight can be lifted by the pulley when 100 newtons of force upwards is applied to the right end of the lever?



**(25)** Circle T or F to mark each statement True or False.

- T    F If an object is accelerating at a constant rate of acceleration, then the forces acting upon the object are balanced.
- T    F An object will be at rest when there are no forces acting upon it.
- T    F If an object is moving to the right and slowing down, then the net force on the object is directed towards the left.
- T    F When no net force is applied to a moving object, it still comes to rest because of its inertia.
- T    F When the net force acting on an object doubles, the velocity of the object doubles too.

**(26)** Circle number 1, 2, or 3 to indicate which of Newton's laws is being described.

- 1 2 3 A light cannon ball launches faster than a heavy cannon ball from the same cannon.
- 1 2 3 A cannon is pushed backwards when it fires a cannon ball.
- 1 2 3 Force equals mass times acceleration.
- 1 2 3 While making a right turn in your car, your body is pushed to the left.
- 1 2 3 An object floating in deep space travels at a constant velocity forever

**(27)** A 12g ball is rolled into a stationary 4g ball. If the heavier ball applies a 30N force on the smaller ball, what force will the smaller ball apply on the large ball?

- A. 1/3 N  
B. 3 N  
C. 12 N  
D. 30 N

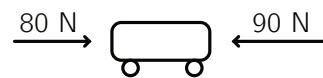
**(28)** How many newtons of upward force is needed to support a 10 kg weight in the air?

- A. 10 N  
B. 16 N  
C. 49 N  
D. 98 N

**(29)** Which option below has the most inertia?

- A. A cow  
B. A car  
C. A blue whale  
D. A wheelbarrow

**(30)** Two kids are pushing opposite ends of a shopping cart with forces as pictured. The total weight of the cart and kids is 130 kg. How quickly, and in what direction will the cart accelerate?

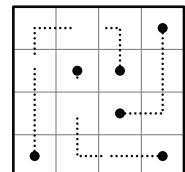


### PIPE FLOW MATCHING - UNIT 3

A				
C				
		B		
	3	4	D	5
	2			
1				E

Match each unit with the quantity being measured by joining them with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

1. energy                  A.  $\text{m}/\text{s}^2$   
2. momentum                B.  $\text{kg}\cdot\text{m}^2/\text{s}^2$   
3. power                    C.  $\text{kg}\cdot\text{m}/\text{s}$   
4. force                    D.  $\text{kg}\cdot\text{m}^2/\text{s}^3$   
5. acceleration            E.  $\text{kg}\cdot\text{m}/\text{s}^2$

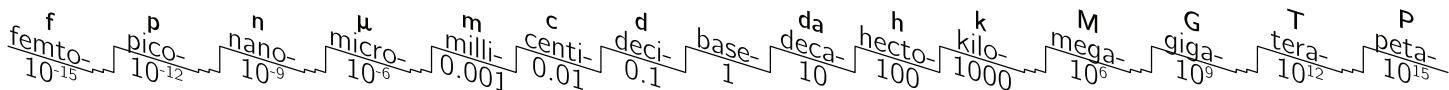


# APPENDIX

-for content that either didn't fit elsewhere or was more advanced

## SI-PREFIXES

Prefix		Base 10	Decimal
Name	Symbol		
quetta	Q	$10^{30}$	1 000 000 000 000 000 000 000 000 000 000
ronna	R	$10^{27}$	1 000 000 000 000 000 000 000 000 000
yotta	Y	$10^{24}$	1 000 000 000 000 000 000 000 000 000
zetta	Z	$10^{21}$	1 000 000 000 000 000 000 000 000 000
exa	E	$10^{18}$	1 000 000 000 000 000 000 000 000
peta	P	$10^{15}$	1 000 000 000 000 000 000
tera	T	$10^{12}$	1 000 000 000 000
giga	G	$10^9$	1 000 000 000
mega	M	$10^6$	1 000 000
kilo	k	$10^3$	1 000
hecto	h	$10^2$	100
deca	da	$10^1$	10
		$10^0$	1
deci	d	$10^{-1}$	0.1
centi	c	$10^{-2}$	0.01
milli	m	$10^{-3}$	0.001
micro	$\mu$	$10^{-6}$	0.000 001
nano	n	$10^{-9}$	0.000 000 001
pico	p	$10^{-12}$	0.000 000 000 001
femto	f	$10^{-15}$	0.000 000 000 000 001
atto	a	$10^{-18}$	0.000 000 000 000 000 001
zepto	z	$10^{-21}$	0.000 000 000 000 000 000 001
yocto	y	$10^{-24}$	0.000 000 000 000 000 000 000 001
ronto	r	$10^{-27}$	0.000 000 000 000 000 000 000 000 001
quecto	q	$10^{-30}$	0.000 000 000 000 000 000 000 000 000 001



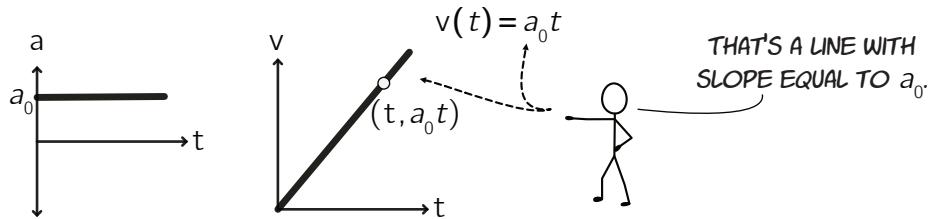
## A BONUS PAGE OF PHYSICS MATH!

Any time a constant net force is acting on an object of constant mass, the acceleration will also be a constant (represented as  $a_0$ ). Newton's 2nd law says that  $F = ma$ . Since force and mass are constant, then so is acceleration.

When the force is gravity,  $a_0$  is denoted by the letter  $g$ . ( $g=9.8 \text{ m/s}^2$  for acceleration)

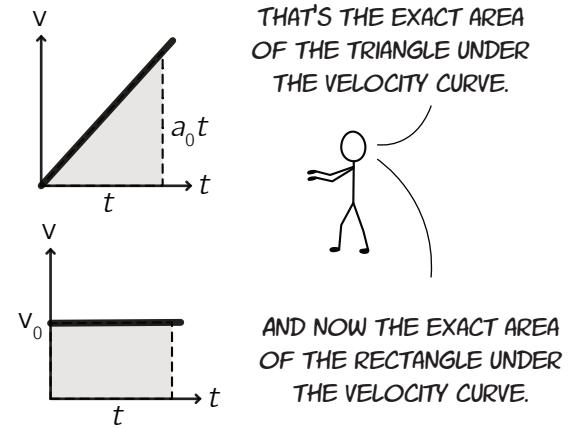
### Velocity. (Constant acceleration from a standstill)

If an object starts with velocity  $0 \text{ m/s}$  and then accelerates at  $a_0 \text{ m/s}^2$  for  $t$  seconds, its velocity will be  $v(t) = a_0 t \text{ m/s}$ . (For example: If your speed started at  $0 \text{ m/s}$  and increased by  $3 \text{ m/s}$  for  $10 \text{ seconds}$ , then you speed would have increased to  $3 \cdot 10 = 30 \text{ m/s}$  in total.)



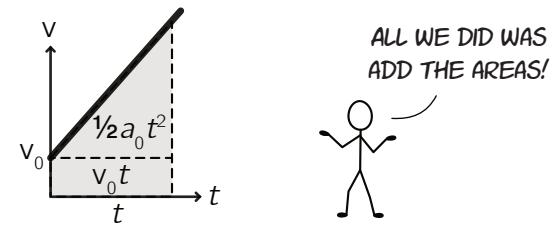
### Displacement. (Constant acceleration from a standstill)

If an object uniformly accelerates from  $0 \text{ m/s}$  to  $a_0 t \text{ m/s}$ , in  $t$  seconds, then the average velocity is  $\frac{1}{2}a_0 t \text{ m/s}$ . Multiply the average velocity by  $t$  seconds to get the displacement of  $d(t) = \frac{1}{2}a_0 t^2 \text{ m}$ .



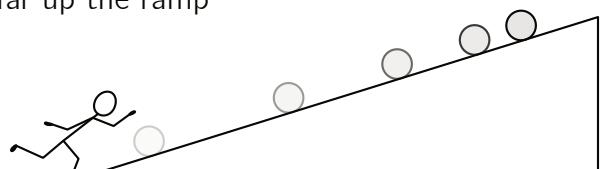
### Displacement. (Constant velocity and no acceleration)

If an object travels at a uniform velocity  $v_0 \text{ m/s}$  for  $t$  seconds, then we can multiply the rate and time to get the total displacement of  $d(t) = v_0 t \text{ m}$ .



### Displacement. (Constant acceleration)

If an object has a starting velocity of  $v_0 \text{ m/s}$  and travels at a constant acceleration of  $a_0 \text{ m/s}^2$  for  $t$  seconds, then the total displacement will be  $d(t) = \frac{1}{2}a_0 t^2 + v_0 t \text{ m}$ . This formula adds the displacement due to starting speed to the displacement due to acceleration.



### Example.

A bowling ball is rolled up a ramp that is sloped so that the net acceleration upward is  $-2 \text{ m/s}^2$ . The initial velocity upward is  $6 \text{ m/s}$ . How far up the ramp relative to the release point is the ball after  $4 \text{ seconds}$ ?

### Solution.

Use  $a_0 = -2 \text{ m/s}^2$  and  $v_0 = 6 \text{ m/s}$  in the displacement formula.

$d(t) = -t^2 + 6t$ . When  $t = 4 \text{ s}$ , we get the displacement

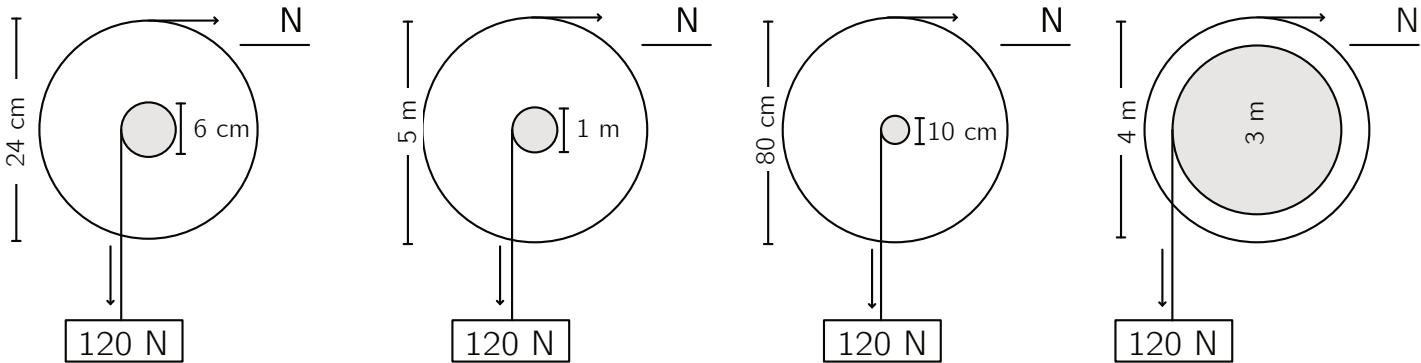
$d(4) = -(4)^2 + 6(4) = 8 \text{ m}$ , so the bowling ball is  $8 \text{ m}$  up the ramp after  $4 \text{ seconds}$ .

## MECHANICAL ADVANTAGE OF SIMPLE MACHINES

### WHEEL AND AXLE

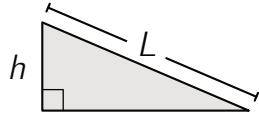
A simple machine that reduces friction and multiplies force. It consists of two connected parts of different diameters.

A cross section of a wheel and axle supports 120 N of weight and is pulled using a crank. Use torque to find how many newtons of force are needed to hold the weight steady.



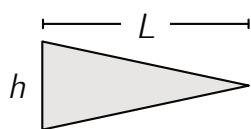
### INCLINED PLANE

Inclined planes, screws, and wedges are similar shapes that make use of a slope to gain mechanical advantage. The mechanical advantage is calculated as a ratio



$$\frac{\text{distance of effort}}{\text{distance of resistance}}.$$

### WEDGE



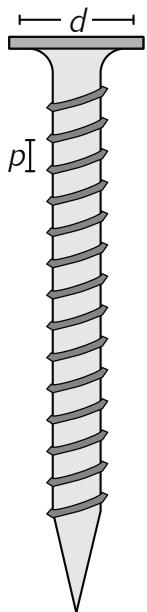
As labeled, the mechanical advantage for an inclined plane and a wedge is

$$\frac{\text{distance of effort}}{\text{distance of resistance}} = \frac{L}{h}.$$

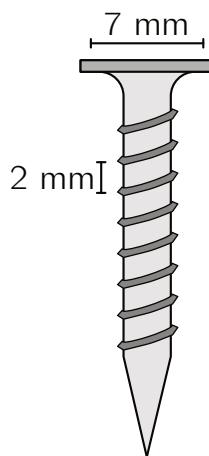
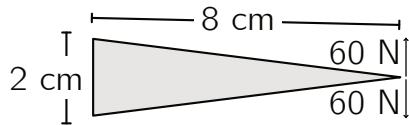
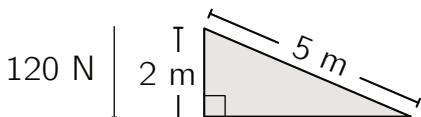
For a screw, the mechanical advantage is

$$\frac{\text{distance of effort}}{\text{distance of resistance}} = \frac{\text{screwdriver circumference}}{\text{pitch (height of one thread)}} = \frac{d\pi}{p}.$$

### SCREW



How much force does each simple machine need to match 120 N of resistance?

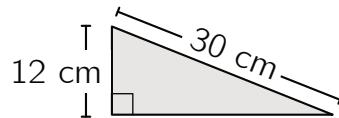
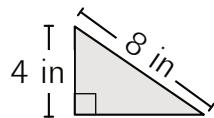
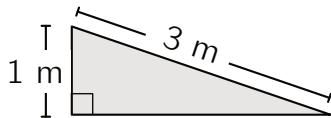


## MORE PRACTICE PROBLEMS – MECHANICAL ADVANTAGE

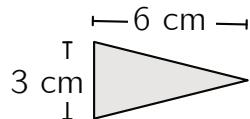
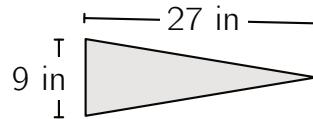
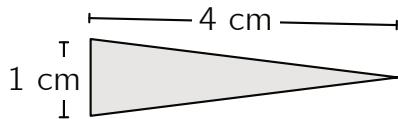
- 1 Screw B has threads that are twice as far apart as screw A. Which screw has the greater mechanical advantage? How many times greater?



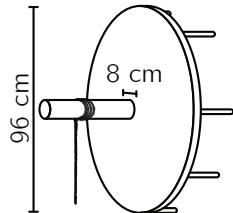
- 2 Find the mechanical advantage for each inclined plane below. If it takes 120 J to lift an object straight up, how many joules will it take to lift it using the ramp. (Assume no friction.)



- 3 Find the mechanical advantage for each wedge below. Which wedge requires the least force to do the same amount of work? Why would anyone use a wedge that requires more force?



- 4 Find the mechanical advantage for the wheel and axle where the wheel diameter is 96 cm and an axle diameter is 8 cm. What force does one need to apply to the wheel to balance a load that weighs 120 N?



# Laws of Motion

## Physics Man

Serge Ballif

Billy Joel

$\text{♩} = 140$

The musical score consists of ten staves of music in common time (indicated by '3') and treble clef. The tempo is marked as  $\text{♩} = 140$ . The lyrics describe the three laws of motion as physics principles. The score includes lyrics such as "The laws of motion are won-der-ful.", "Newton wrote the laws one two and three.", "They tell us of move-ment and for-ces and time\_\_\_\_ how the world works and how it should be.", "I - ner - tia force andre - action", "All mo - tion is re\_\_\_\_\_ la - tive.", "Law one says an ob-ject in mo tion stays that way un-til force is a - pplied. It", "rests in its place or moves through-out space 'til a-cted u - pon it will glide\_\_\_\_ I - ner - tia", "force andre - action All mo - tion is re\_\_\_\_\_ la - tive. Law", "two says that a -ccel - e - ra - tion times mass re - sults in the force\_\_\_\_ Ve - lo - ci - ty", "chan-ges as mass or force ran - ges each change in mo - tion has a source\_\_\_\_ I - ner - tia force andre-", "a - ction All mo - tion is re\_\_\_\_\_ la - tive. Law three is a", "rule a - bout ba - lance. when you give an ob-ject a smack. For e - ve - ry ac - tion an", "e - qual re - ac - tion That ob - ject will push you right back\_\_\_\_". Measure numbers 9, 17, 28, 38, 47, 58, 67, 76, 87, and 96 are indicated on the left side of the score.

## USEFUL FORMULAS

### Distance

$d$  = distance,  $r$  = rate,  $t$  = time

$$d = rt$$

### Weight

$w$  = weight,  $m$  = mass,  $g = 9.8 \text{ m/s}^2$

$$w = mg$$

### Newton's 2<sup>nd</sup> Law

$F$  = force,  $m$  = mass,  $a$  = acceleration

$$F = ma$$

### Fall Distance

$h$  = feet fallen,  $t$  = fall time in seconds

$$h = 16t^2$$

### Law of Universal Gravitation

$F$  = gravitational force,  $G = 6.674 \times 10^{-11} \text{ m}^3/(\text{kg} \cdot \text{s}^2)$ ,  
 $m_1$  = mass 1,  $m_2$  = mass 2,  $d$  = distance to center

$$F = G \frac{m_1 m_2}{d^2}$$

### Kinetic Energy

$m$  = mass,  $v$  = velocity

$$KE = \frac{1}{2}mv^2$$

### Potential Energy

$m$  = mass,  $g = 9.8 \text{ m/s}^2$ ,  $h$  = height

$$PE = mgh$$

### Power

$P$  = power,  $w$  = work,  $t$  = time

$$P = \frac{W}{t}$$

### Law of Conservation of Energy

$$PE_1 + KE_1 = PE_2 + KE_2$$

### Work

$w$  = work,  $F$  = force,  $d$  = distance

$$W = Fd$$

### Momentum

$p$  = momentum,  $m$  = mass,  $v$  = velocity

$$p = mv$$

### Torque

$\tau$  = torque,  $r$  = radius,  $F$  = force

$$\tau = rF$$