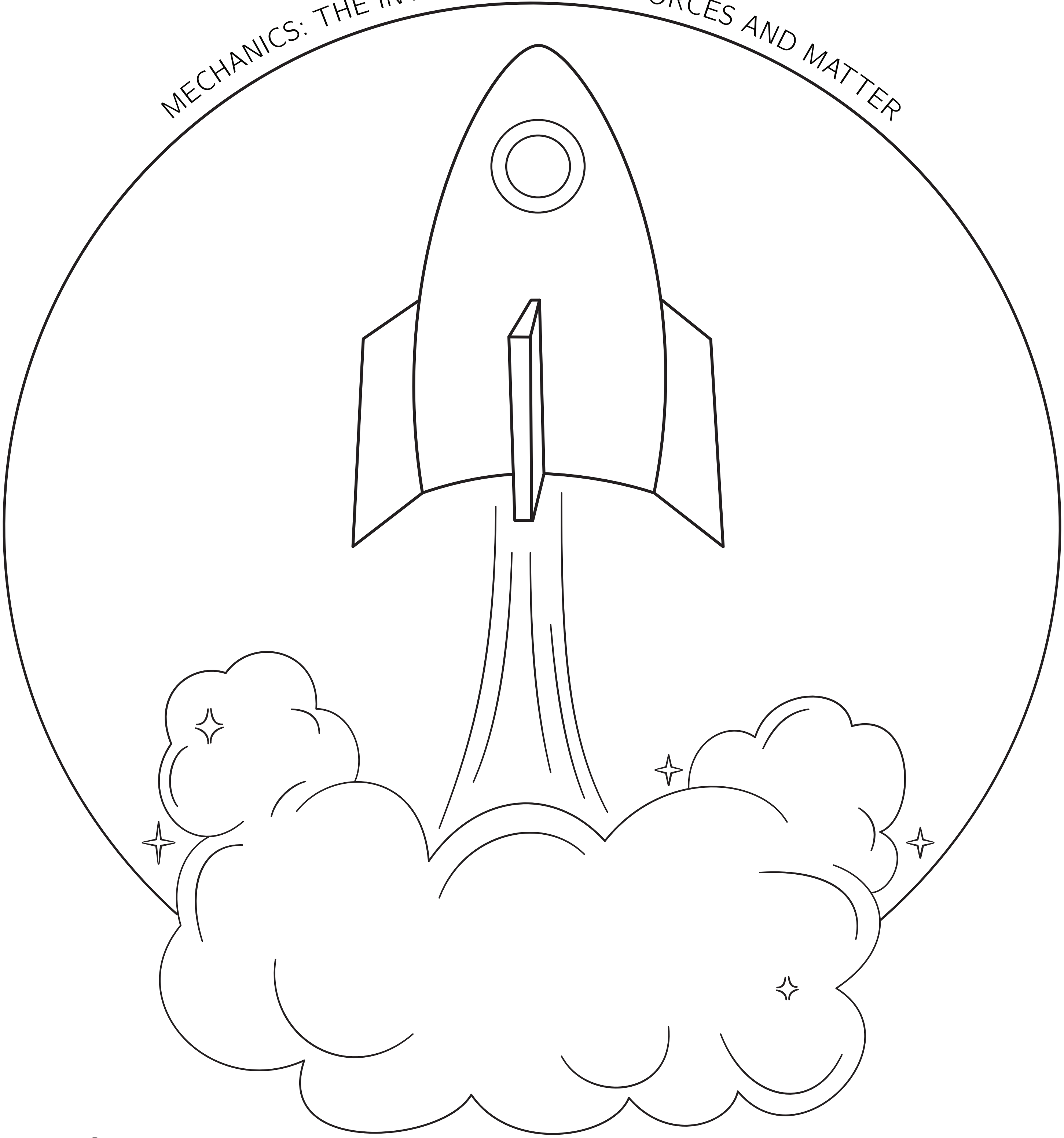
Physics 1

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	-
	12	Assessment	44-47
Unit 2. Laws of Motion	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	Assessment	96-97
Unit 3. Work and Energy	27	Kinetic vs Potential Energy	98-102
	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

	Lesson	Topic	Pages
Unit 3. Work and Energy	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!

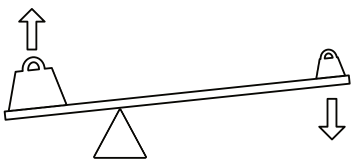
**A water rocket kit is recommended for this activity*

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!

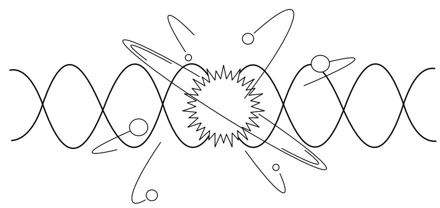
If you could spend a day working with a physicist, which of these areas would you like to explore? Put a star or checkmark by your top three choices.

CLASSICAL MECHANICS



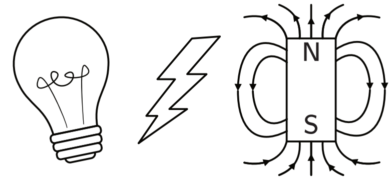
☐ The study of how everyday objects move and behave

QUANTUM MECHANICS



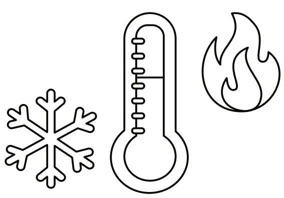
☐ The study of how very small particles behave

ELECTROMAGNETISM



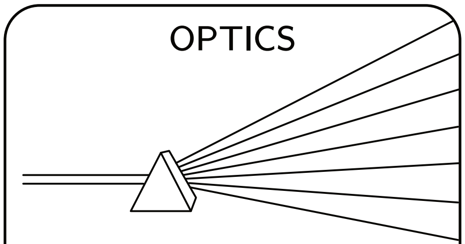
☐ The study of electric and magnetic fields

THERMODYNAMICS



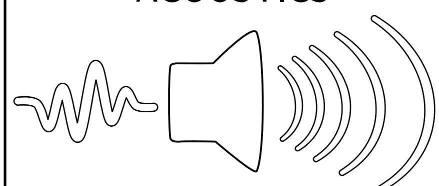
☐ The study of heat, energy, and entropy

OPTICS



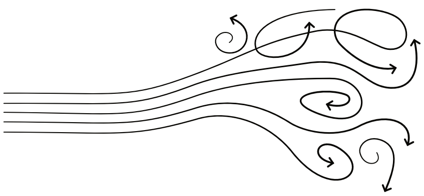
☐ The study of the behavior and properties of light

ACOUSTICS



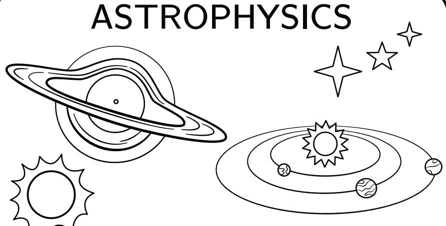
☐ The study of mechanical waves such as sound

FLUID DYNAMICS



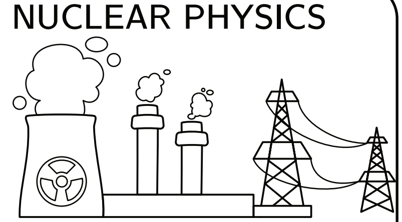
☐ The study of the flow of liquids and gases

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:

____

____

____

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:

____

____

____

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.

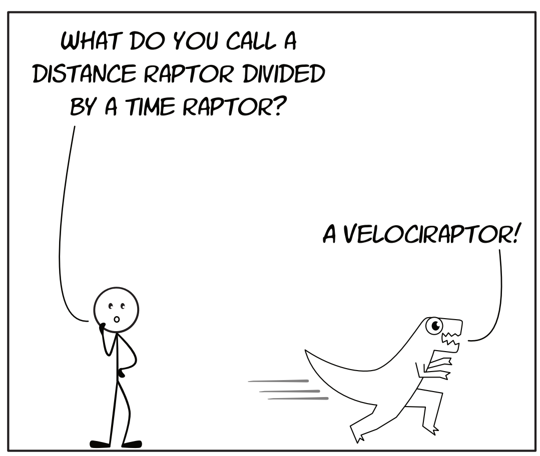
Make a specific plan for learning the language of physics:

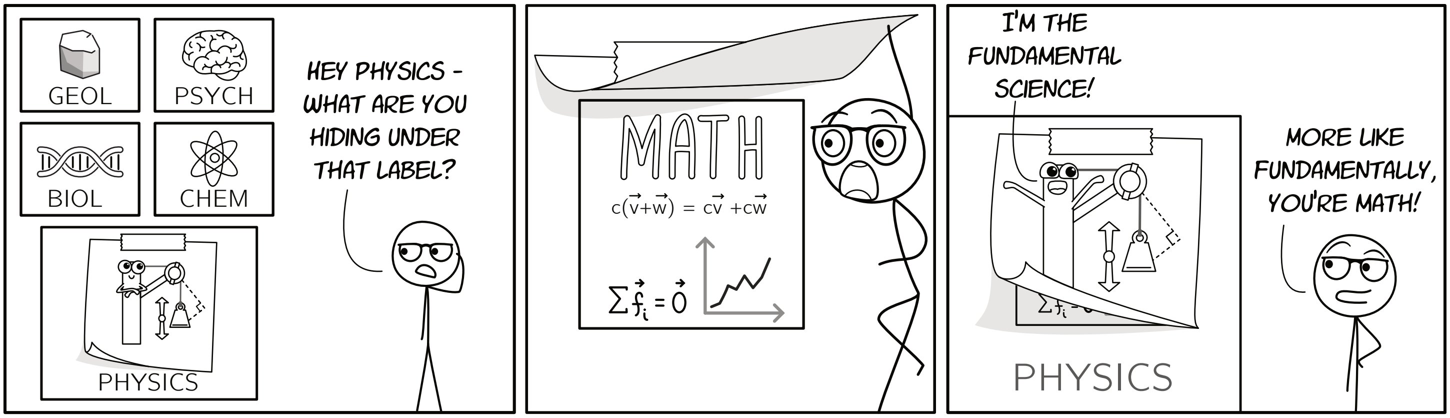
____

____

____

____





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?

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

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

HOW WILL YOU MEASURE YOUR PROGRESS OR CHECK YOUR WORK?

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.

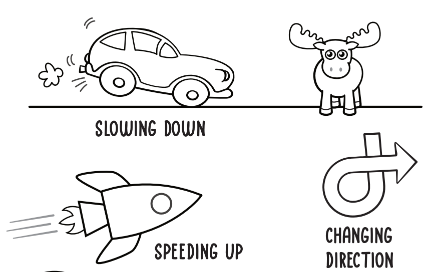
Can recognize and interpret numbers in scientific notation (Optional. We won't use scientific notation often and it could be picked up during class.)

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

Unit 1: Kinematics

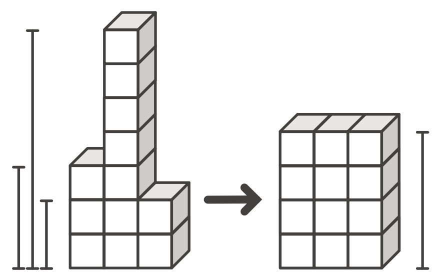
This unit covers how to describe and explain the motion of objects using graphs, diagrams, numbers, and words. Kinematics is all about how measurements are made!

ACCELERATION



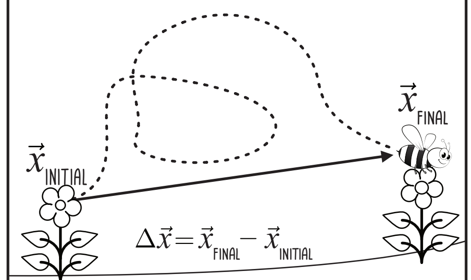
$\vec{a} = \frac{\Delta \vec{v}}{\Delta t}$ The rate of change of velocity

AVERAGE



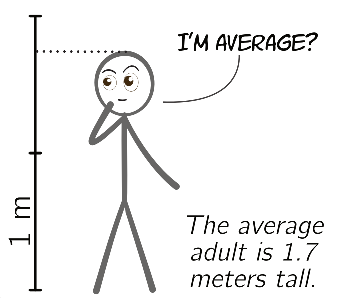
$\frac{x_1 + \cdots + x_n}{n}$ Sum of all values divided by the number of values

DISPLACEMENT



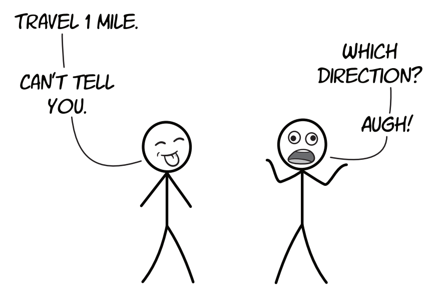
$\Delta \vec{x}$ The straight line distance between initial and final position

METER



m A metric unit of length

SCALAR

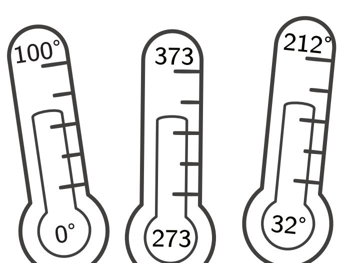


A quantity that has a magnitude (measurement) but no direction

SPEED

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

TEMPERATURE

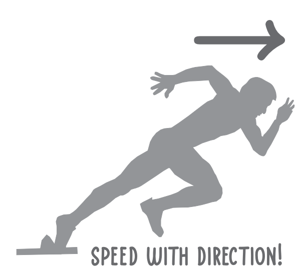


K °C °F Three different systems for measuring temperature

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 __standard__ of measurement. The SI has 7 base __units__ that are defined in relation to universal constants. One __advantage__ of SI is that it has only __one__ unit for each quantity or type of measurement. SI systems uses the same __prefixes__ 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.

In mathematics, we can always add zero, multiply by one, or substitute something of equal value.

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

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

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

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

2. How many meters tall is Math Dad?

There are 3.28 feet in 1 meter.
Math Dad is 5.5 ft tall.

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

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

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

$$= 1.68\text{ m}$$

3. How many marathons would it take to equal the circumference of the Earth?

Circumference of the Earth = 24,902 miles.

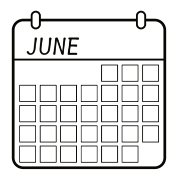
$$1\text{ circ} = 24{,}902\text{ mi}$$

$$= 24{,}902\text{ mi} \cdot \frac{1\text{ marathon}}{26.2\text{ mi}}$$

$$= 950.45\text{ marathon}$$

So it would take about 950.5 marathons to circle the whole Earth.

4. How many minutes are there in June?



$$\text{June} = 30\text{ days}$$

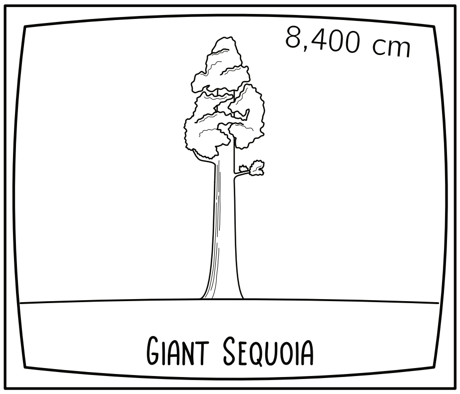
$$= 30\text{ days} \cdot \frac{24\text{ h}}{1\text{ day}} \cdot \frac{60\text{ min}}{1\text{ h}}$$

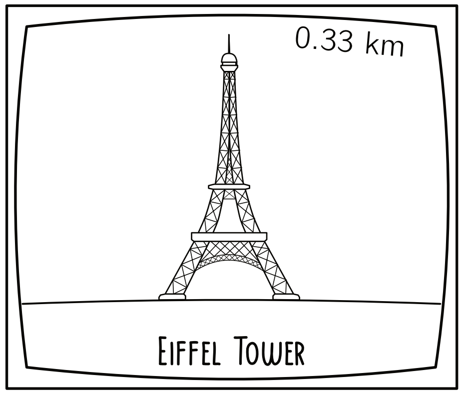
$$= 43{,}200\text{ min.}$$

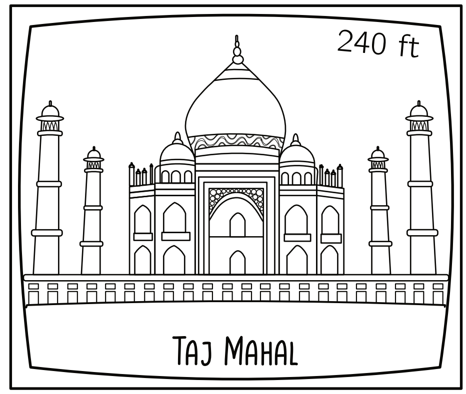
When we multiply a number by a unit conversion fraction, we're really just multiplying by 1!

Mighty Measures

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

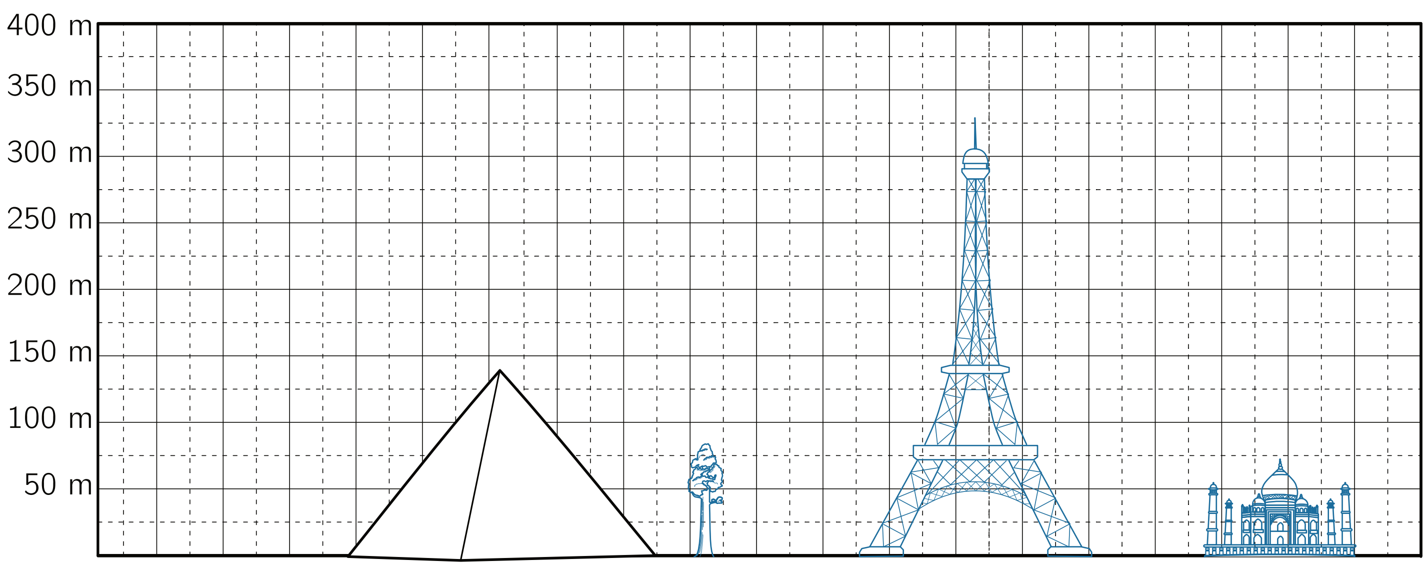
1 inch ≈ 2.54 centimeters	
1 mile ≈ 1.609 kilometers	
1 foot ≈ 0.3 meters	

$$8,400 \text{ cm} = 8,400 \text{ cm} \cdot \frac{1 \text{ m}}{100 \text{ cm}}$$
$$= 84 \text{ m.}$$

$$0.33 \text{ km} = 0.33 \text{ km} \cdot \frac{1,000 \text{ m}}{1 \text{ km}}$$
$$= 330 \text{ m.}$$

$$240 \text{ ft} = 240 \text{ ft} \cdot \frac{12 \text{ in}}{1 \text{ ft}} \cdot \frac{2.54 \text{ cm}}{1 \text{ in}} \cdot \frac{1 \text{ m}}{100 \text{ cm}}$$
$$= 73.152 \text{ m.}$$

The Taj Mahal is the shortest. Then the giant sequoia. The tallest is the Eiffel Tower.



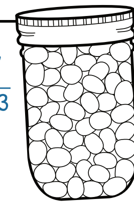
Direct vs Indirect Measurement

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?

Perhaps you estimate that the candies only fill 64% of the space. You might estimate:

$$1 \text{ jar space} = (0.64) \cdot 473 \text{ cm}^3 \cdot \frac{1 \text{ candy}}{1.65 \text{ cm}^3}$$
$$= 183.67 \text{ candies.}$$



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

Perhaps you like the idea of viewing the jar as stacked rows. You might estimate:

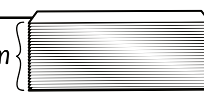
$$1 \text{ jar space} = 10 \text{ rows} \cdot \frac{17 \text{ candy}}{1 \text{ row}}$$
$$= 170 \text{ candies.}$$

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?

$$1 \text{ page} = 1 \text{ page} \cdot \frac{1 \text{ stack}}{100 \text{ pages}} \cdot \frac{1.2 \text{ cm}}{1 \text{ stack}}$$
$$= 0.012 \text{ cm.}$$

1.2 cm

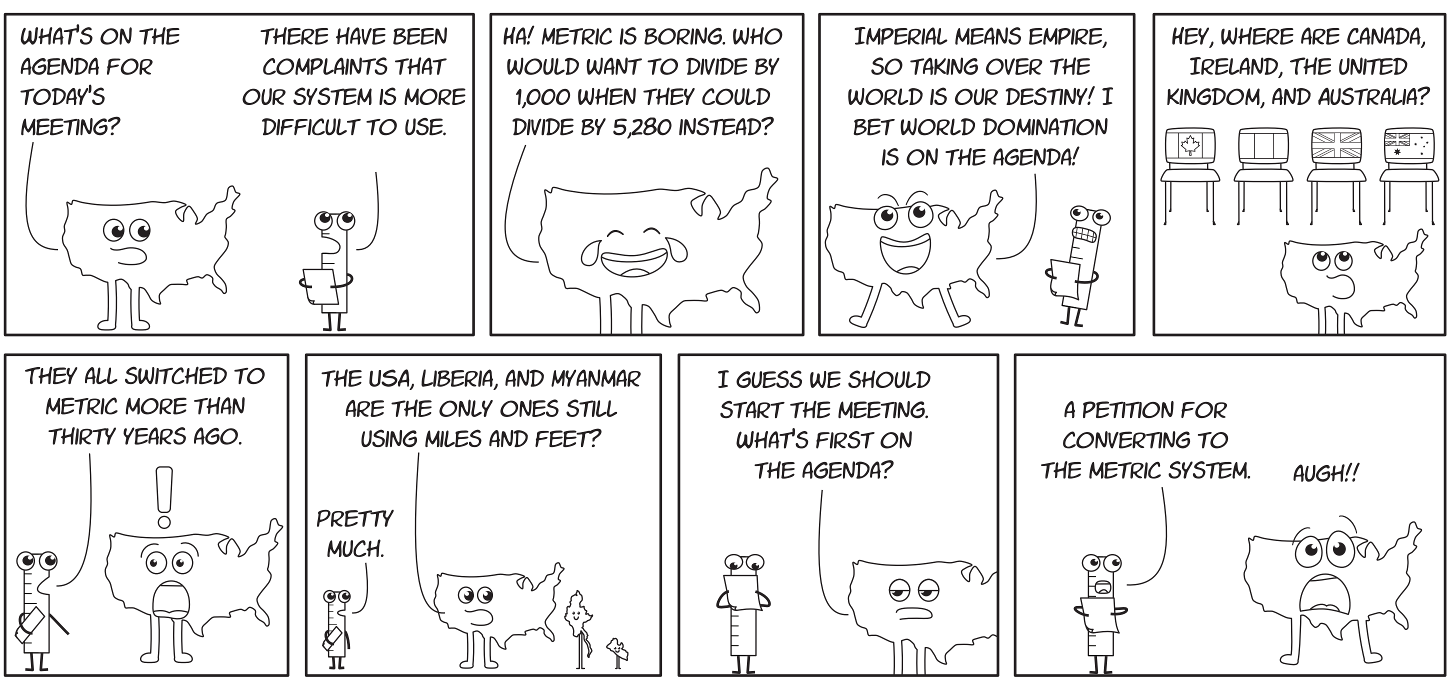


A stack of 100 papers is 1.2 cm tall.

As usual, there are many ways to get the same answer.

$$\frac{1.2 \text{ cm}}{100 \text{ pages}} = 0.012 \text{ cm/page.}$$

A MEETING OF IMPERIAL MEASURES



THE BASE UNITS	WHERE THEY CAME FROM
Length **meter** (m)	The distance from the North Pole to the equator divided by ten million
Time **Second** (s)	1/86,400 of a day
Quantity **Mole** (mol)	The number of atoms in 12 grams of carbon
Electric current **Ampere** (A)	1/10 the electric current that produces a certain amount of force
Temperature **Kelvin** (K)	Kelvin = Celsius + 273 degrees (the C° temperature scale comes from the freezing/boiling points of water)
Luminous intensity **Candela** (cd)	The brightness of a standard candle flame
Mass **Kilogram** (kg)	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
volt watt
ohm joule
lumen
farad
sievert coulomb

SI PREFIXES

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

Symbol
Prefix

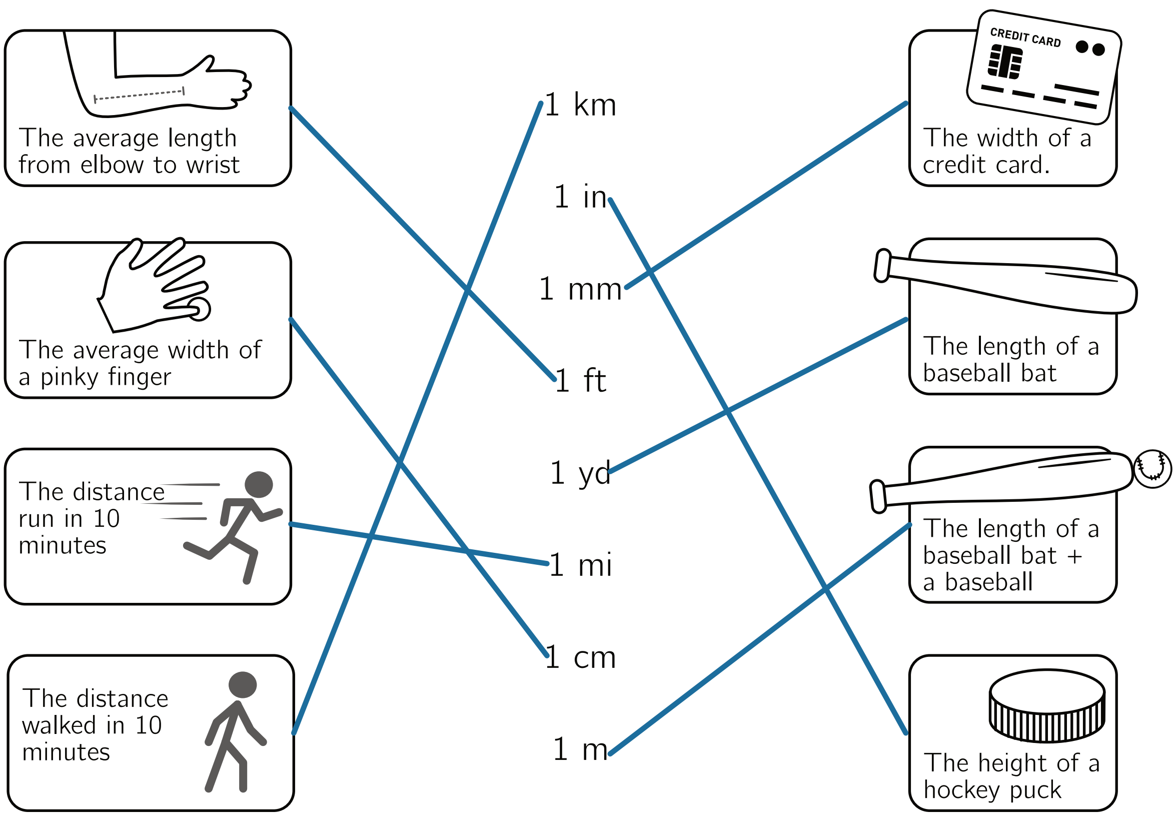
SMALLER BIGGER

Prefix	pico	nano	micro	milli	centi	base unit	kilo	mega	giga	tera	peta
Symbol	p	n	μ	m	c		k	M	G	T	P
	1 trillion times smaller	1 billion times smaller	1 million times smaller	1,000 times smaller	100 times smaller	1	1,000 times bigger	1 million times bigger	1 billion times bigger	1 trillion times bigger	Quadrillion times bigger!
Exponential Multiplier	10^{-12}	10^{-9}	10^{-6}	10^{-3}	10^{-2}		10^{3}	10^{6}	10^{9}	10^{12}	10^{15}

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

MATCHING LENGTHS:

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



A TABLE ON COMPUTER DATA:

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

Unit:	***Number of bytes:***
byte	1
Kilobyte (KB)	1,000
Megabyte (MB)	$1{,}000{,}000 = 10^6$
Gigabyte (GB)	$1{,}000{,}000{,}000 = 10^9$
Terabyte (TB)	$1{,}000{,}000{,}000{,}000 = 10^{12}$
Petabyte (PB)	$1{,}000{,}000{,}000{,}000{,}000 = 10^{15}$

1,000 KB = 1 MB.

1,000 megabytes = 1 gigabyte.

1 terabyte = 1,000,000 megabytes.

1,000,000 GB = 1 PB

How many kilobytes are in a petabyte?

1,000,000,000,000

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?

$$41 \text{ dimes} = 41 \text{ dimes} \cdot \frac{\$1}{10 \text{ dimes}} = \$4.10.$$

$$16 \text{ quarters} = 16 \text{ quarters} \cdot \frac{\$1}{4 \text{ quarters}} = \$4.$$

Jill has more money after the trade.

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

$$61 \text{ quarters} = 61 \text{ quarters} \cdot \frac{\$1}{4 \text{ quarters}} = \$15.25.$$

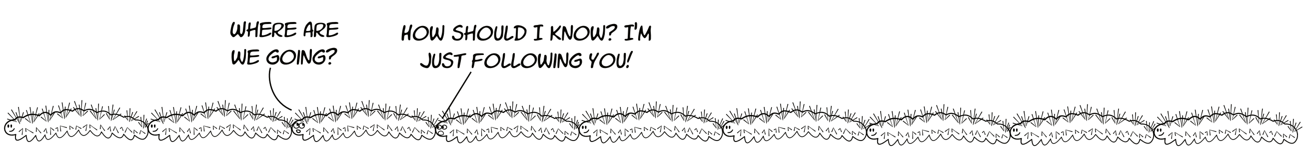
(3) How many Abs are in 10 Gabs?

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

$$10 \text{ Gab} = 10 \text{ Gab} \cdot \frac{6 \text{ Fab}}{1 \text{ Gab}} \cdot \frac{7 \text{ Dab}}{1 \text{ Fab}} \cdot \frac{2 \text{ Cab}}{3 \text{ Dab}} \cdot \frac{3 \text{ Bab}}{7 \text{ Cab}} \cdot \frac{1 \text{ Ab}}{4 \text{ Bab}} = 30 \text{ Ab}.$$

Challenge Question 1: How many Fabs are in 8 Babs?

$$8 \text{ Bab} = 8 \text{ Bab} \cdot \frac{7 \text{ Cab}}{3 \text{ Bab}} \cdot \frac{3 \text{ Dab}}{2 \text{ Cab}} \cdot \frac{1 \text{ Fab}}{7 \text{ Dab}} = 4 \text{ Fab}.$$



Challenge Question 2:

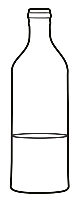
The pine processionary caterpillar (*Thaumetopoea pityocampa*) is 4 cm long. When migrating, the caterpillars march in a single-file line. If a line of caterpillars is just under 1 mile long, then how many caterpillars are marching in the line?

$$1 \text{ mi} = 1 \text{ mi} \cdot \frac{5{,}280 \text{ ft}}{1 \text{ mi}} \cdot \frac{12 \text{ in}}{1 \text{ ft}} \cdot \frac{2.54 \text{ cm}}{1 \text{ in}} \cdot \frac{1 \text{ caterpillars}}{4 \text{ cm}} = 40{,}233.6$$

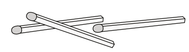
*Since there won't be a fraction of a caterpillar walking in line, the answer is 40,233 caterpillars.

FUN PHYSICS TRICKS

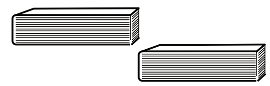
MATERIALS



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



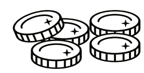
3 matches or flat-tipped toothpicks



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 ¼ 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.

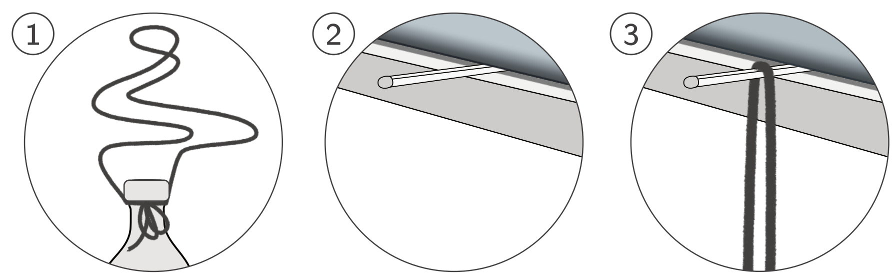
2. Place a match on the edge of a table so that it dangles a bit more than half-way over the edge. Place a counterweight (such as the two books) on the end of the match to hold it in place.

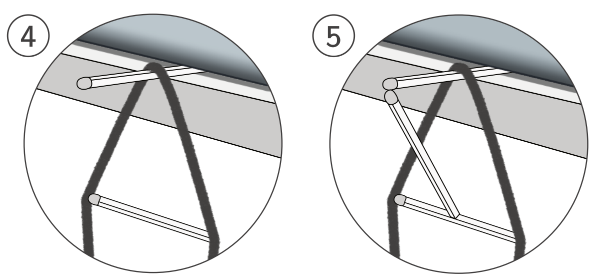
3. Hang the bottle from the match so that the string is up against the side of the table.

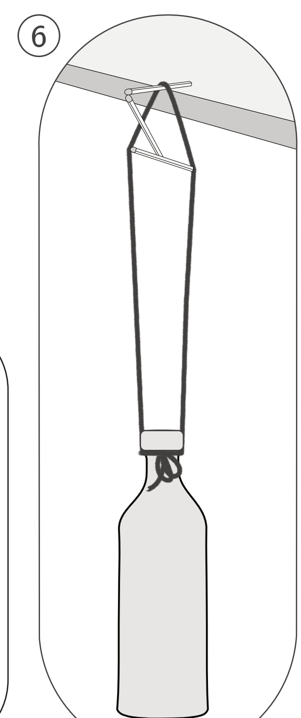
4. Place a second match about one match length below the match that is placed on the table and orient it so that it is wedged between the two strands of string.

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!

2 DOLLAR BILL CHALLENGE

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

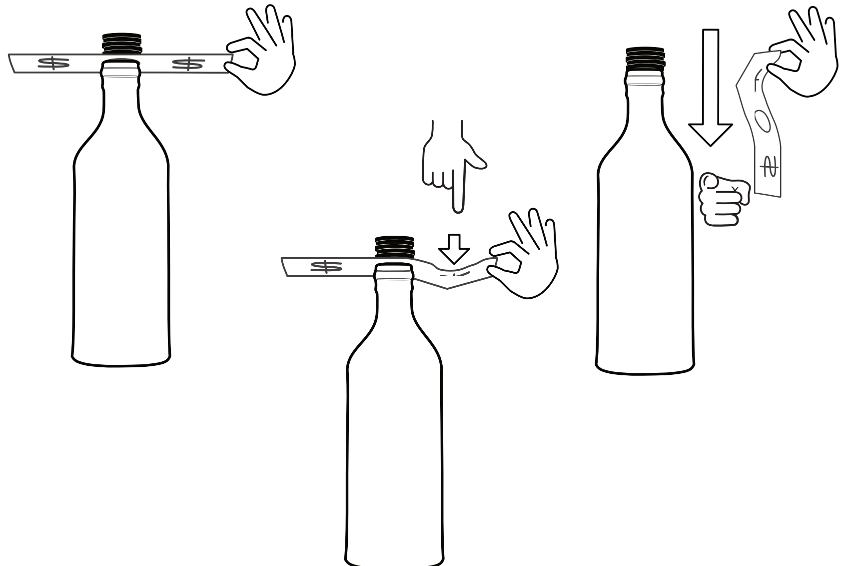
1. Place a dollar bill on a bottle and then place 5 large coins such as quarters on top. Challenge a friend to remove the bill without touching the bottle or knocking off the coins.

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!*

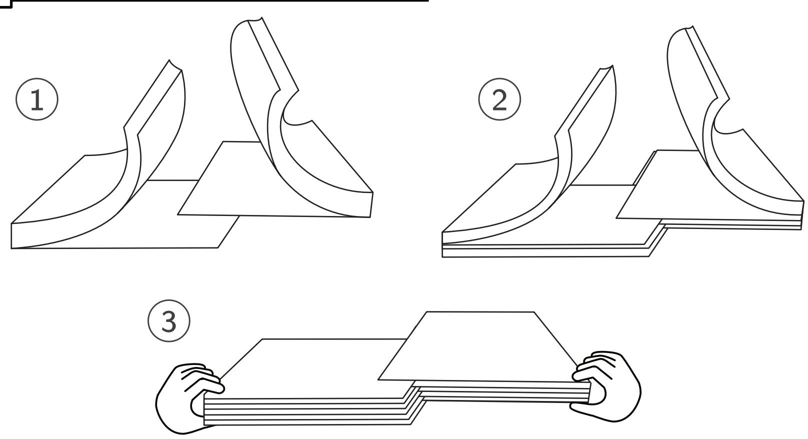
3 BOOK PULL CHALLENGE

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 ¼ to ½ 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?

2 DOLLAR BILL CHALLENGE

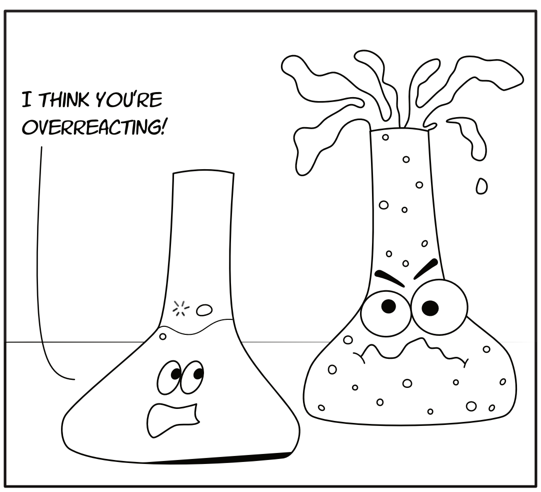
Did the demonstration work? What tips would you give someone else trying this for the first time? Did the activity spark any questions or discoveries?

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?

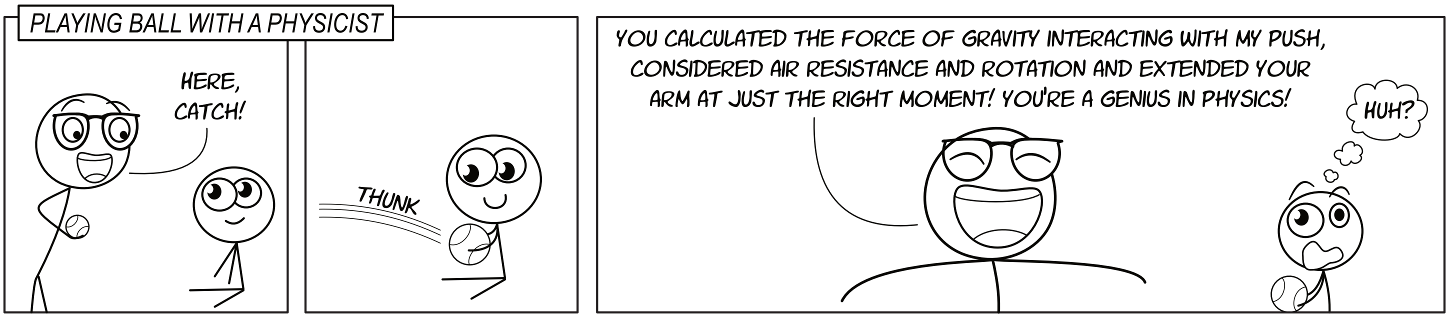
EXPERT:
A PERSON WHO HAS MADE ALL THE **MISTAKES** THAT CAN BE MADE IN A VERY NARROW FIELD.

-NIELS BOHR



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

MEASURING MOTION



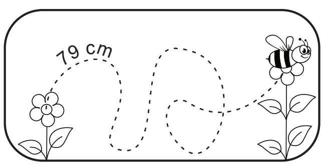
You already have a lot of experience with **mechanics**, the branch of physics that studies the motion of objects. Understanding vectors will help give you tools to make models and speak the language of physics!

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.

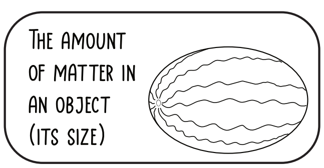
SCALARS VS VECTORS

SCALARS

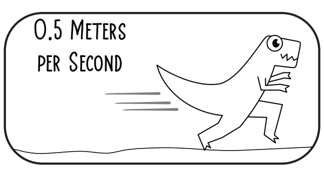
DEFINITION:
Any quantity that doesn't depend on direction.



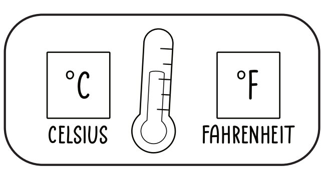
→ Distance



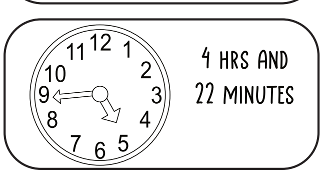
→ Mass



→ Speed



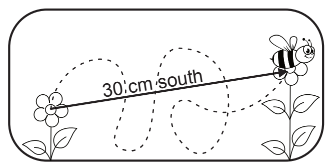
→ Temperature



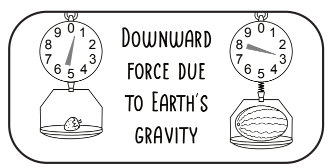
→ Time

VECTORS

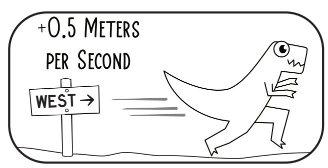
DEFINITION:
Any quantity that has both a magnitude and a direction



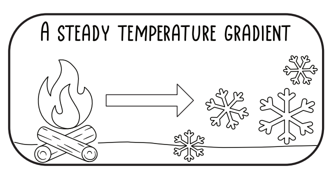
→ Displacement (total change in position – includes direction)



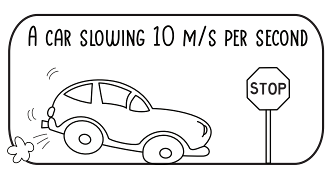
→ Weight



→ Velocity



→ Temperature gradient



→ Acceleration

FILL IN THE BLANKS:

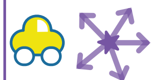
vector	magnitude	direction	scalar

In physics, the size or measurement of something is called its magnitude. A quantity that tells us the magnitude but NOT the direction is called a scalar quantity. Often, we need to know both measurement AND direction. 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 vector 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

This one could also be interpreted as NOT being a vector.

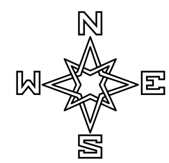


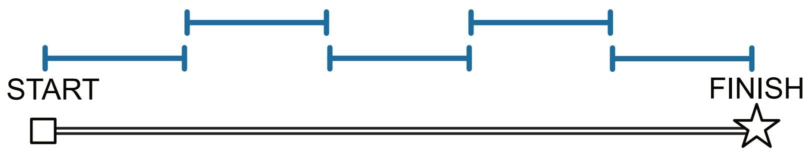
5 ft/s east (tells you position, but speed could be going in any direction from that position)

5 ft/s eastward (speed with direction)

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.

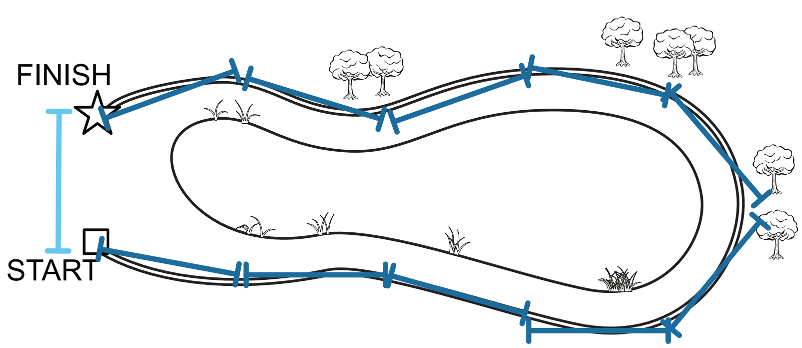
1 km





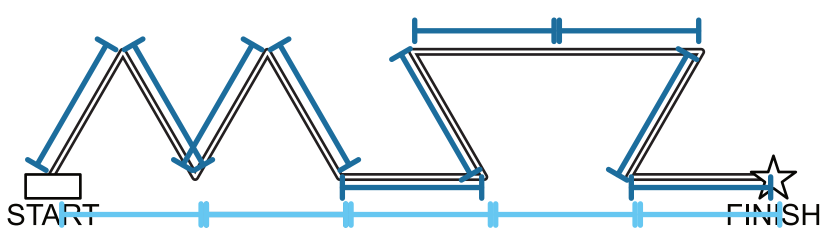
Distance: 5 km

Displacement: 5 km east



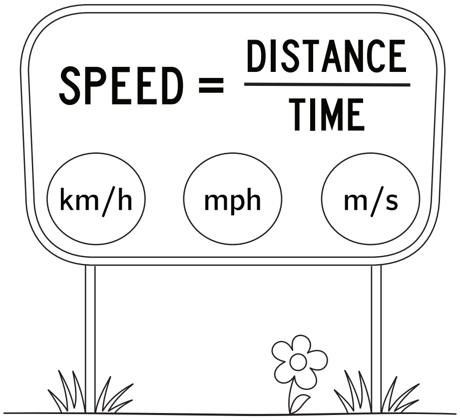
Distance: 10 km

Displacement: 1 km north

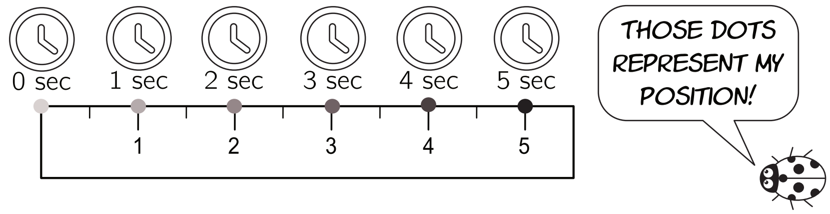


Distance: 10 km

Displacement: 5 km east

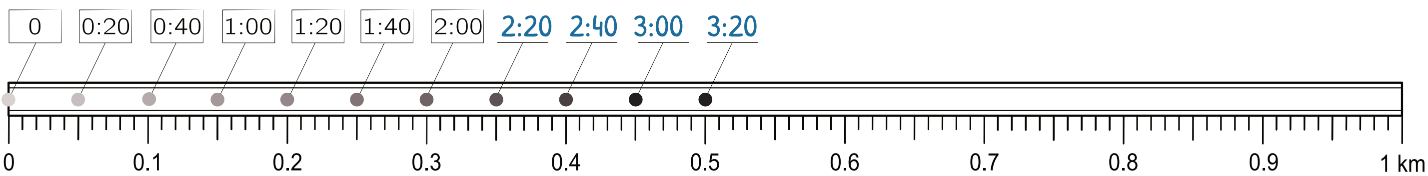


When we know the distance traveled and how much time it took, we can calculate how fast an object was moving, or its **speed**. The ladybug on the ruler moved 5 cm in 5 seconds, so its speed is 5 cm/5 seconds or 1 cm/s.



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!

They ran 0.5 km.

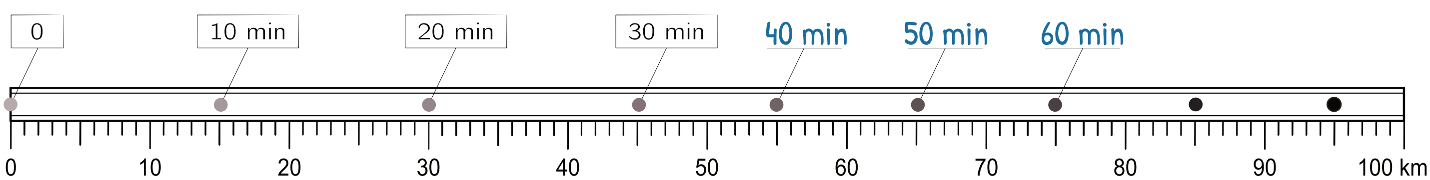
How fast did they run? (Answer in km/hr) Distance divided by time can be calculated a few different ways:

$\frac{0.15 \text{ km}}{1 \text{ min}} \cdot \frac{60 \text{ min}}{1 \text{ h}} = 9 \frac{\text{km}}{\text{h}}$ OR $\frac{0.3 \text{ km}}{2 \text{ min}} \cdot \frac{60 \text{ min}}{1 \text{ h}} = 9 \text{ km/hr}$

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

$1 \text{ km} = 1 \text{ km} \cdot \frac{1 \text{ h}}{9 \text{ km}} \cdot \frac{60 \text{ min}}{1 \text{ h}} = 6\frac{2}{3} \text{ min}$

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?

The car drove 45 km in 30 min, so its speed was $\frac{45 \text{ km}}{30 \text{ min}} \cdot \frac{60 \text{ min}}{1 \text{ h}} = 90 \frac{\text{km}}{\text{h}}$.

When did the car slow down?

The car slowed down at the 30 minute (45 km) mark because all the subsequent dots are closer together.

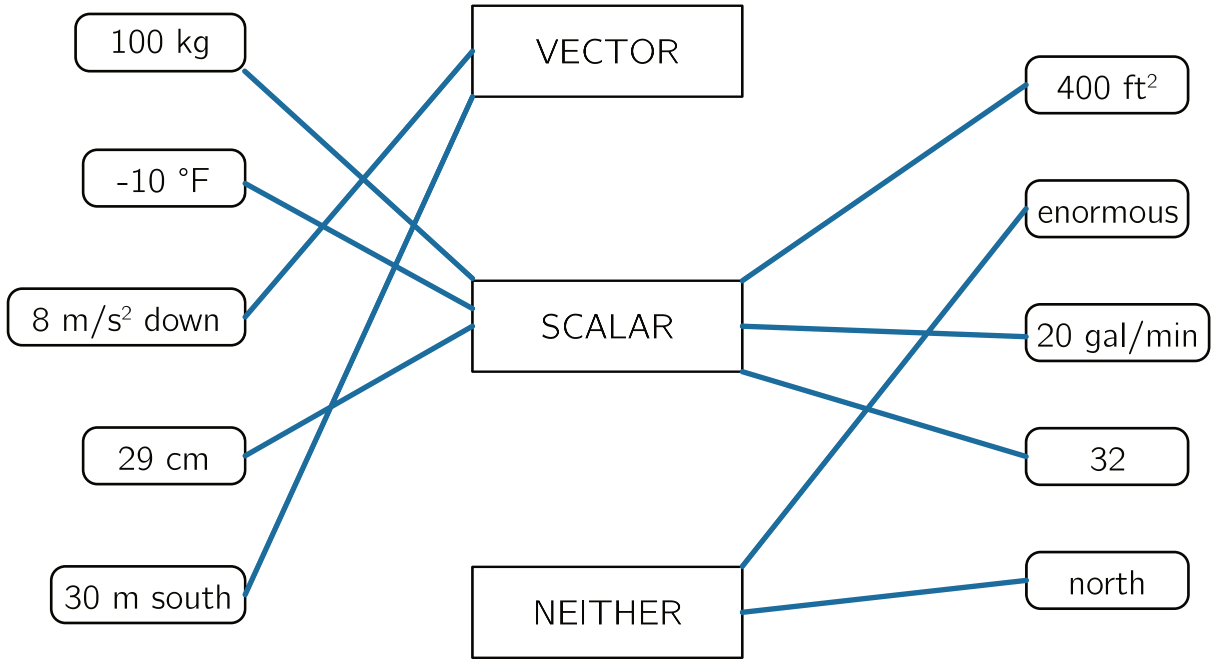
How long did it take the car to reach the 75 km mark?

It took 60 minutes to reach 75 km.

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.

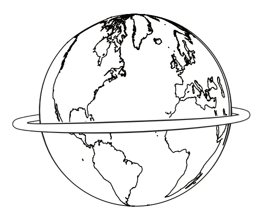


Measure this motion:

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?

   Relative to the Earth, Eli's displacement is 0 m.

   (Relative to the sun, Eli has a much larger 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?

   Distance is more useful. They don't care about the net distance. They only care about the total distance they have traveled.

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

   200 mi / 4 h = 50 mi/h.

(4) A car is driving on a freeway at a speed of 100 km/h.

A. How far does the car travel in 1 min?

$$1 \text{ min} = 1 \text{ min} \cdot \frac{1 \text{ h}}{60 \text{ min}} \cdot \frac{100 \text{ km}}{1 \text{ h}} = 1.\overline{6} \text{ km}$$

B. A blink lasts for about 0.3 s. How many meters does the car travel while the driver blinks?

$$0.3 \text{ s} = 0.3 \text{ s} \cdot \frac{1 \text{ min}}{60 \text{ s}} \cdot \frac{1 \text{ h}}{60 \text{ min}} \cdot \frac{100 \text{ km}}{1 \text{ h}} \cdot \frac{1000 \text{ m}}{1 \text{ km}} = 8.\overline{3} \text{ m}$$

(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*.

The formula $d = rt$ can be rearranged to read: $r = \frac{d}{t}$, and $t = \frac{d}{r}$

(6) On her bike, Jade travels *n* miles north and then turns around and travels *s* miles south.

A. Use *s* and *n* to write an expression that shows how far Jade traveled.

The total distance Jade travels can be written as:

$d = n + s$

B. If Jade travels directly north and then turns around and travels directly south, will her **displacement** be the same as the total **distance** traveled?

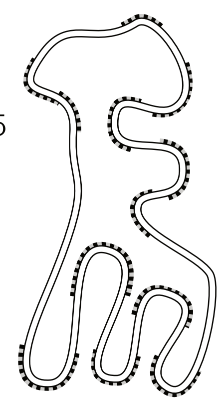
No. The displacement is the difference between starting end ending position. It's a vector so it will be + or – depending on direction. Calculate displacement by $n - s$ or $s - n$.

C. Calculate Jade's displacement when $n = 4$ and $s = 7$. Then write a sentence explaining what the calculation means.

If Jade traveled 4 miles north and then 7 miles south, her distance traveled was 11 miles. Displacement could be calculated either as miles north or miles south.

Jade's displacement is 3 miles south.

(7) A go-kart track has a length of 500 m.



A. What is the average speed in m/s of a go-kart that completes 3 laps in 2.5 minutes?

$$\frac{3 \text{ laps}}{2.5 \text{ min}} \cdot \frac{500 \text{ m}}{1 \text{ lap}} \cdot \frac{1 \text{ min}}{60 \text{ s}} = 10 \frac{\text{m}}{\text{s}}.$$

B. How many laps would be completed in 4 minutes at an average speed of 8 m/s?

$$4 \text{ min} \cdot \frac{60 \text{ s}}{1 \text{ min}} \cdot \frac{8 \text{ m}}{1 \text{ s}} \cdot \frac{1 \text{ lap}}{500 \text{ m}} = 3.84 \text{ laps}.$$

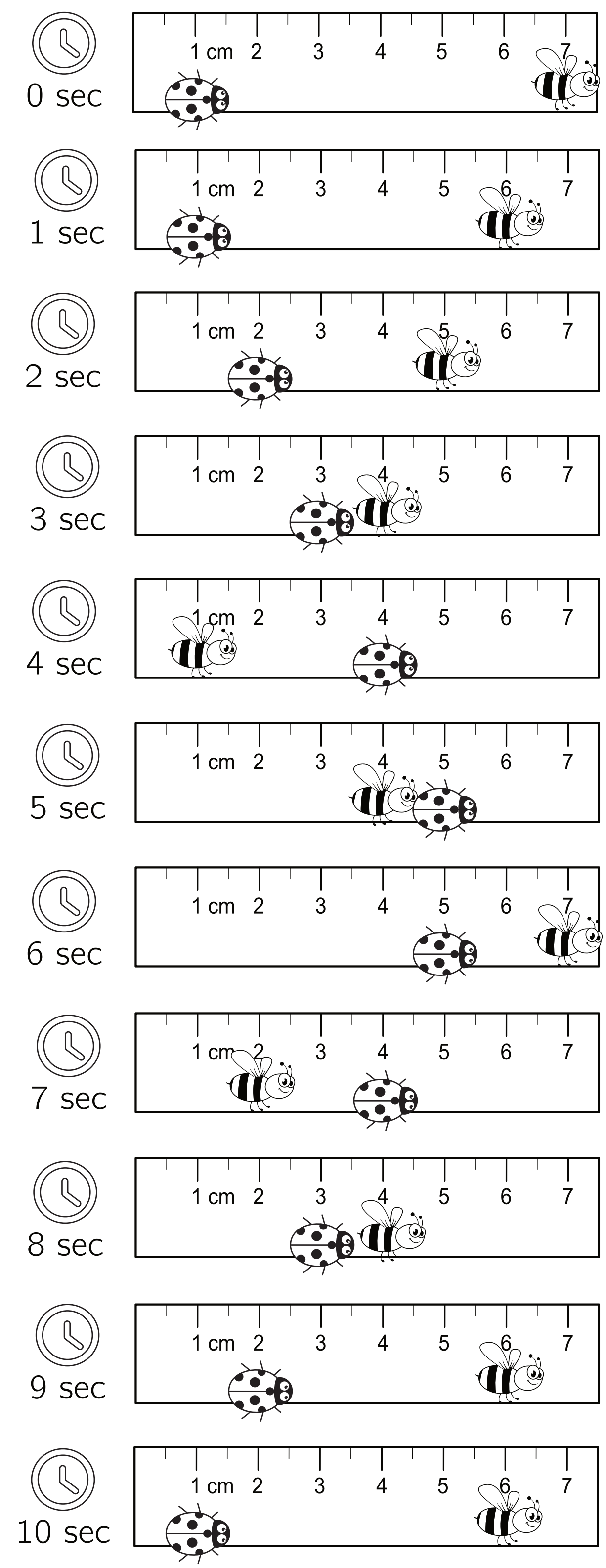
C. What is the displacement for a go-kart that has completed 7 complete laps?

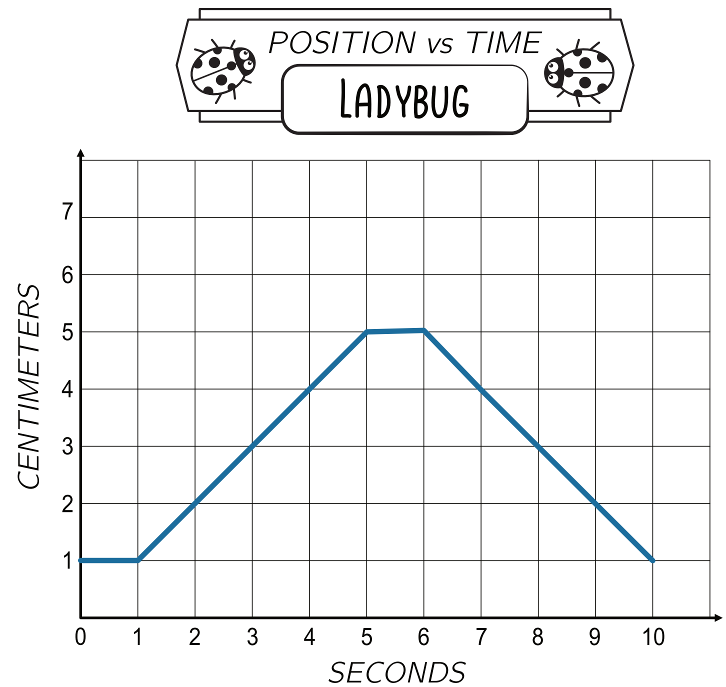
After the go-kart completes each lap, its displacement is 0 m.

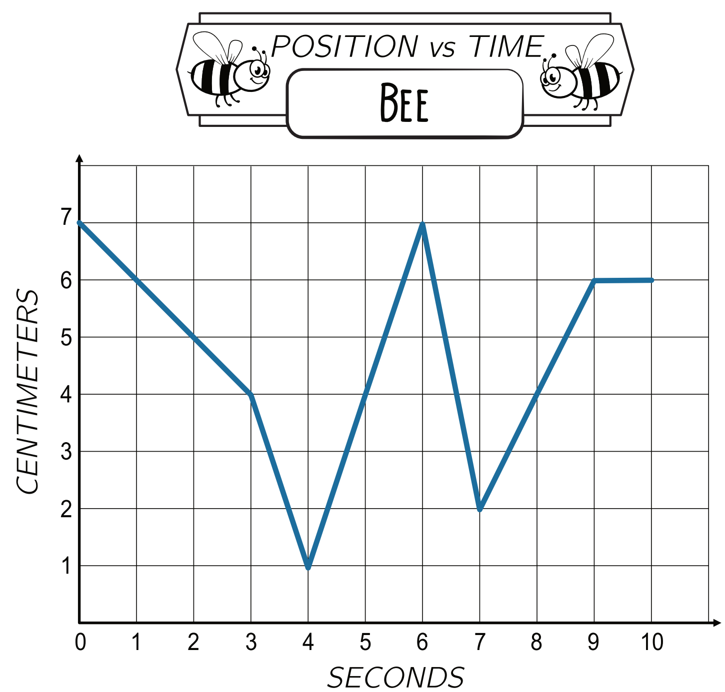
Graphing Motion

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.

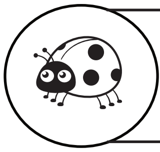
Graph the movement of the bee and ladybug below with **position** on the **vertical axis** and **time** on the **horizontal axis**.

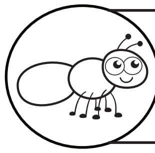


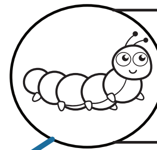




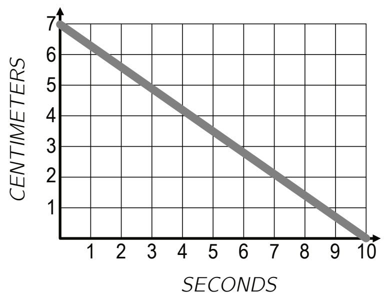
Match the time/position graph with the correct insect:


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

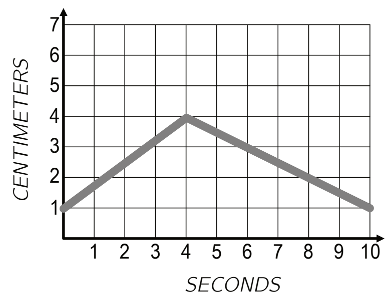

An ant travels to 3 cm and rests for 5 seconds before going forward to the 7 cm mark.


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

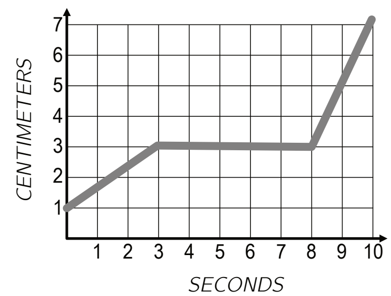
Graph 1



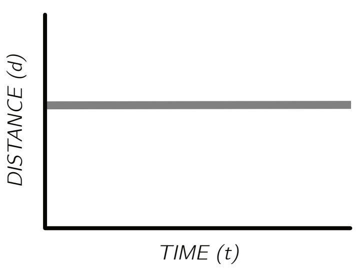
Graph 2



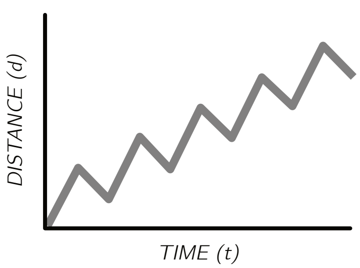
Graph 3



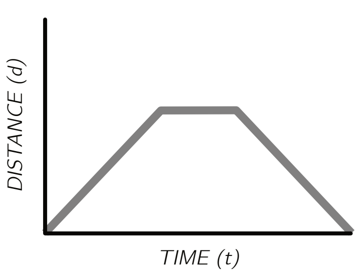
The graphs below represent the position of 3 birds on the ruler. Write a sentence or two describing what each bird is doing.



The bird didn't move at all. It stayed exactly where it started.



The bird started at the left end of the ruler. Then it kept repeating 2 steps right, 1 step left

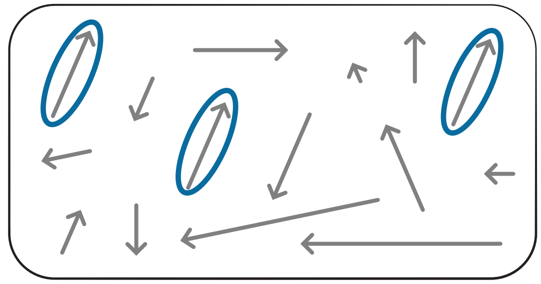


The bird started at the left end of the ruler. It walked at a uniform pace to the a little past the center of the ruler, waited a bit, and then traveled back to the left end at a uniform pace.

PLOTTING VECTORS

VECTORS have both magnitude and direction

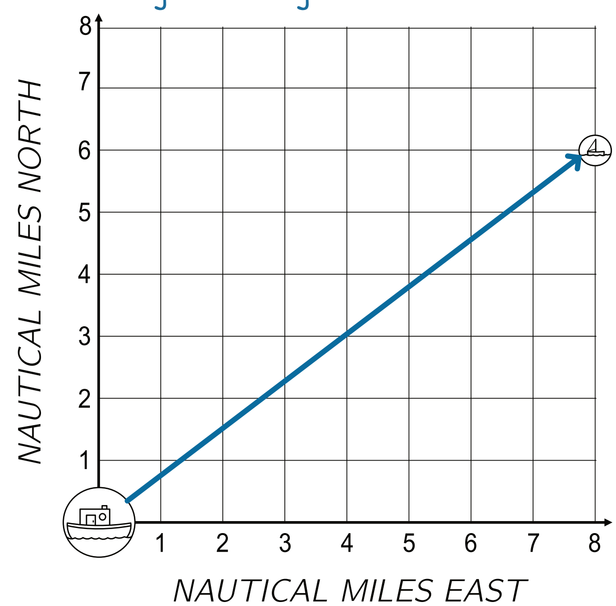
Vector quantities are often represented by an arrow. Identify the vectors that are the same.



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

VECTOR A *d* = 10 miles 8 mi E, 6 mi N (8,6)	**VECTOR B** *d* = 10 miles 8 mi W, 6 mi S (-8,-6)	**VECTOR C** *d* = 10 miles 6 mi E, 8 mi N (6,8)
VECTOR D *d* = 5 miles 4 mi E, 3mi N (4,3)	**VECTOR E** *d* = 10 miles 10 mi N (0,10)	**VECTOR F** *d* = 17 miles 15 mi E, 8 mi N (15,8)

Vector A will guide the big boat to the small boat



Which vectors have the correct magnitude but the wrong direction?

Vectors B, C and E

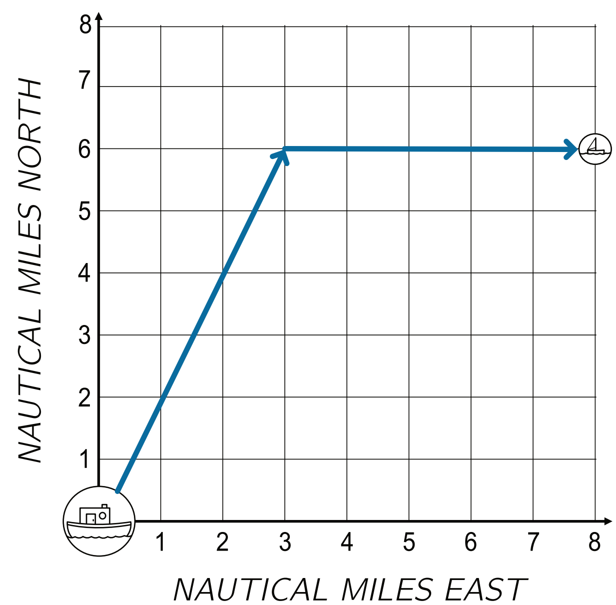
Which vectors have the correct direction but the wrong magnitude?

Vector D

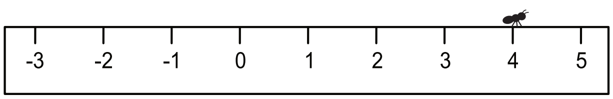
Identify 2 or more vectors that the Coast Guard could combine to reach the boat.

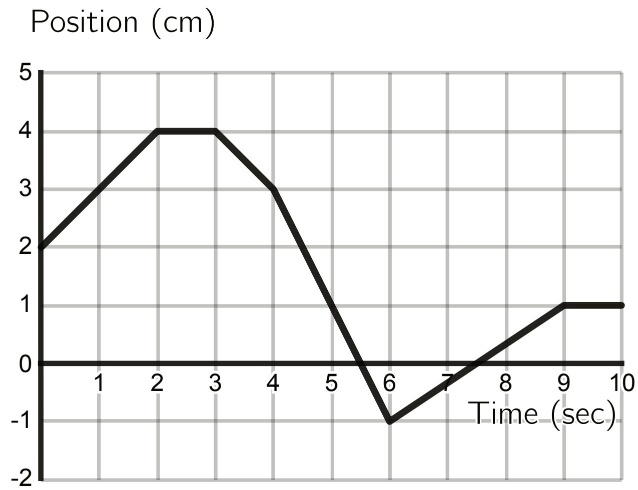
There are many possible correct answers. Any sequence of arrows that starts at (0,0) and ends at (8,6) will work.

One possible answer is to use the vectors ⟨3,6⟩ and ⟨5,0⟩.



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?

   Started at the 2 cm mark

2. When was ant at rest?

   The flat lines are from 2 s to 3 s and from 9 s to 10 s

3. When was the ant crawling to the right?

   Position was increasing from 0 s to 2 s and from 6 s to 9 s.

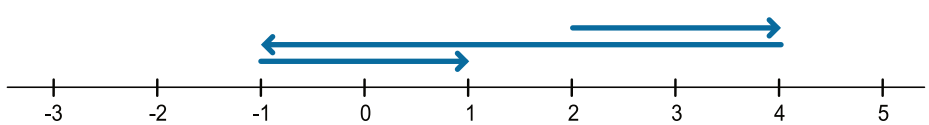
4. When was the ant at the 1 cm mark?

   -At 5 s and for the interval from 9s to 10 s.

5. When was the ant traveling fastest?

   Slope is steepest from 4 s to 6 s.

6. Use the number line to trace the path of the ant from start (0 seconds) to finish (10s)

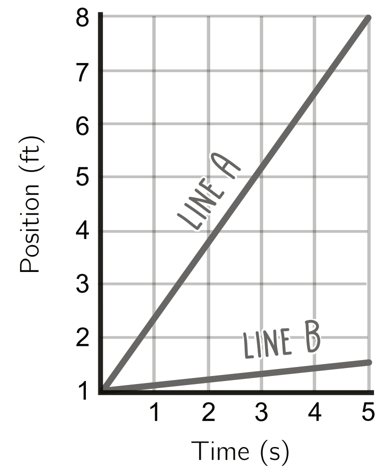


7. Write a short narration explaining the meaning of the graph. How would you explain the ant's motion it to a person who couldn't see the graph?

   The ant started at the 2 cm mark. Over the first two seconds it walked to the 4 cm mark where it waited one full second. From 3s to 4 s, it turned back around and walked to the 3 cm mark. Then it sped up from 4 s to 6 s and walked to the -1 cm mark. It abruptly turned around and walked slowly from 6 s to 9 s to the 1 cm mark where it stood still.

8 FAST OR SLOW?

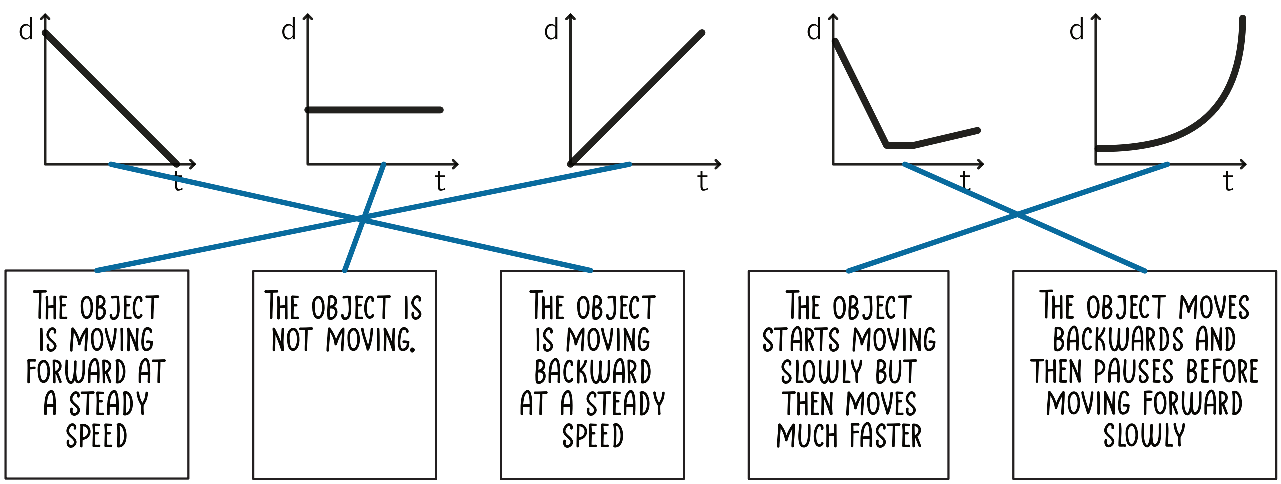
One of these lines represents the motion of a rabbit moving forward very quickly. The other is for a tortoise moving slowly. Which is which and how can you tell?



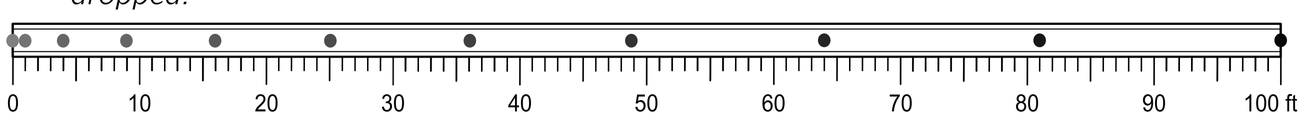
Line A is the rabbit, and line B is the tortoise. The steeper slope of line A shows that more feet are traveled per second.

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.



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?

It takes almost 2 seconds for the rock to fall 60 feet (8 quarter seconds).

When was the rock falling slowest?

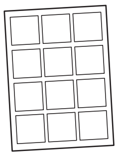
The rock was falling slowest as it was dropped and then it sped up.

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

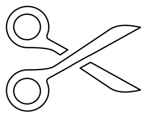
It fell from 16 ft to 64 ft. $\text{avg} = \frac{\Delta \text{ft}}{\Delta \text{s}} = \frac{64\text{ ft} - 16\text{ ft}}{2\text{ s} - 1\text{ s}} = 48\ \frac{\text{ft}}{\text{s}}$

PHYSICS VOCAB MEMORY GAME

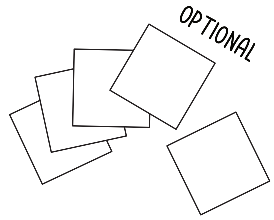
MATERIALS



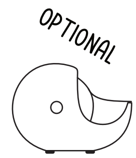
The printable memory cards



scissors



72 pieces of cardboard cut to 2.5" squares



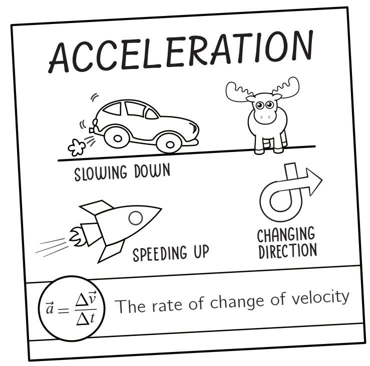
glue or tape

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.

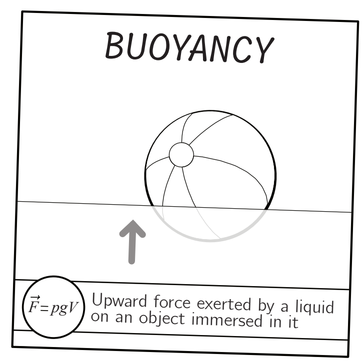


HOW TO PLAY:

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.



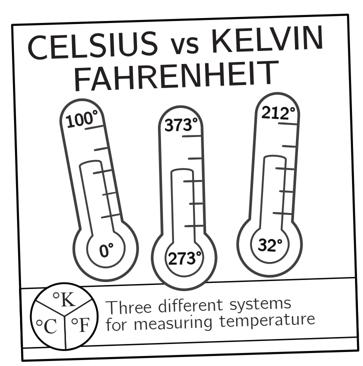
When a player turns over two cards that do not match, those cards are turned face down again (in the same position) and it becomes the next player's turn. Continue playing until all of the cards have been paired. The person with the most pairs at the end of the game wins.

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."

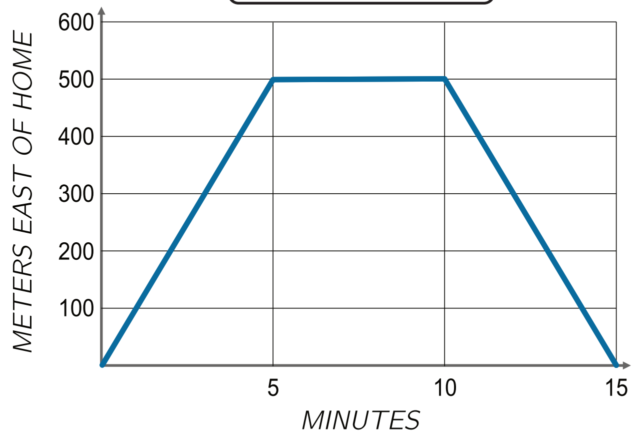


VELOCITY

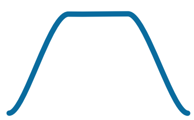
Velocity is the speed of something in a given direction. The box below describes a dinosaur's activity over 15 minutes. Use that information to plot the dinosaur's motion on the position/time graph. Then calculate its speed and velocity for each interval.

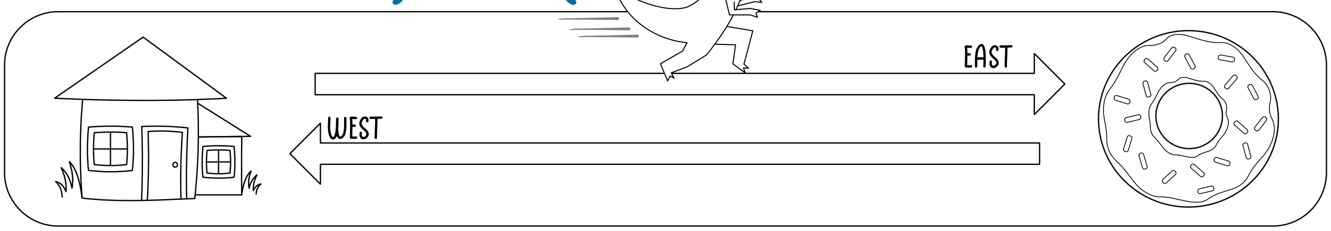
0-5 min	The dinosaur runs to a donut shop 500 meters east of his home.
5-10 min	At the donut shop, the dinosaur eats 1 donut.
10-15 min	The dinosaur runs 500 meters to return back home.

POSITION VS TIME



More realistically, the lines wouldn't be perfectly straight.





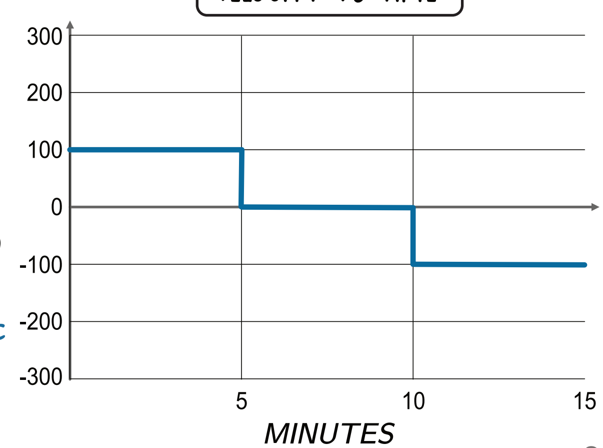
WHAT WERE THE SPEED AND VELOCITY OF THE DINOSAUR DURING EACH INTERVAL?

Interval 1	0-5 min	speed: 100 m/min	velocity: 100 m/min east
Interval 2	5-10 min	speed: 0 m/min	velocity: 0 m/min east
Interval 3	10-15 min	speed: 100 m/min	velocity: 100 m/min west or (-100 m/min east)

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

VELOCITY VS TIME

VELOCITY
(METERS PER MINUTE WHILE TRAVELING EAST)



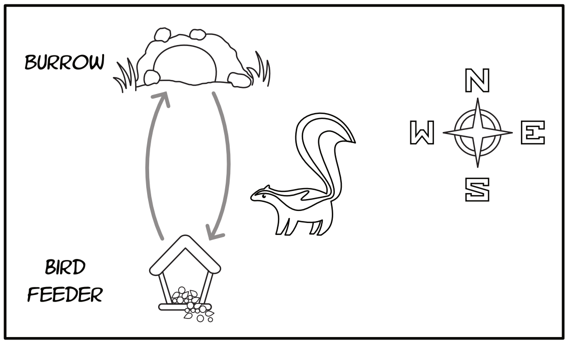
CAN A VELOCITY BE NEGATIVE?

YES!

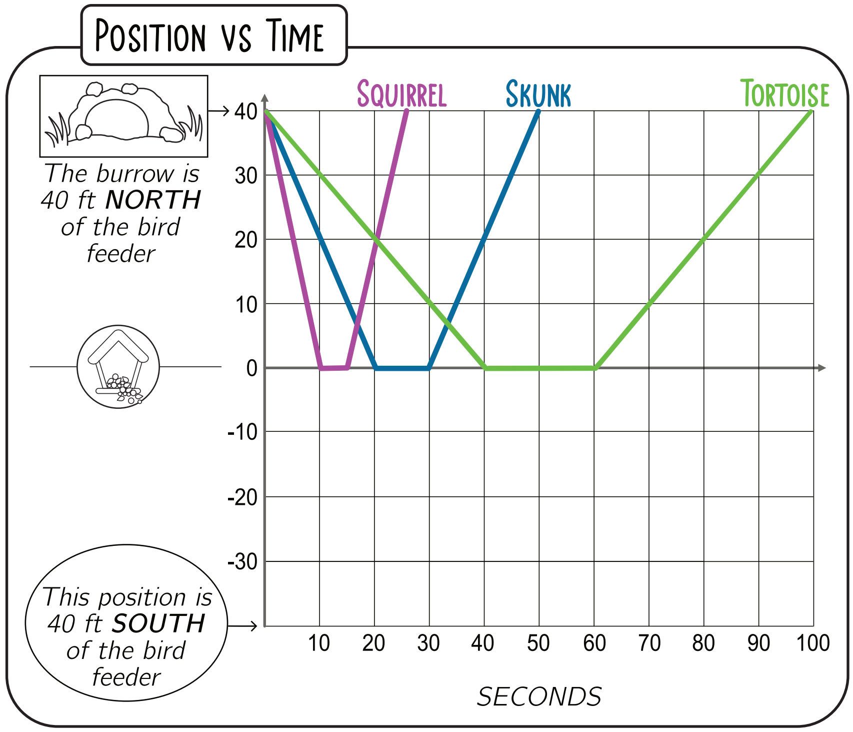
Positive and negative can be used to show direction, just like east and west or up and down!

It takes time to speed up, so a more realistic shape would be:

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.



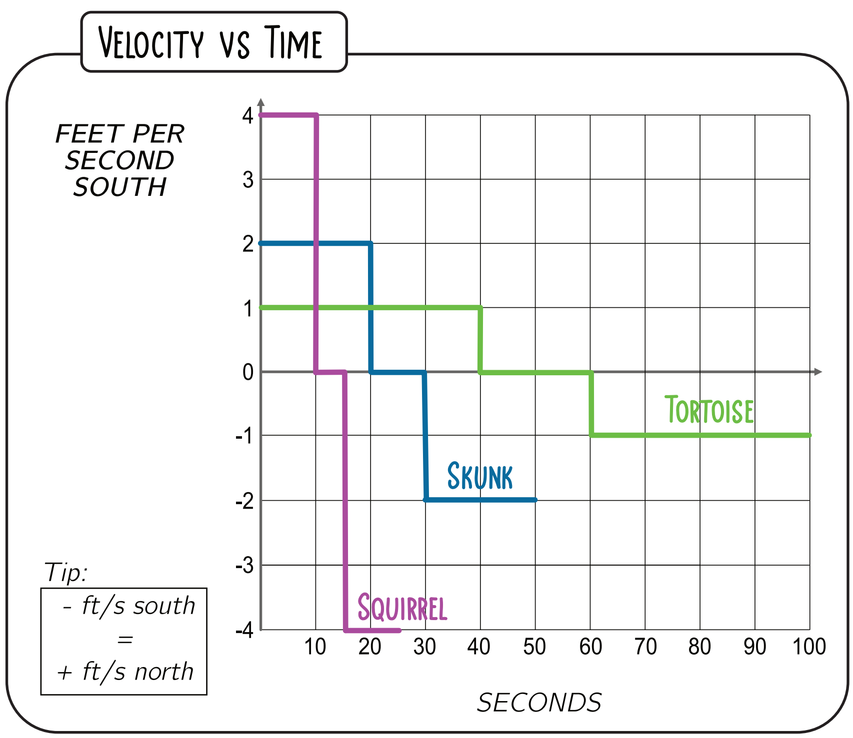
When the skunk is traveling at 2 ft/s toward the bird feeder, which direction is it going? (circle the answer)

2 ft/s south or 2 ft/s north

Velocity traveling toward feeder (0-20 s): 2 ft/s South (-2 ft/s N)

Velocity at feeder (20-30 s): 0 ft/s

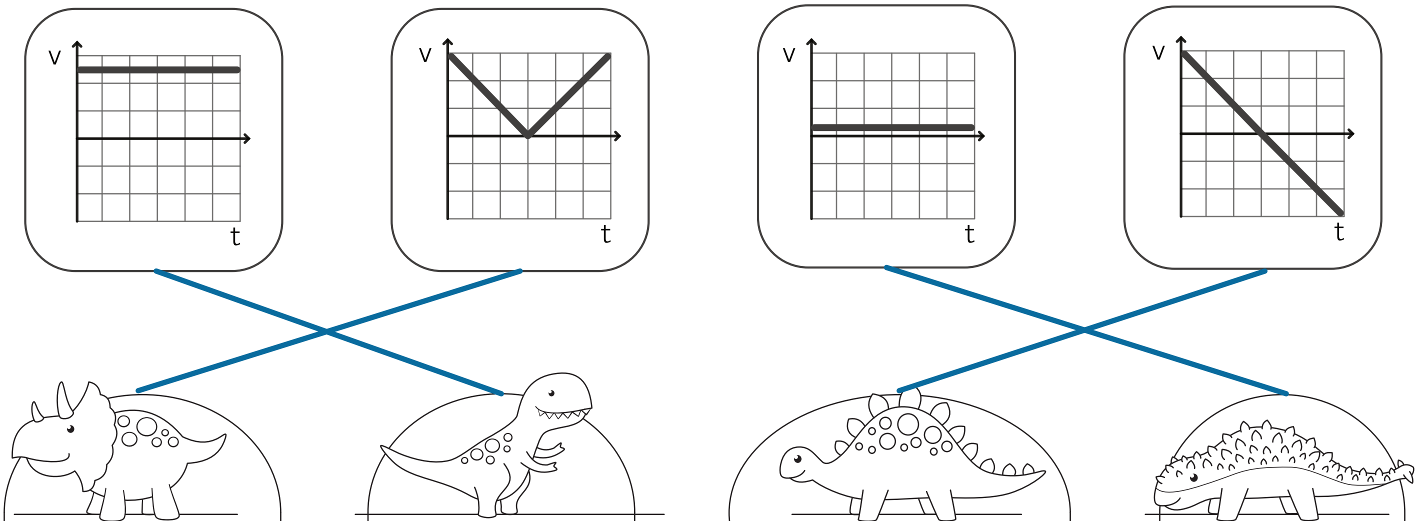
Velocity traveling away from feeder (30-50 s): 2 ft/s North (-2 ft/s S)



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.



The triceratops starts out running but then slows to a stop before steadily speeding up again.

The tyrannosaur runs to the donut shop, keeping the same speed all the way there.

The stegosaurus starts out running but then slows to a stop before turning around and going back in the opposite direction.

The ankylosaurus walks to the donut shop at a steady and consistently slow pace.

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.

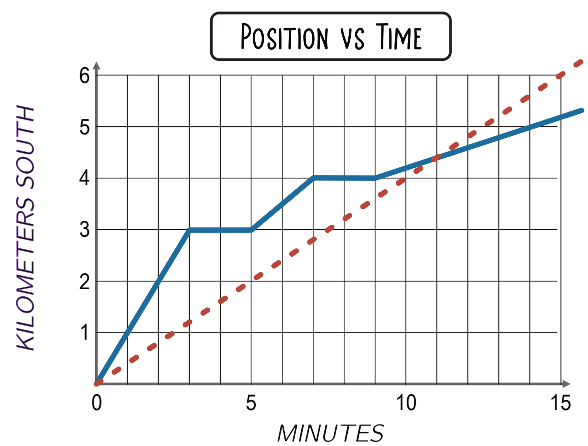
The donut truck

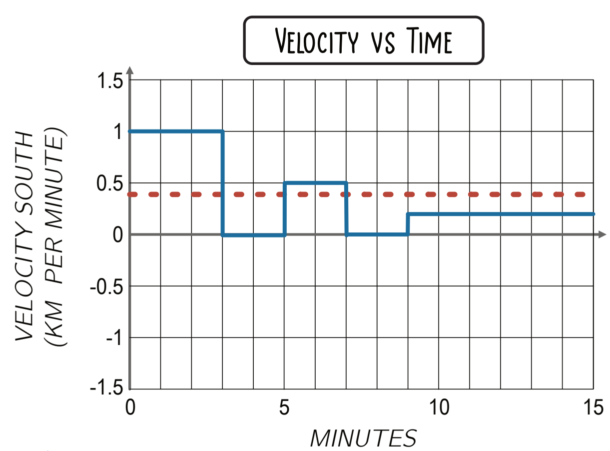
- drives for 3 minutes at 60 km/h,
- stops for 2 minutes,
- drives 30 km/h for 2 minutes,
- stops for 2 minutes, and
- drives 12 km/h after that.

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.





At the 11 minute mark, the dinosaur catches the donut truck.

Practice Problems – Velocity

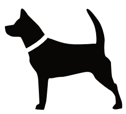
① A car travels 240 km north in 3 hours. What is the average velocity of the car?

$$\frac{240\text{ km}}{3\text{ h}} = 80\text{ km/h northward}$$

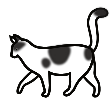
② A car travels west at 60 mi/h for 4 hours. What is the displacement of the car?

$$60\,\frac{\text{mi}}{\text{h}} \cdot 4\text{ h} = 240\text{ mi west}$$

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

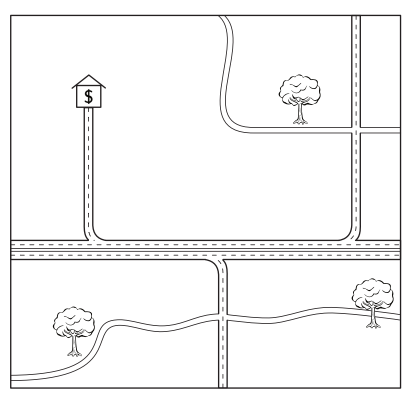
Carma
speed: 4 m/s

Abe will finish the race in the time it takes Carma to run her half of the race, so Abe will win.

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.

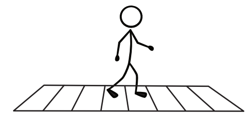
The police intercepted the note, and they are standing by with a helicopter. Explain to the police how the helicopter can find the location on a map.



The helicopter should travel from the bank in the direction of the vector ⟨21,−3⟩ (21 km east, 3 km south) to reach the tree.

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?



The total velocity is 12 ft/s east, but Sandy is only walking 7 ft/s east, so the rest of Sandy's speed must come from the sidewalk moving east at a rate of 5 ft/s.

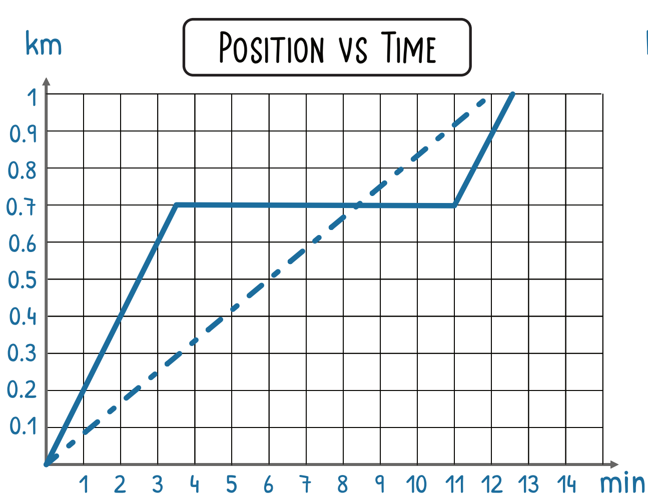
6. Bob jogs onto the east end of the moving sidewalk running at a velocity of 9 ft/s west. What will his new velocity be now that he is on the moving sidewalk.

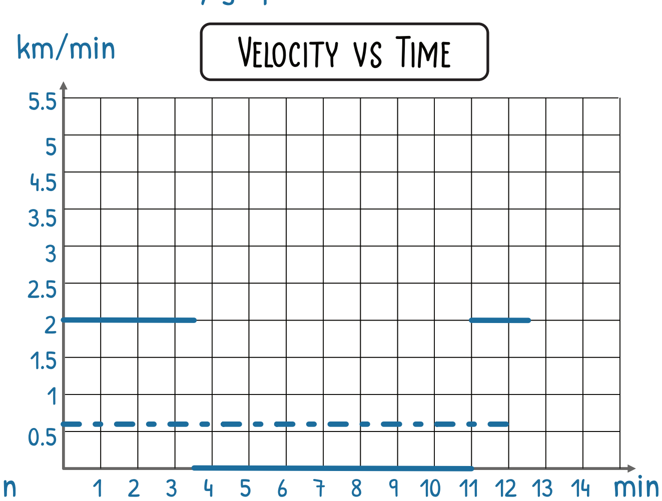
The westerly velocity is
Bob's walking velocity + sidewalk velocity = 9 ft/s + (-5) ft/s = 4 ft/s west.

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.

In a race, the confident Hare ran quickly at first. However, the hare stopped and took a nap shortly before the finish line (starting at 3.5 minutes). The slow but steady tortoise plodded along at a slow pace from start to finish. The hare woke up (at the 11 minute mark) and tried to catch the tortoise, but it was too late. The slow but steady tortoise won the race.

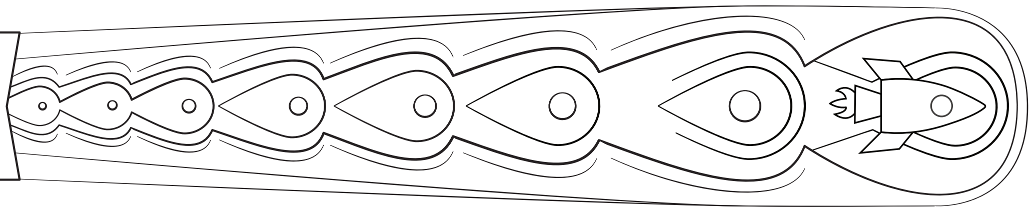
The slope of the position graph is the y-coordinate on the velocity graph.





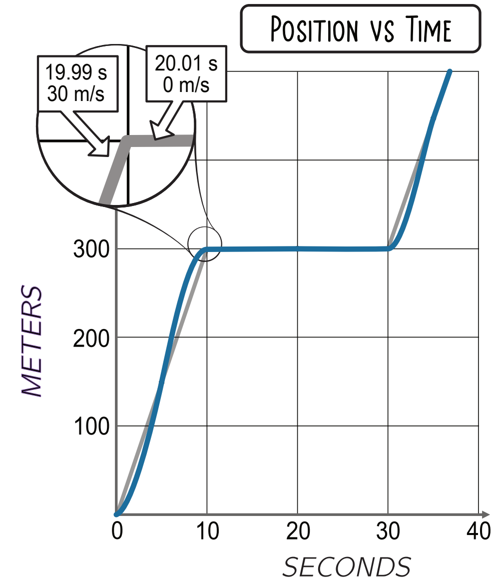
ACCELERATION

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?

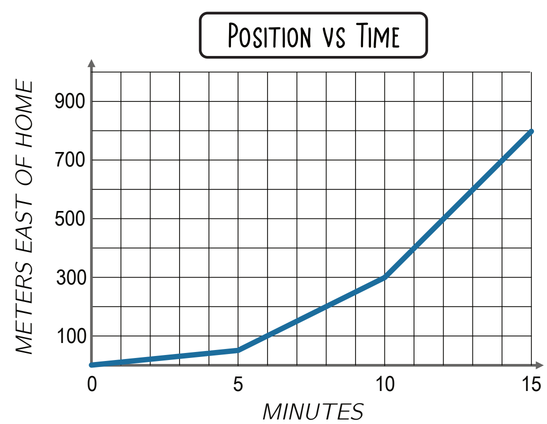
The graph shows "stops" and "starts" that happen in no time. Such abrupt changes would definitely injure the driver.



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

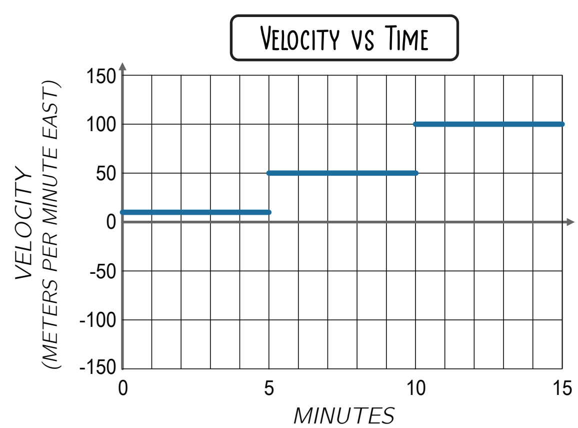
- A dinosaur started walking east from home while carrying two donuts. Its starting pace was 10 meters per minute.
- At 5 minutes, the dinosaur ate a donut and increased its speed to 50 meters per minute.
- At 10 minutes, the dinosaur ate another donut and increased its speed to 100 meters per minute.



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

The slope of the position graph is increasing. A "smile"-shaped position graph is where velocity is increasing.

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



VELOCITY VS ACCELERATION

Velocity is the rate of change of position or the rate of change of displacement.

Example Units: m/s, mi/h, km/h

Acceleration is the rate of change of velocity or the rate at which velocity is changing.

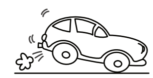
Example Units: m/s^2, (mi/h)/s, km/h^2

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

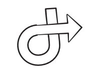
$$\frac{\Delta \vec{v}}{\Delta t} = \frac{60\frac{mi}{h} - 0\frac{mi}{h}}{3\ s} = 20\frac{\frac{mi}{h}}{s}.$$

$$\vec{A} = \frac{\Delta \vec{V}}{\Delta T}$$

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

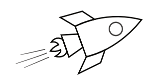

SLOWING DOWN

1. Brake pedal


CHANGING DIRECTION

2. Steering wheel

3. Gas pedal


SPEEDING UP

CHANGING SPEED 2

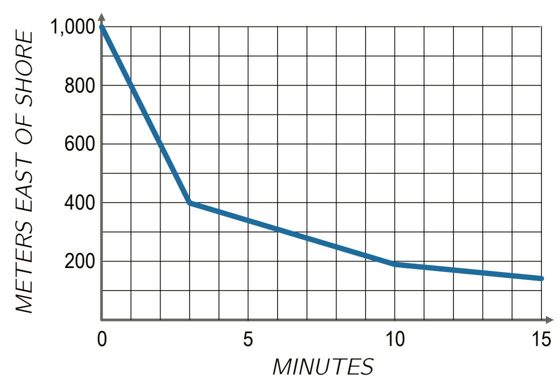
- A boat is 1,000 meters east of the shore and moving toward the shore at 200 meters per minute.
- After traveling for 3 minutes, it runs low on fuel. Its speed drops to 30 meters per minute.
- At 10 minutes the boat begins traveling with the currents toward shore at 10 meters per minute.

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

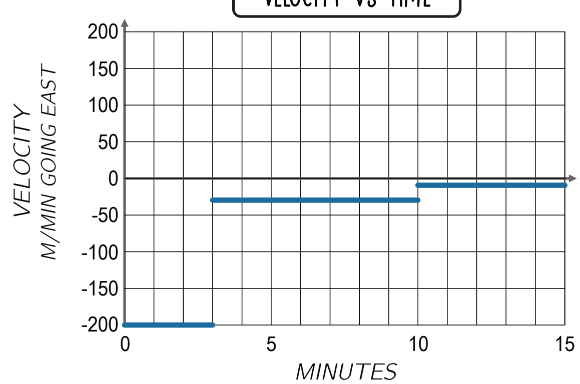
The boat is slowing down because the position graph starts with a steep slope and then gets more shallow.

Graph the velocity vs time for the boat.

POSITION VS TIME



VELOCITY VS TIME



1. Eliza runs 6 m/s for 12 seconds and then 2 m/s for 4 seconds? What was Eliza's average speed?

First find the distance using the formula: $d = r \cdot t$

First 12 s: $d = r \cdot t = 6\frac{m}{s} \cdot 12\,s = 72\,m$

Next 4 s: $d = r \cdot t = 2\frac{m}{s} \cdot 4\,s = 8\,m$

$$\text{speed} = \frac{\text{total distance}}{\text{total time}} = \frac{72\,m + 8\,m}{12\,s + 4\,s} = \frac{80\,m}{16\,s} = 5\frac{m}{s}$$

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?

$$\frac{\Delta\vec{v}}{\Delta t} = \frac{70\frac{km}{h} - 90\frac{km}{h}}{4\ s} = -5\frac{\frac{km}{h}}{s}.$$

Over that 4 second period, the car's velocity westward was decreasing at a rate of 5 km/h per second.

3. An object starts at rest and then accelerates 2 m/s^2 south for 10 seconds. What is its velocity after 10 seconds?

The car is gaining 2 m/s of velocity southward each second going from 0 m/s to 2 m/s to 4 m/s and so on until after 10 seconds, its southward velocity is 20 m/s.

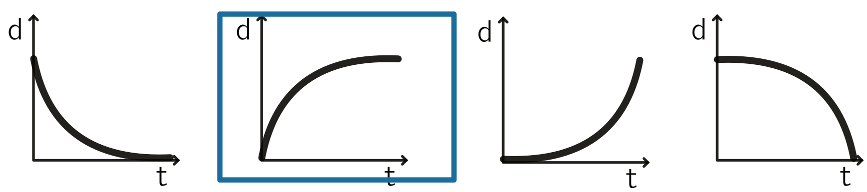
One could also find the missing value in the acceleration equation.

$$\frac{\Delta\vec{v}}{\Delta t} = \frac{2\frac{m}{s}}{s} = \frac{?\frac{m}{s} - 0\frac{km}{h}}{10\ s}.$$

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?

Each second, the bus loses 4 m/s, so it will take 5 seconds to drop from 20 m/s to 0 m/s.

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



The bus started faster (steeper slope) in the northward direction and slowed down (flatter slope).

5. Mark each statement as True or False.

T $\boxed{F}$ When speed is constant, there is no acceleration. Direction might change.

T $\boxed{F}$ When acceleration is constant, velocity is constant. See problems 3 and 4.

T $\boxed{F}$ An object's instantaneous velocity is always greater than its average velocity. Sometimes

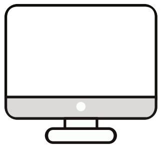
$\boxed{T}$ F A positive acceleration shows up on a position graph as a curve shaped like part of a smile (concave up).

$\boxed{T}$ F The slope of a velocity-vs-time graph shows an object's acceleration.

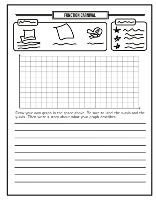
T $\boxed{F}$ If velocity increases from 5 ft/s to 12 ft/s, then acceleration is 7 ft/s. Only true if that increase happens over 1 second

FUNCTION CARNIVAL

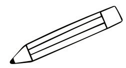
MATERIALS



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



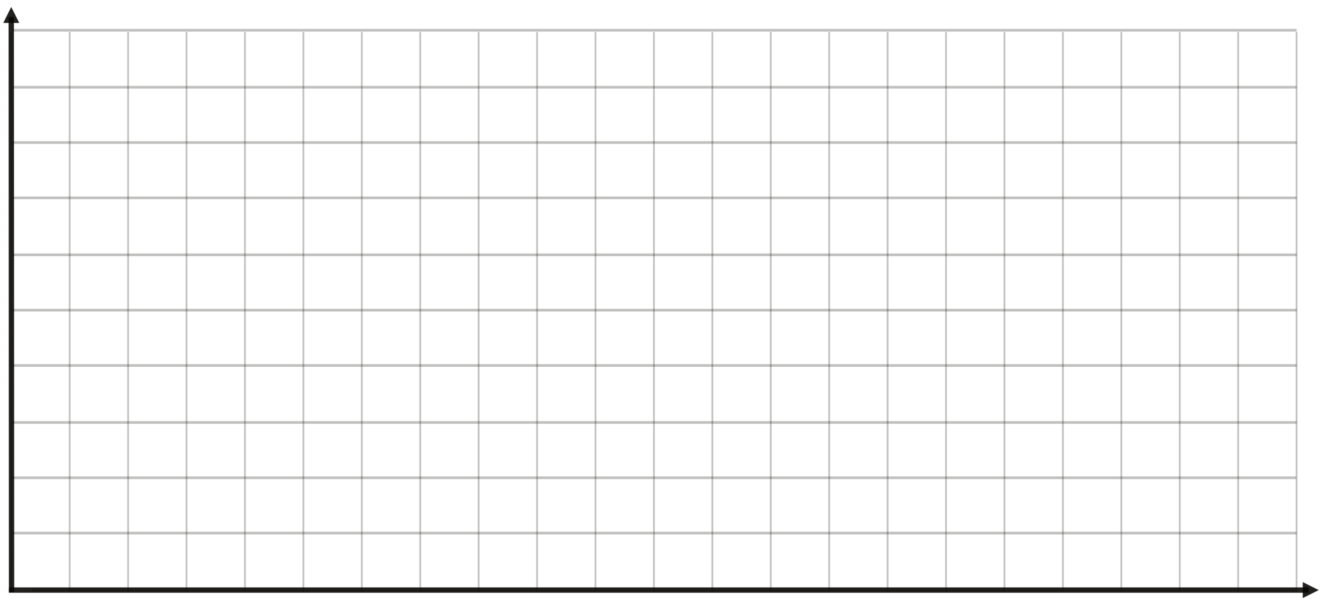
This worksheet



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.

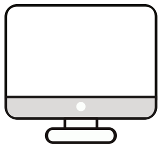


Draw your own graph that shows position vs time in the space above. Be sure to label the axes. Then write a story about what your graph describes.

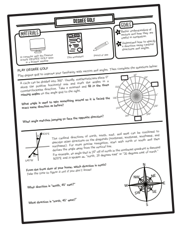
Answers will vary! The axes need to be labeled for the graph to be useful. The story should be compatible with the graph.

DEGREE GOLF

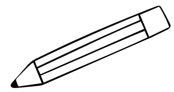
MATERIALS



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



This worksheet



Pencil or pen

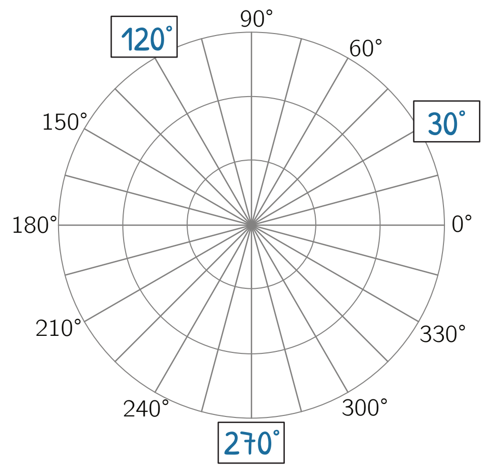
GOALS

- 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°. Usually, mathematicians place 0° 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.



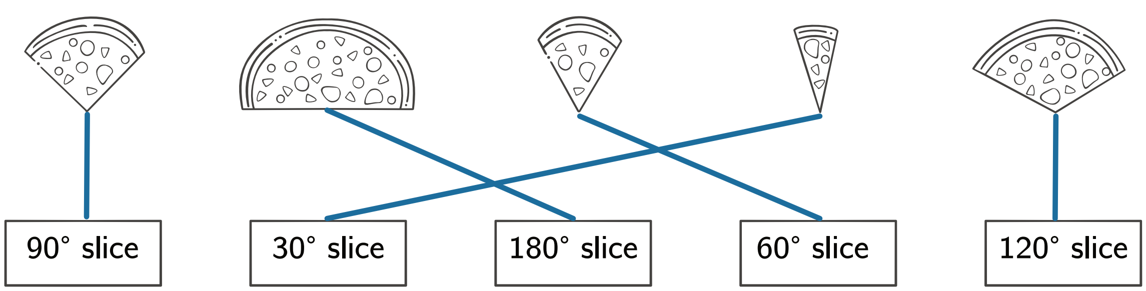
What angle is used to spin something around so it is facing the exact same direction as before?

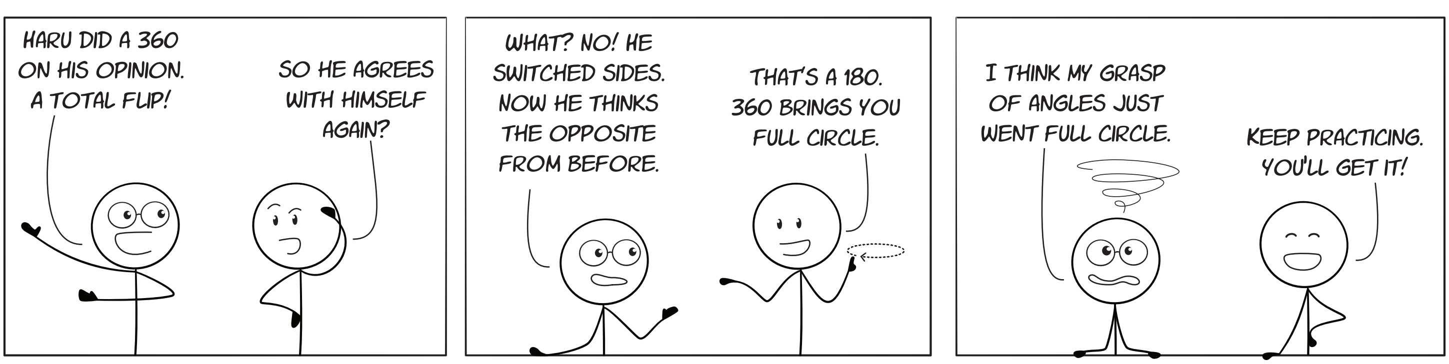
Any multiple of 360° will spin you back to the starting direction.

What angle matches jumping to face the opposite direction?

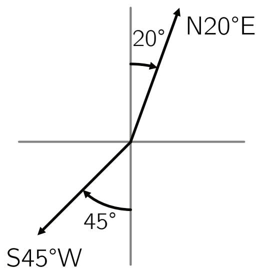
Jumping 180° reverses your direction.

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.





DEGREE GOLF

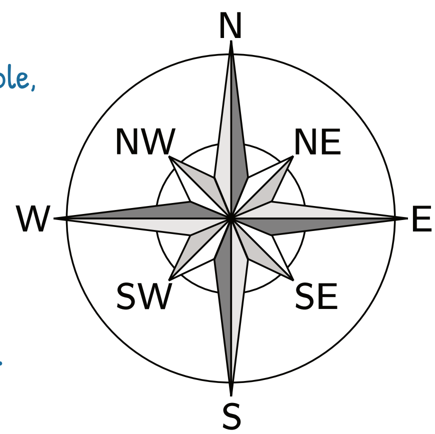


The cardinal directions of north, south, east, and west can be combined to describe other directions on the diagonals (northeast, southeast, southwest, and northwest). For more precise navigation, start with north or south and then declare the angle away from the vertical line.

For example, an angle that is 20° off of north in the northeast quadrant is denoted N20°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!

Observing the sunrise (due east) and sunset (due west) can be helpful. If possible, identify landmarks near home that align with one of the cardinal directions.



What direction is "south, 45° east?"

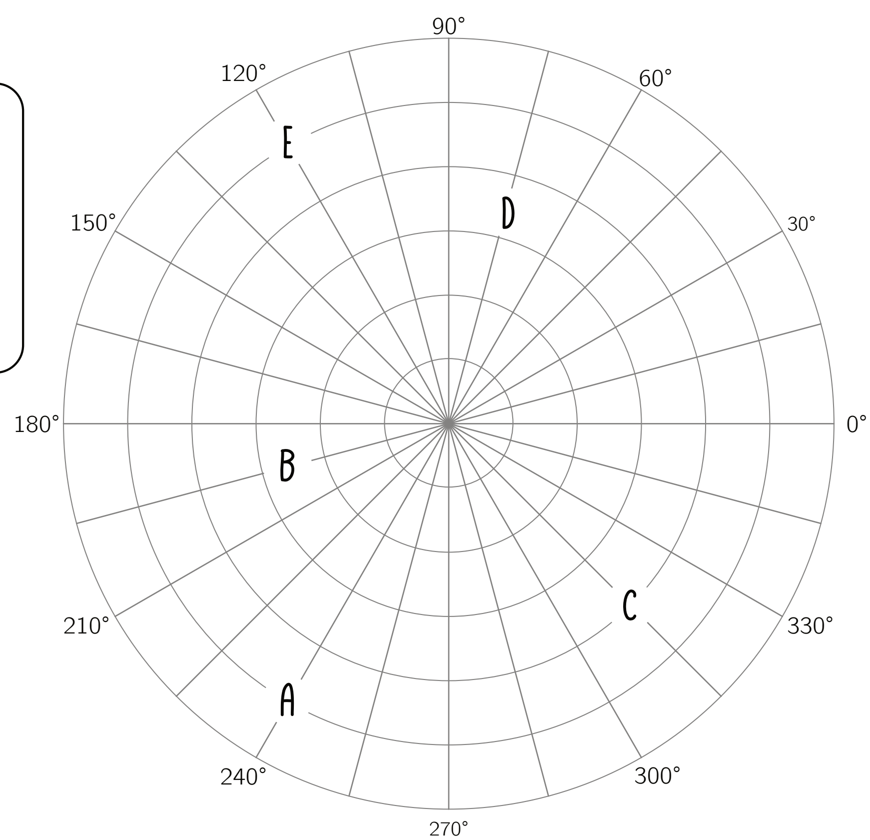
It's the same as southeast.

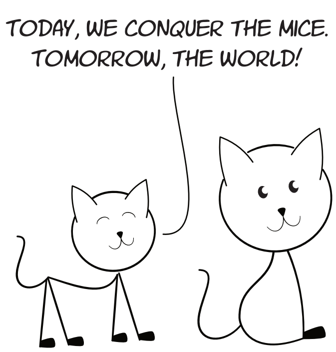
What direction is "north, 10° west?"

You might describe it as north-northwest. It's almost north but 10° to the 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° West
Heading for B: South 75° West
Heading for C: South 45° East
Heading for D: North 15° East
Heading for E: North 30° West



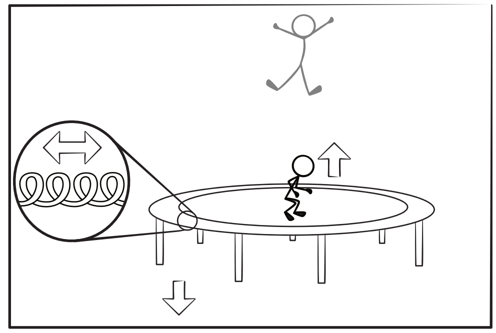


MOTION COMMOTION

ADDING VECTORS AND RELATIVE MOTION

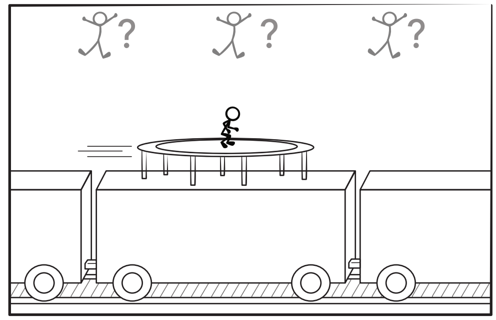
What forces are involved when Omar jumps on a trampoline? If he jumps straight up from the center of the trampoline, where will he land?

Gravity pulls Omar down, and Omar's gravity pulls the Earth up. Omar pushes on the trampoline mat when he lands, and the trampoline pushes back, transferring the energy of the springs back to Omar. Omar will land in the center of the trampoline.



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

Omar will land in the middle of the trampoline. He might be pushed a little toward the back of the train by air resistance, but at this speed, the air won't offer much resistance.



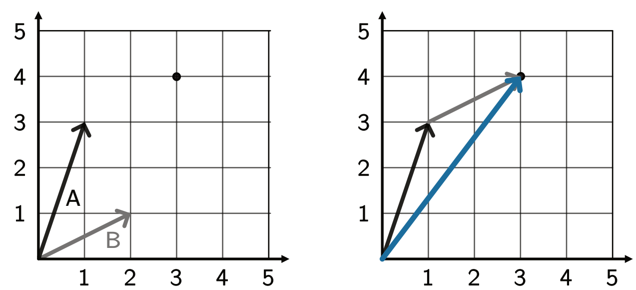
ADDING VECTORS

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

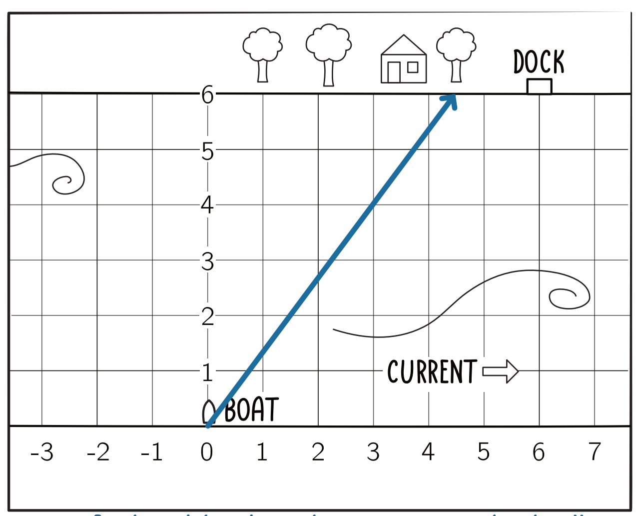
$$\vec{A} + \vec{B} = \langle 1,3 \rangle + \langle 2,1 \rangle$$
$$= \langle 3,4 \rangle$$

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?

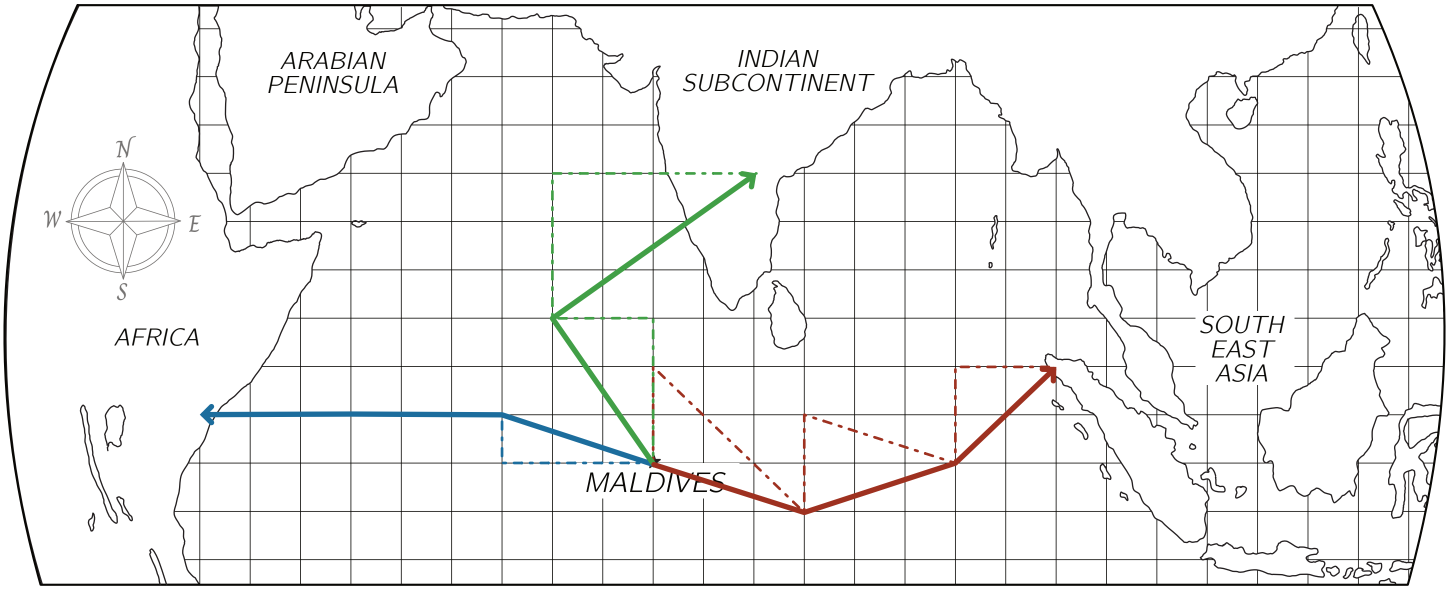
There are no units on the graph, but we can still use the slope to find the trajectory. For every 4 units up, the current will move the boat 3 units to the right. In other words, we move ¾ as far to the right as we move up, so the boat will land at the point (4.5,6) near the tree between the house and the dock.



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.*

The boat's speed will still be 4 ft/s, so for every foot up it goes 1.5 feet right. When it goes up 6 units it will go right 9 units, so we start 9 units to the left of 6 at the point (-3,0) to end at the dock.

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

   Nacho Boat lands in East Africa (perhaps Kenya or Tanzania) after three weeks.

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

   Boaty McBoatface ends up in Sumatra after three weeks.

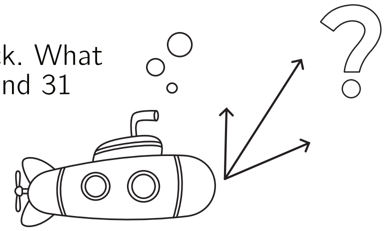
3. The ship **Seas the Day** sails directly north at 3 squares per week.
   Week 1: The wind blows 2 squares to the west
   Week 2: The wind blows 4 squares to the east
   Week 3: The wind blows 3 squares to the north

   Seas the Day will reach the west coast of India after about 11 days at sea.

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

   Week 1. Do nothing.
   Week 2. Sail 3 squares north.
   Week 3. Do nothing.

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?

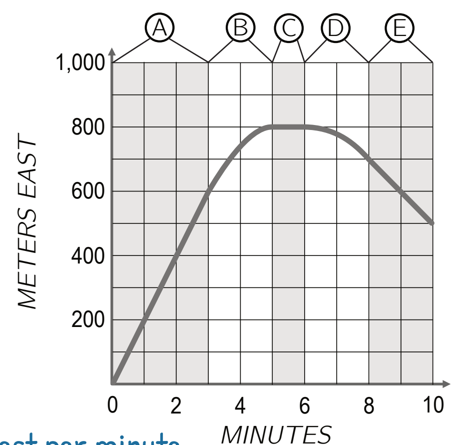
   It needs to go 10-(-6)=16 km north and 31-2=29 km east, so the direction vector in the plane is ⟨29,16⟩.

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?

   The net displacement by adding the vectors is 2 ft west.

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?

   The net velocity eastward is 600 km/h, so after 5 hours it has flown 3000 km. (That would place it near Knoxville Tennessee.)



Position vs Time

4. In this position vs time graph for a dinosaur, what is happening in section A?

   A. $\boxed{\text{The dinosaur moves east at 200 meters per minute.}}$
   B. The dinosaur moves west at 200 meters per minute.
   C. The dinosaur moves east at 100 meters per minute.
   D. The dinosaur moves west at 100 meters per minute.
   E. The dinosaur does not move.

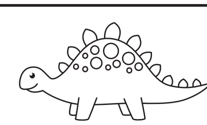
5. What is the dinosaur doing in sections C and E?

   In section C, the dinosaur is not moving east or west.

   In section E, the dinosaur is traveling at a rate of 100 meters west per minute.

6. In which section is the dinosaur moving west?

   The downward slope reveals that the dino is moving west in sections D and E.



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

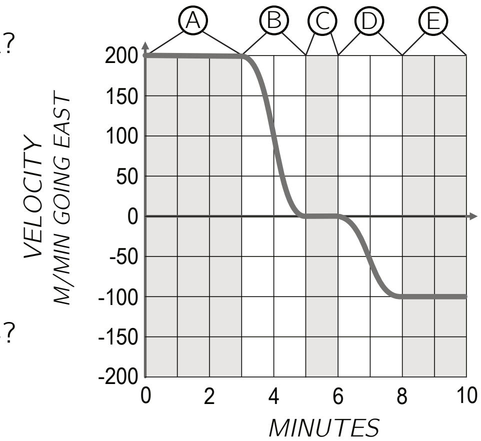
   Straight lines indicate constant speeds in sections A, C, and E.

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

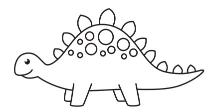
   Curved lines indicate changing speed in sections B and D.

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

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



Velocity vs Time



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

The slope of a position graph represents the velocity (rate of change of position).

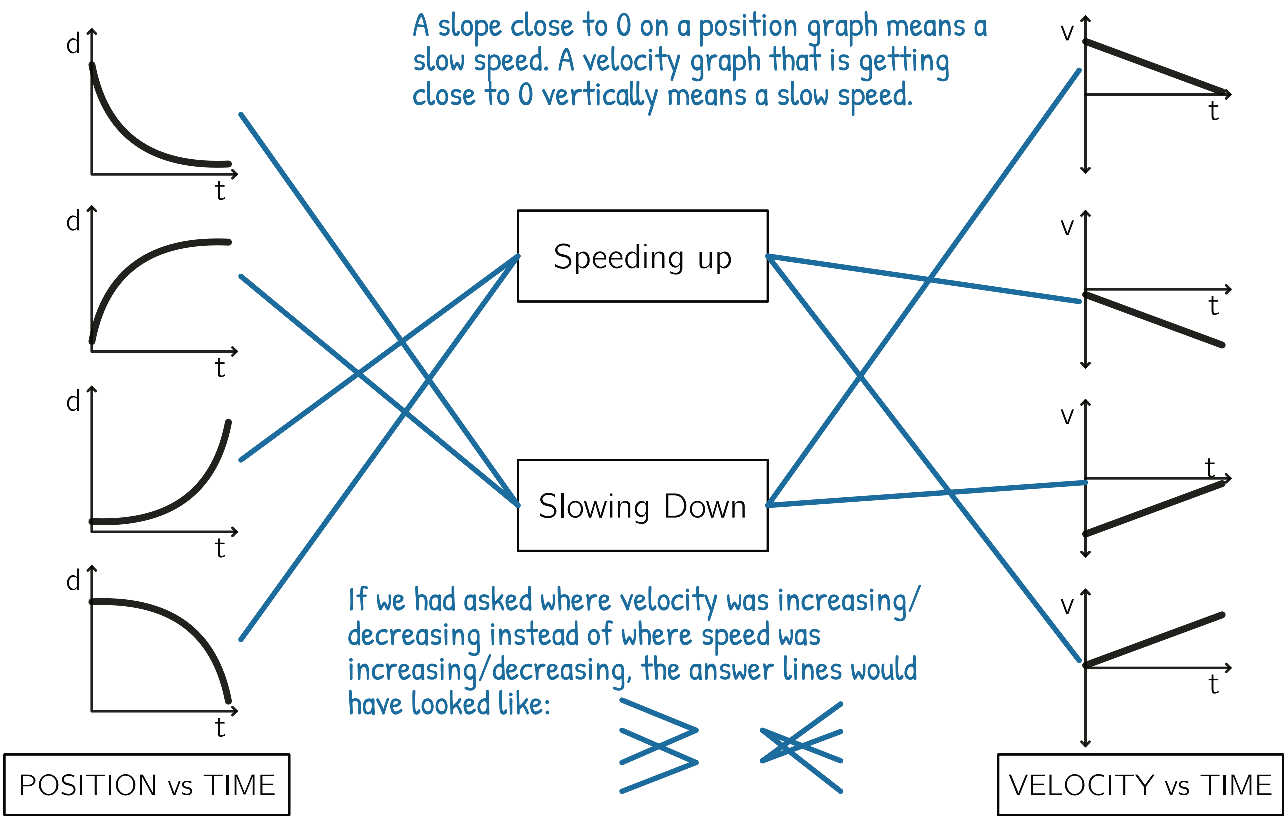
12. In a velocity vs time graph, what is the slope?

The slope of a velocity graph represents the acceleration (rate of change of velocity).

13. MATCHING GRAPHS:

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

A slope close to 0 on a position graph means a slow speed. A velocity graph that is getting close to 0 vertically means a slow speed.

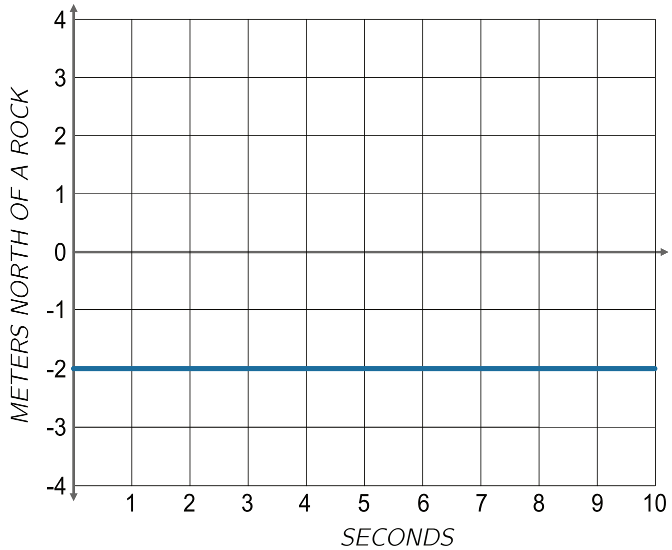


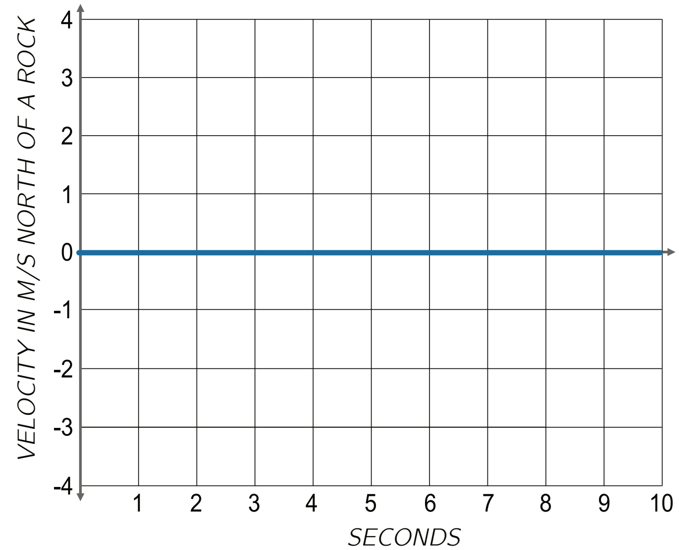
If we had asked where velocity was increasing/ decreasing instead of where speed was increasing/decreasing, the answer lines would have looked like:

ASSESSMENT

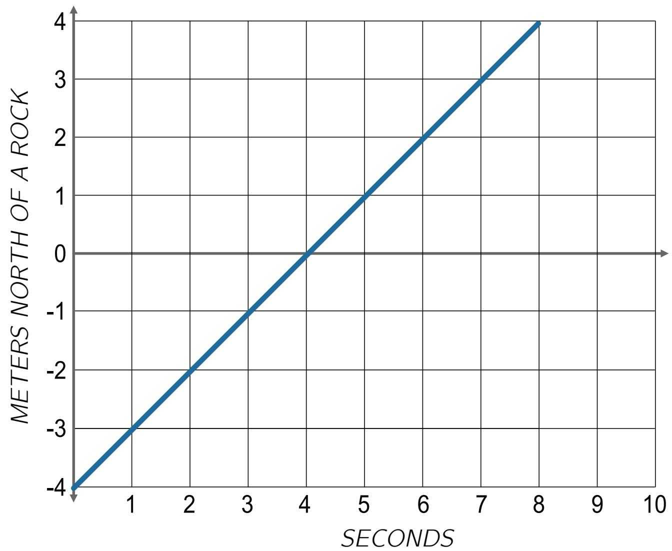
BE SURE TO HAVE A PENCIL AND SCRATCH PAPER!

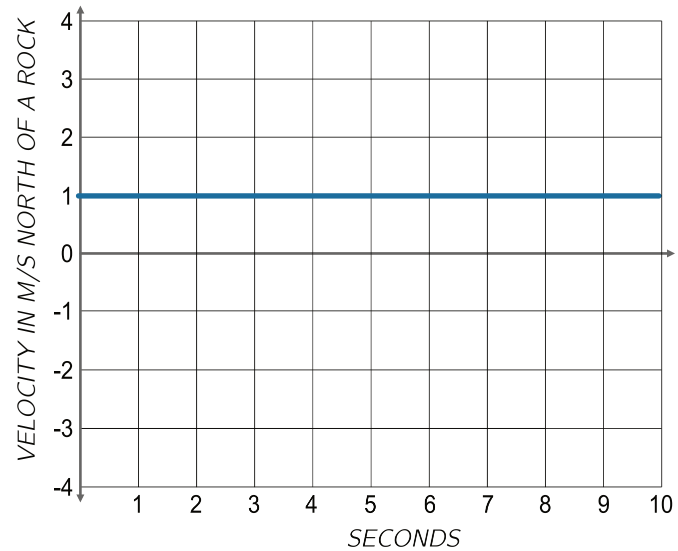
1. A dog is standing still 2 meters south of the rock and does not move for 10 seconds. Draw the position vs time and velocity vs time graphs for the dog:





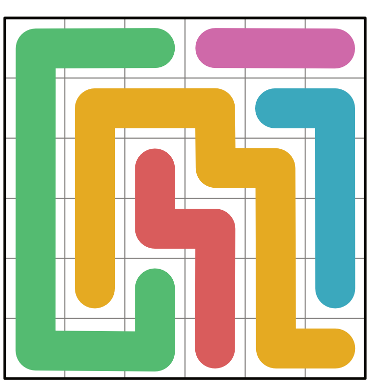
2. Meanwhile, the squirrel started at 4 meters south of the rock and ran north at a constant rate of 1 meter per second. Graph the squirrel's motion on each graph:





PIPE FLOW MATCHING - UNIT 1

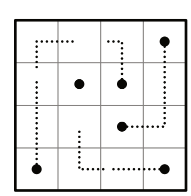
3.



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
2. mass
3. velocity
4. acceleration
5. length

A. kg
B. cm
C. m/s
D. m/s^2
E. mL



4. Which statements about a moving object are true?
   - $\boxed{\text{A. If you know the current velocity, then you also know the current speed.}}$
   - B. If you know the current speed, then you also know the current velocity.
   - C. If you know the total displacement, then you know how far it traveled.
   - D. 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 m/s^2. If it starts at rest, how fast will it be going after 5 seconds?
   - A. 8 m/s
   - $\boxed{\text{B. 15 m/s}}$
   - C. 20 m/s
   - D. 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?
   - $\boxed{\text{A. 0 mi}}$
   - B. 4 mi
   - C. 8 mi

7. Which distance below is closest to 10 ft?
   - A. 25 m 82 ft
   - B. 200 mm 8 in
   - C. 0.1 km 328 ft
   - $\boxed{\text{D. 300 cm}}$ 9.8 ft

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?
   - A. 60 km
   - B. 75 km

     40 km + 30 km + 20 km
   - $\boxed{\text{C. 90 km}}$
   - D. 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?
   - A. 5 m/s
   - B. 6 m/s
   - C. 7 m/s
   - $\boxed{\text{D. 8 m/s}}$

$$\frac{10\ \frac{m}{s}\cdot 4\ s + 4\ \frac{m}{s}\cdot 2\ s}{4\ s + 2\ s} = 8\ \frac{m}{s}.$$

10. What is the displacement for an object that moves 6 m west, 7 m east, 9 m west, and 4 m east?
    - A. 20 m west
    - $\boxed{\text{B. 4 m west}}$
    - C. 3 m east
    - D. 30 m east

11. Circle **T** or **F** to mark each statement as either True or False:

T $\boxed{F}$ Velocity is a scalar quantity.

Velocity is a vector.

$\boxed{T}$ F If an object is at rest, its position vs time graph will show a horizontal line.

T $\boxed{F}$ The units m/s are units of acceleration.

Those are units of velocity.

$\boxed{T}$ F The slope of a line on a position function is the object's velocity.

$\boxed{T}$ F If an object's velocity is constant, then acceleration is zero.

T $\boxed{F}$ If an objects average velocity over a time interval is $\vec{0}$, then it's average speed is also 0.

Remember velocity can be positive or negative. Average velocity is 0 when displacement is 0. Average speed is 0 only when the object is not moving/stationary.

T $\boxed{F}$ Temperature and distance are vectors.

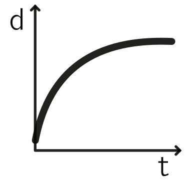
Vectors need a direction along with a magnitude.

T $\boxed{F}$ A scalar quantity has a magnitude and a vector quantity does not.

Vectors also need a magnitude.

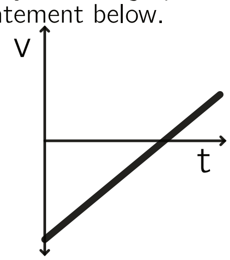
$\boxed{T}$ F Acceleration is positive when velocity is increasing.

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.

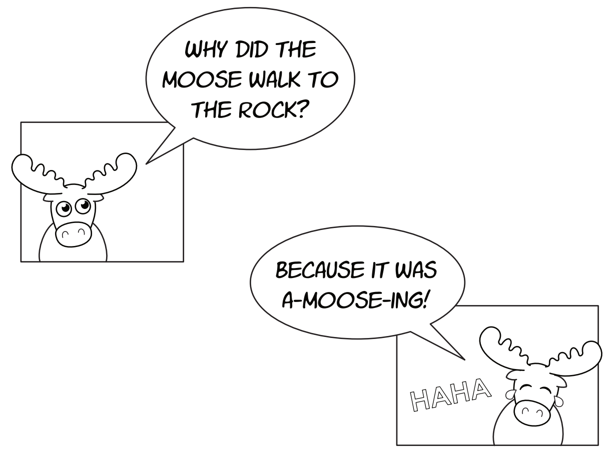
14. Which statement is true for an object moving at constant velocity of 4 km/h?

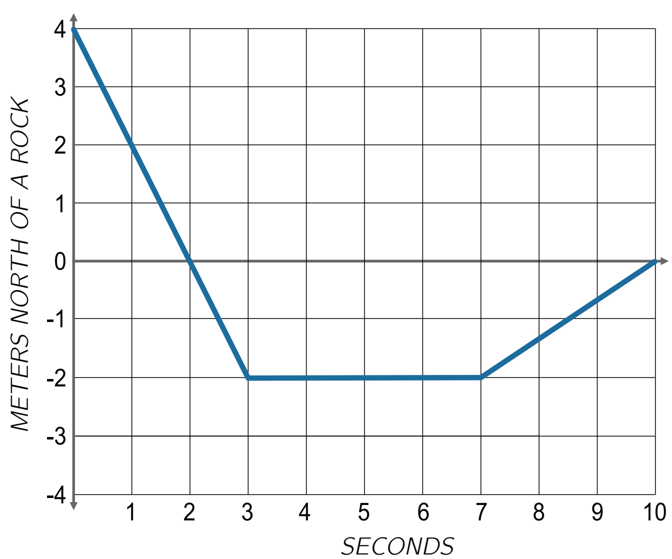
A. The acceleration is 0 km/h^2.
B. The acceleration is increasing.
C. The acceleration is negative.
D. The acceleration is positive.

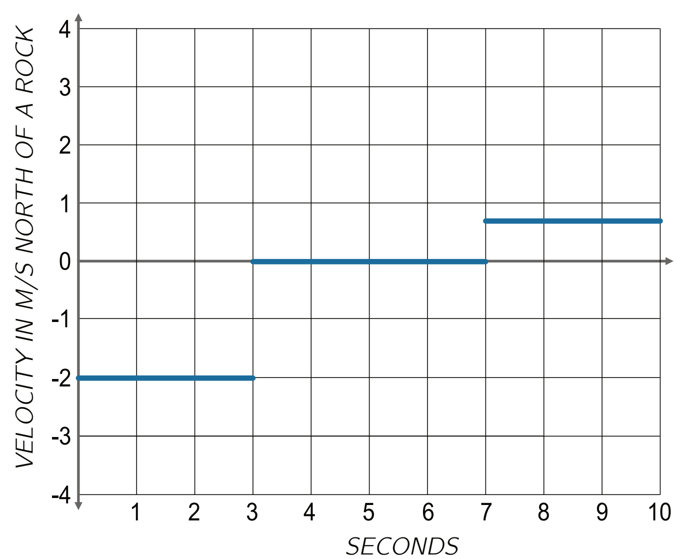
15. A moose is standing 4 meters north of a rock. Then, over a 10-second interval, it

- 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 motion (noun) in terms of its position, velocity, and acceleration. Position is the location (noun) of an object. It's important to know where the object is at any given time (noun).

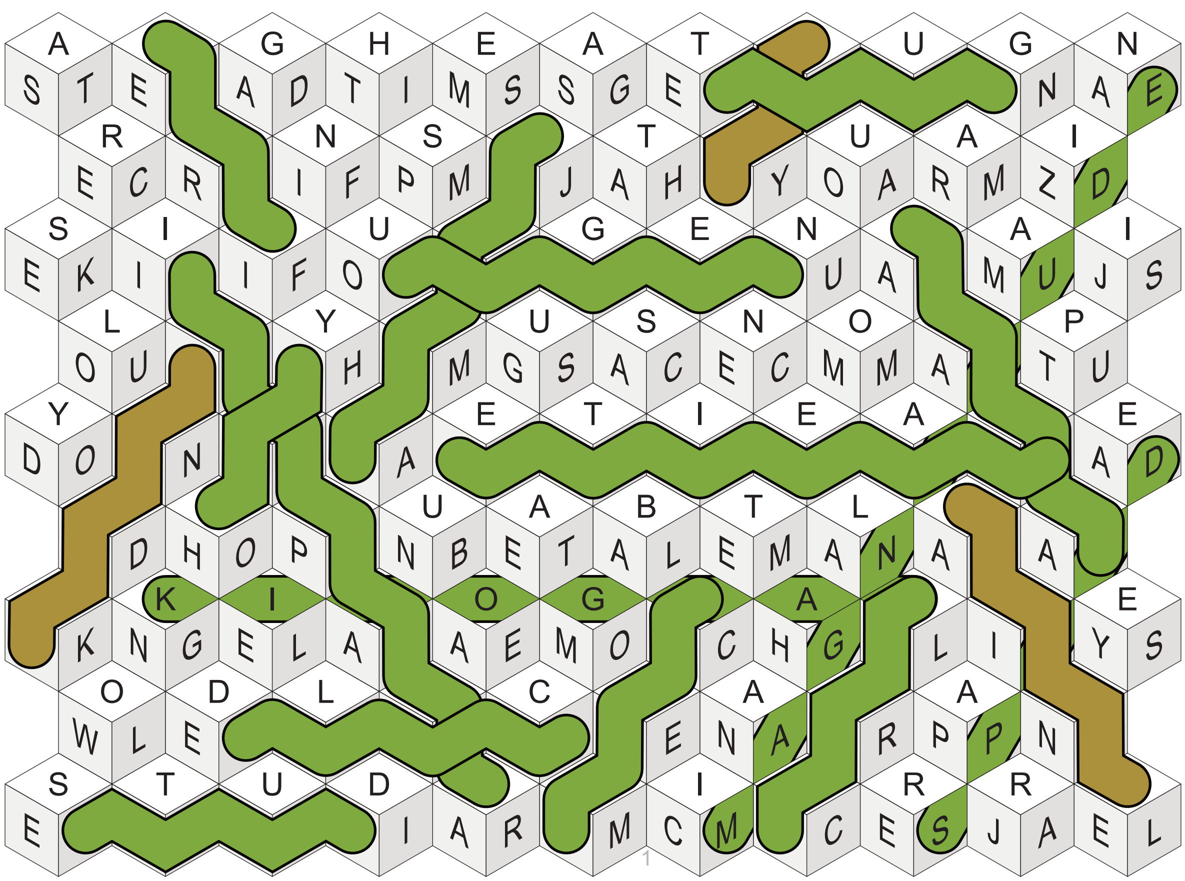
Velocity is the rate at which the object (noun) changes (verb) from one position to another. It's like how quickly you can cross (verb) the street or how fast a bird (noun) can fly (verb).

Acceleration is the rate at which the object (noun) changes its velocity. If it can quickly change (verb) 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	DISPLACEMENT	GRAVITY	METER	MAGNITUDE
POSITION	DISTANCE	SECOND	VECTOR	TIME
ACCELERATION	SPEED	KILOGRAM	SCALAR	MOTION



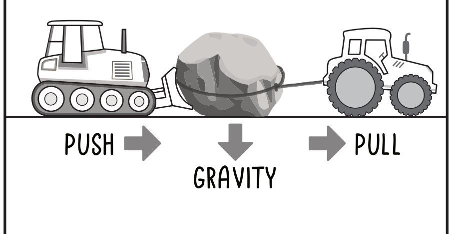
Unit 2: Laws of Motion

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

The Laws of Motion

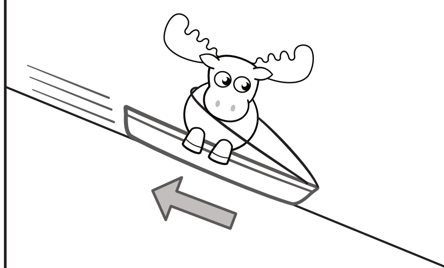
1. Law of inertia
2. F = ma (Force is equal to mass times acceleration)
3. Forces between objects always come in equal and opposite pairs

FORCE



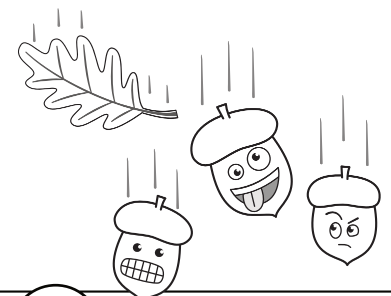
$\vec{F}=m\vec{a}$ A push or pull that can make objects move, change, or bend

FRICTION



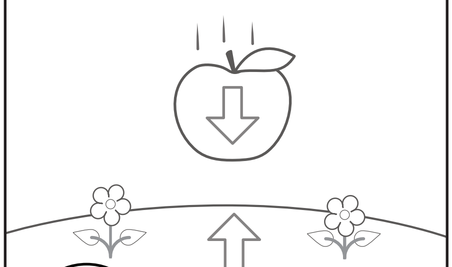
$\vec{F}=\mu\vec{N}$ Resistive force between objects in contact

FREE FALL



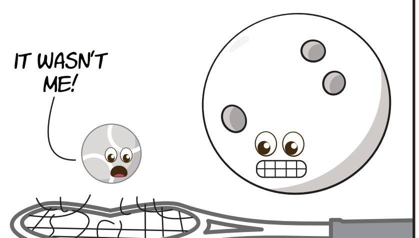
$9.8\ m/s^2$ on Earth — Downward acceleration under the force of gravity only

GRAVITY



$F=G\frac{m_1 m_2}{r^2}$ The force that pulls objects toward each other

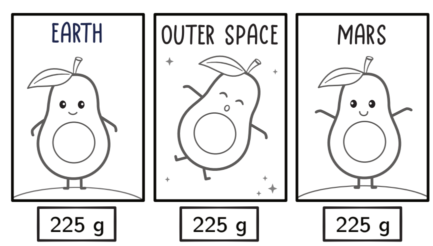
INERTIA



Resistance to a change in motion

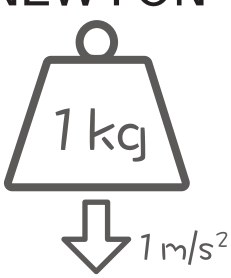
MORE MASS = MORE INERTIA

MASS



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

NEWTON

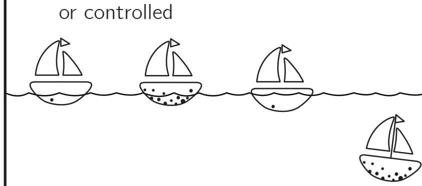


$1 kg \cdot m/s^2$ The force that gives 1 kg an acceleration of 1 m/s^2

VARIABLE

INDEPENDENT What is changed or controlled

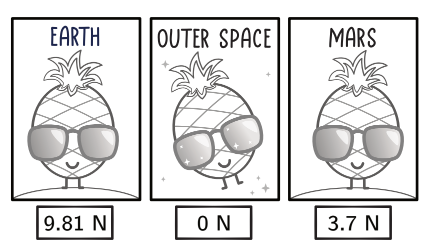
DEPENDENT What is measured



Number of holes in boat — How fast boat sinks

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

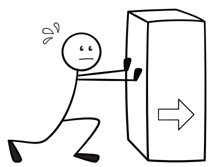
FILL IN THE BLANKS:

two	interaction	motion

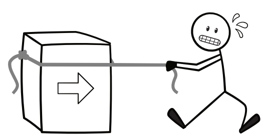
A **force** is an ___interaction___ that can cause the ___motion___ of an object to change. A force must occur between _two_ or more objects.

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).

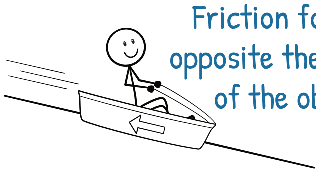
CONTACT FORCES



PUSH *(applied)*

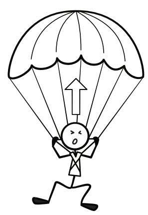


PULL / TENSION *(applied)*

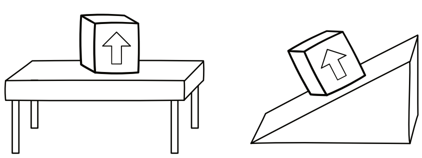


Friction force is opposite the motion of the object

FRICTION *(surface resistance)*



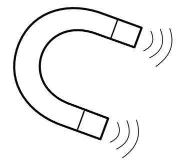
DRAG *(air resistance)*



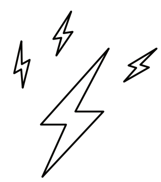
NORMAL

Always perpendicular to the surface (which is how it got its name)

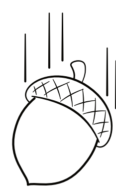
NON-CONTACT FORCES



MAGNETIC



ELECTROSTATIC



On Earth is always present and always down toward the ground

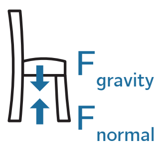
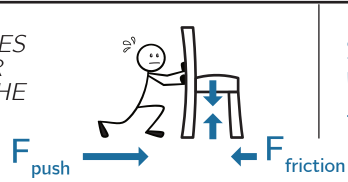
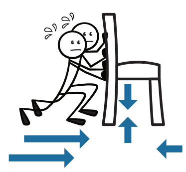
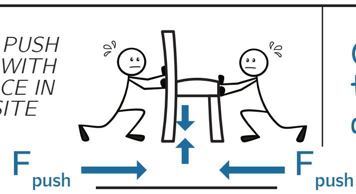
GRAVITY

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?*

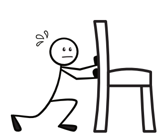
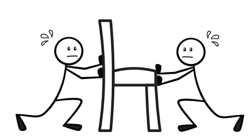
Net Forces

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.

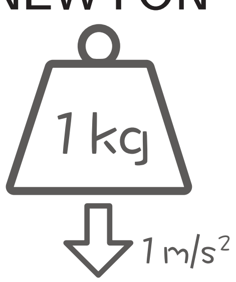
Scenario	Forces?	Movement?
1 *THE CHAIR RESTS ON THE FLOOR* 	Gravity pulls the chair down. The normal force keeps chair from falling through the floor.	No movement
2 *BOB PUSHES THE CHAIR ACROSS THE FLOOR* 	Still have gravity and normal force, but Bob is pushing and friction force is opposite from Bob's push.	Chair moves or accelerates forward
3 *TWO BOBS PUSH THE CHAIR WITH EQUAL FORCE IN THE SAME DIRECTION* 	Still have gravity and normal force. Friction will be the same. But two Bobs can push more than one.	Chair accelerates faster (twice as fast)
4 *TWO BOBS PUSH THE CHAIR WITH EQUAL FORCE IN THE OPPOSITE DIRECTION* 	Gravity and normal force are there. Bob's pushes are opposite and cancel or balance each other	No movement

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)?

		
70 N	70 N + 70 N = 140 N	70 N – 70 N = 0 N

NEWTON



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

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

add them together

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

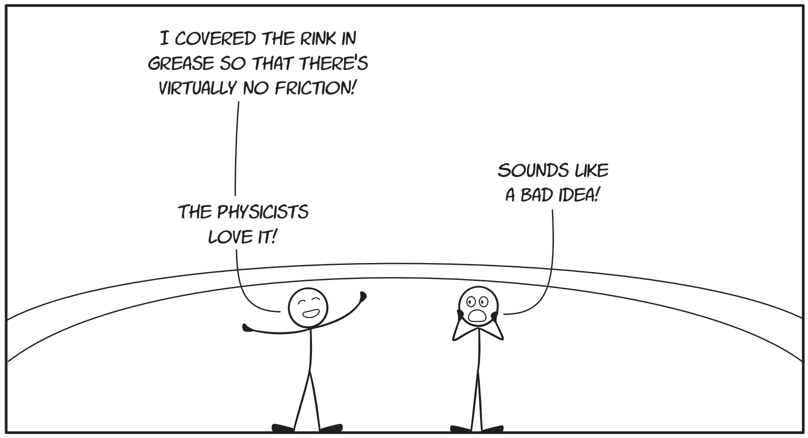
subtract!

⇩ Misconception Alert! ⇩

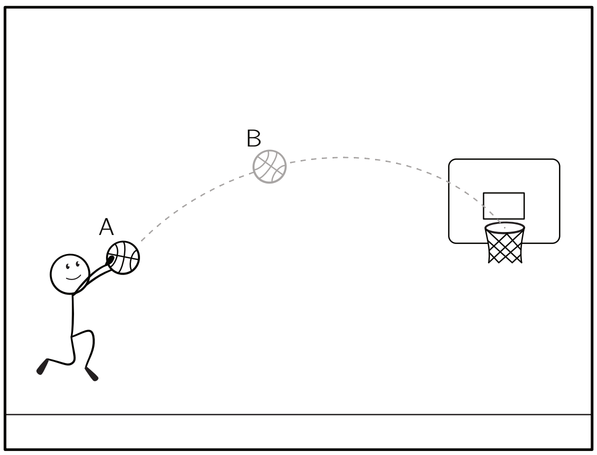
Bob gives the chair a huge push and then lets go. The chair goes forward and then stops moving. **Why did it stop?** One of these answers is correct. The other is a common misconception. Can you mark the correct one?

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



Forces are required to change the way an object moves. Forces are NOT required for an object to keep moving.



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

Gravity (which is pulling down) and the push being applied from Lily are the main forces on the ball. Also air resistance (minimal) and the normal force (perpendicular to Lily's hands).

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

No. The ball is not in contact with anything but air so the only forces are gravity (down) and air resistance (minimal).

MECHANICAL EQUILIBRIUM = BALANCED FORCES = NET FORCE OF ZERO

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

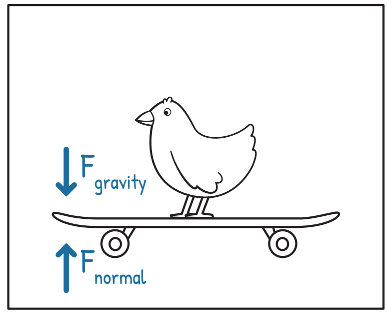
- ☑ Book resting (not moving) on a table
- ○ Semi truck speeding up
- ○ Bicycle slowing down
- ☑ Large rock sitting in a garden
- ○ Marmoset climbing a tree with frequent pauses
- ☑ Comet moving at 100 m/s through outer space (The comet has been traveling at this speed for decades)

SUPER IMPORTANT! MAKE SURE TO REMEMBER:

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

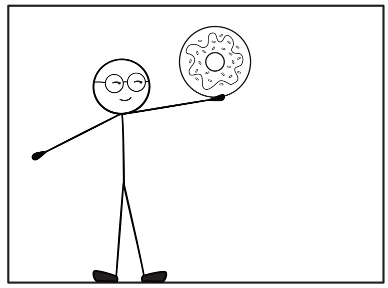
Practice Problems – Forces

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?



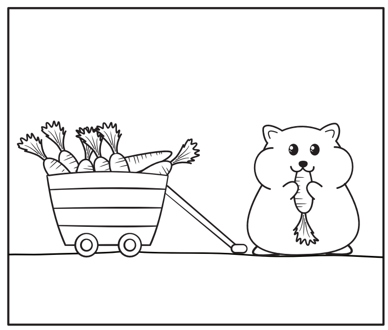
Answer: Two forces act on the chicken-skateboard system: gravitational force (Fg) acting downward and the normal force (Fn) acting upward. The forces are equal in magnitude and opposite in direction, so the net force is zero (also called "mechanical equilibrium" or "balanced forces")

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



Answer: Two forces act on the donut: gravitational force acting downward and the upward force (applied force) exerted by Math Dad's hand. The forces are equal in magnitude and opposite in direction, indicating mechanical equilibrium.

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

Answer: Friction (and also a small amount of air resistance)

Friction is the force that opposes the motion of objects when they are in contact with a surface. Air resistance in this case would be very small (almost negligible)

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?

Answer: newton (N)

The SI unit of force is the newton, named after Sir Isaac Newton. One newton of force will accelerate 1 kg of matter by 1 meter per second per second.

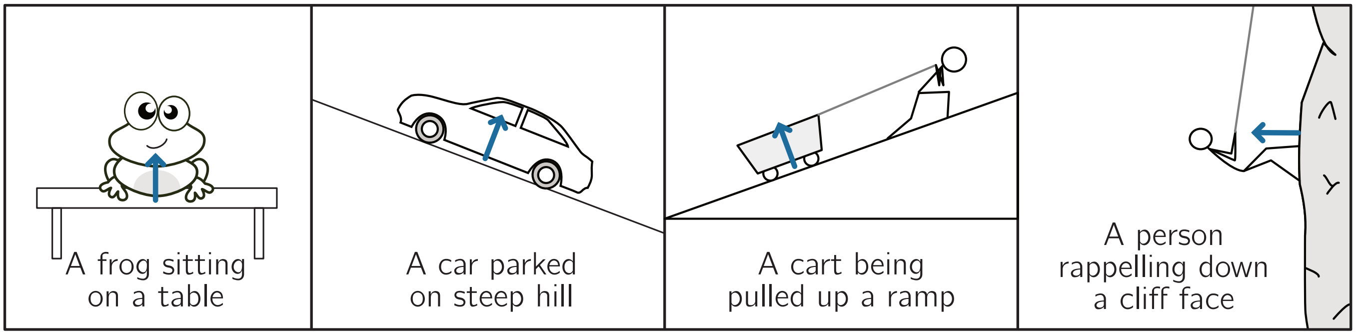
5. Which statements about the normal force is true?

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.

A and C are true. The word "normal" has a different meaning in mathematics. Normal vectors are always perpendicular to their surface, which is how the normal force got its name.

PRACTICE PROBLEMS – FORCES

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



A frog sitting on a table | A car parked on steep hill | A cart being pulled up a ramp | A person rappelling down a cliff face

(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
50N → , 50N →	100N →
← 50N, 50N →	0 N No net force
← 70N, 100N →	30 N →
← 70N, 30N →	40 N ←
← 40N, ← 30N	70 N ←

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

A. True

B. False

It will never be greater. The magnitude of the net force will be equal to the sum of forces only when all forces are pointing the same direction. If the forces are in opposite directions, then the net force will be smaller than the sum.

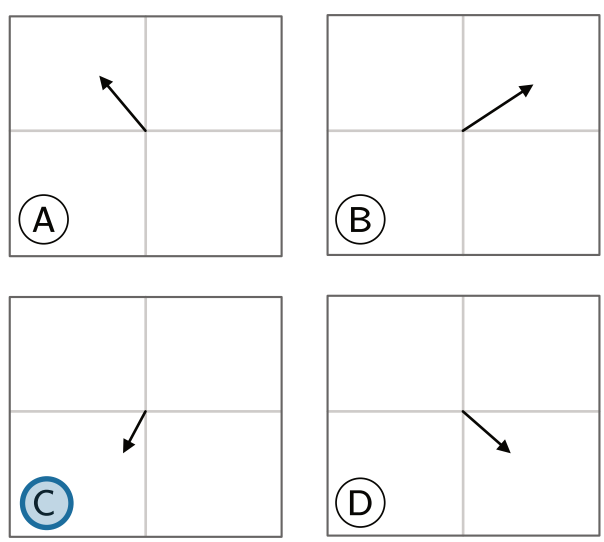
(9) Which of the following forces require direct contact to be influencing the motion of an object?

A. Gravity

B. Friction

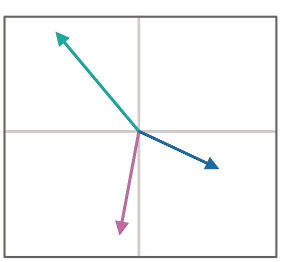
C. Magnetism

D. Normal Force

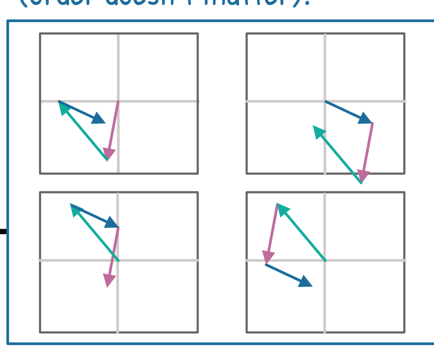


Challenge Question:

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



Vector C. Add the vectors by drawing them end-to-end (order doesn't matter).

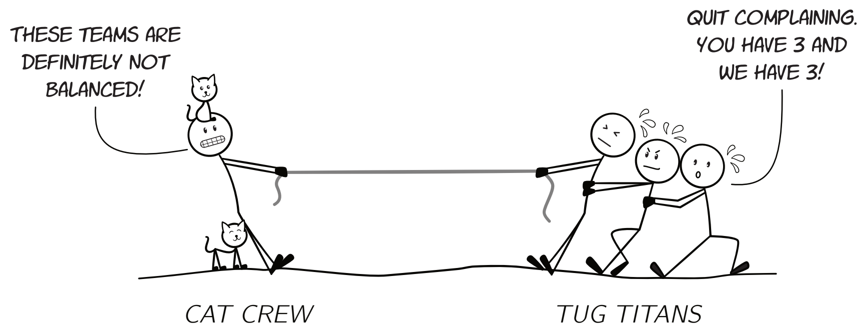


Free Body Diagrams

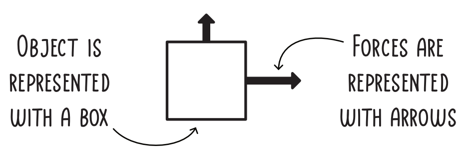
A free body diagram (FBD) uses arrows to represent the forces acting on an object.

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.*

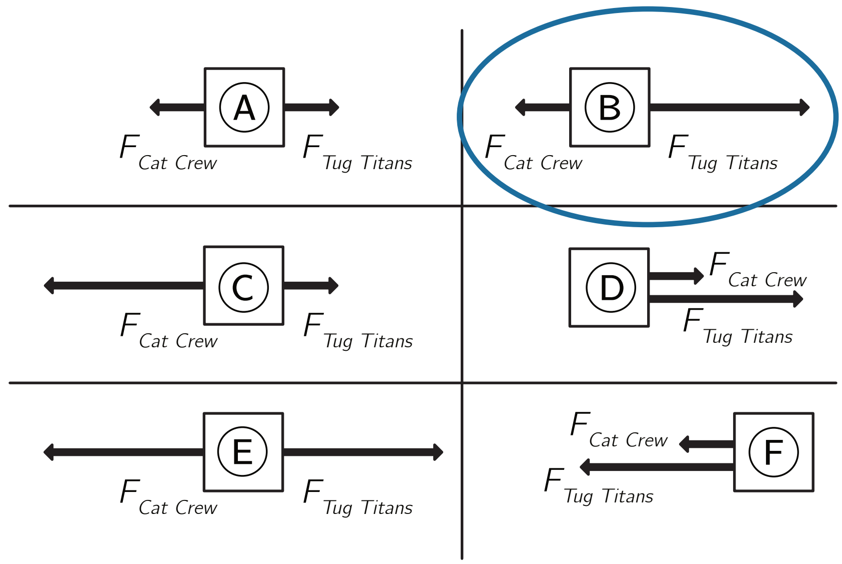


Anatomy of a Free Body Diagram:



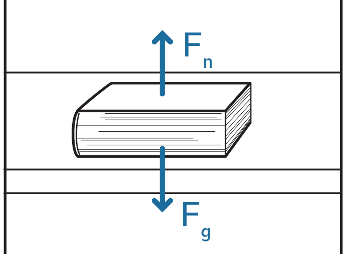
Which free body diagram would best represent the forces of the two teams on the rope? Why is it the best choice?

Assuming that each person can pull with roughly equal force and that the cats don't contribute, B is the best choice because it shows the Tug Titans causing 3x as much force as the Cat Crew.



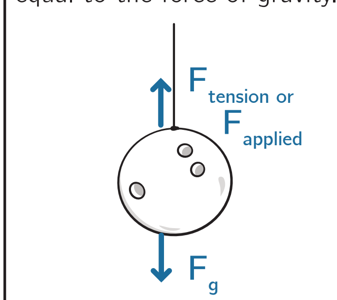
Draw and label an arrow for each force described below. (Note: the description may not include ALL of the forces acting on the object. Only draw arrows for the forces which are described.) Are the forces equal in size (balanced) or not?

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



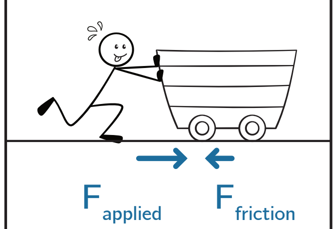
- [x] Balanced
- [ ] Not Balanced

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



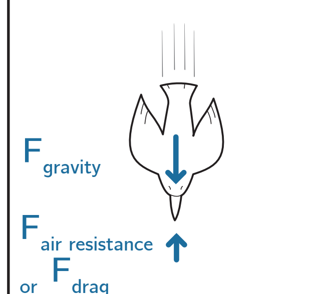
- [x] Balanced
- [ ] Not Balanced

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



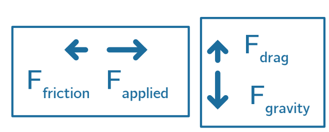
- [ ] Balanced
- [x] Not Balanced

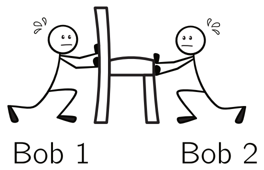
A kingfisher dives toward a lake. The bird feels some air resistance but accelerates downward.



- [ ] Balanced
- [x] Not Balanced

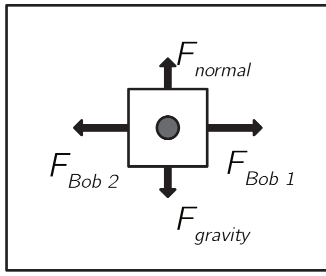
*Note: These arrows showing the forces acting on the cart and kingfisher were drawn facing inward but it would also be correct to draw them facing outward:





Bob 1 and Bob 2 push with equal but opposite force. The chair does not move.

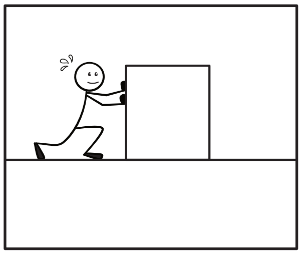
Free body diagram for the chair:



The net force is zero because there is no acceleration.

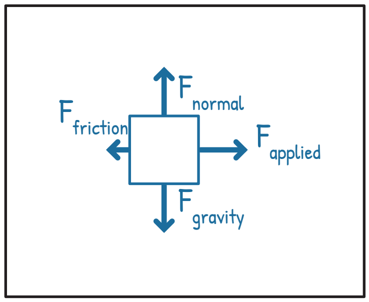
The chair experiences equal forces from opposite directions.

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

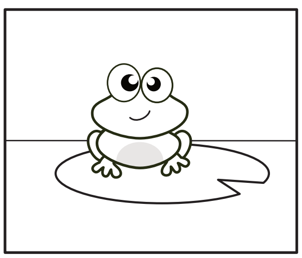


Pam pushes a box faster and faster. It slides across the ground, accelerating to the right.

Free body diagram for the box:

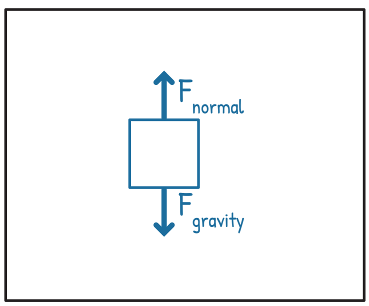


The net force is NOT zero because the box is accelerating toward the right. When the net force is zero there is NO acceleration.



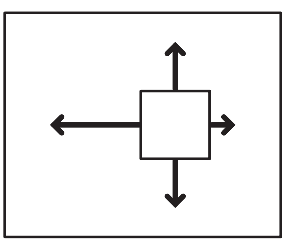
A frog sits on a lily pad. It is holding completely still as it waits for an insect to come by.

Free body diagram for the frog:



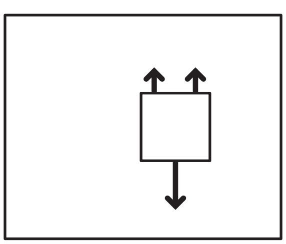
The net force is zero because the velocity of the frog is not changing. Gravity and the normal force are equal and opposite.

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



Artwork will vary!

Answers will vary! As long as there are explanations to back them up, they are valid. If the object is on Earth, the downward force should be gravity. Upward force could be normal force or air resistance. The horizontal arrows could be applied force and friction (if the object is slowing down, friction should be greater than applied. If the object is speeding up, applied should be greater.



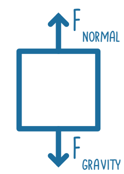
Artwork will vary!

Answers will vary! The downward force could be gravity, and the upward forces could be a push from a jet booster and air resistance. Another possibility is that the upward forces are the force of tension from two ropes that are holding the object aloft.

Practice Problems – Free Body Diagrams

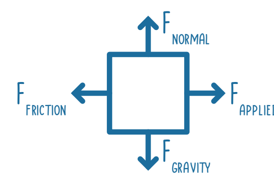
1. A cat is sitting at rest on a flat table. Draw a free-body diagram for the cat. How many forces are acting on the cat and what are they?

   There are two forces acting on the cat: gravity (downwards) and the normal force (upwards) from the table. These forces are equal in magnitude and opposite in direction, which is why the cat is at rest.



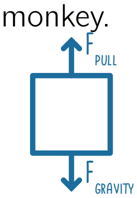
2. A child is pushing a toy car on a horizontal surface with a constant speed. Draw a free-body diagram and identify the forces acting on the car.

   There are four forces acting on the toy car: the force of gravity (downwards), the normal force from the surface (upwards), the applied force from the child (forward), and the frictional force (backwards).



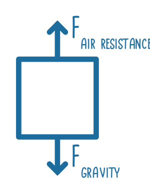
3. A marmoset is relaxing by dangling from a branch by its tail. Draw a free-body diagram for the marmoset. Identify the forces acting on this small monkey.

   There are two forces acting on the marmoset: the force of gravity pulling it downwards, and the pull on the branch lifting it upward. Since the marmoset is motionless, these forces are equal in magnitude and opposite in direction.



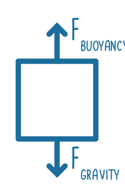
4. A parachute is descending slowly towards the ground. Draw a free-body diagram for the parachute. What are the forces acting on it?

   There are two forces acting on the parachute: the force of gravity pulling it downwards, and the air resistance (or drag force) acting upwards.



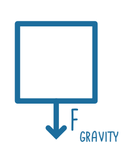
5. A hot air balloon is rising at a constant speed. Draw a free-body diagram for the balloon. What are the forces acting on it?

   Two forces are acting on the balloon: gravity (downwards) and the buoyant force (upwards). Since the balloon is rising at a constant speed, these two forces are equal in magnitude but opposite in direction.



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?

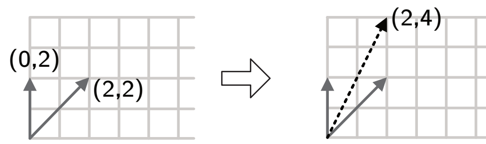
   Only one force is acting on the soccer ball after it has been kicked and is in mid-air: the force of gravity pulling it downwards. (You could also argue there is some air resistance.)



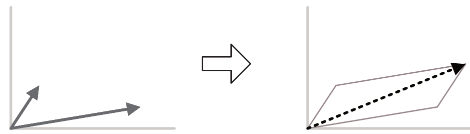
BONUS CONTENT! EXTRA STRATEGIES FOR ADDING VECTORS/FORCES

We can add any two vectors by:

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

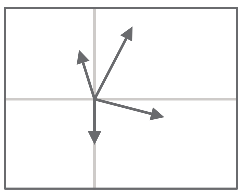


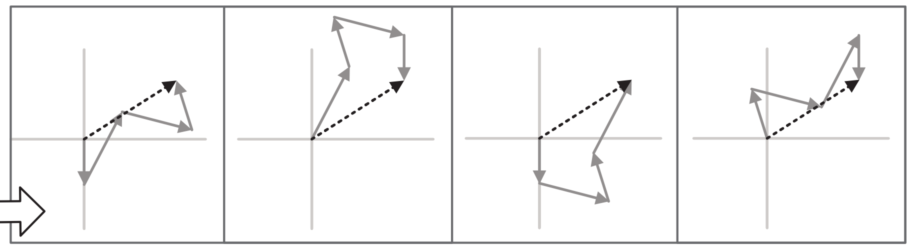
- Forming a parallelogram out of them and then drawing the arrow from the origin to the furthest corner.



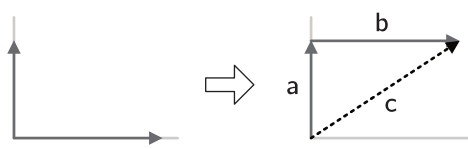
- Placing them in sequence so that one starts where the previous one ended. Works for more than two vectors and order doesn't matter!

WHAT IS THE NET FORCE OF THESE VECTORS?



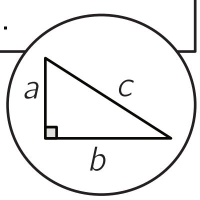


- Use the pythagorean theorem (only if they are at a 90° or a right angle to each other)



Pythagorean Theorem:

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

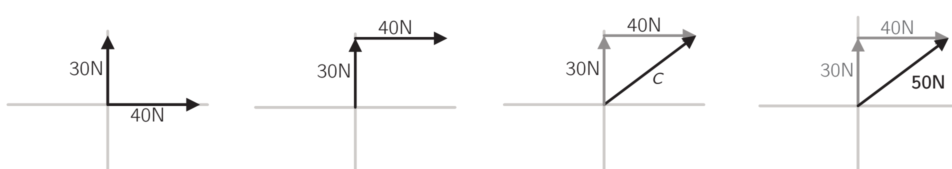


Careful, this only works with right triangles!

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 $2500 = c^2$

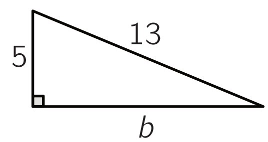
Take the square root of 2500 to get 50 = c.

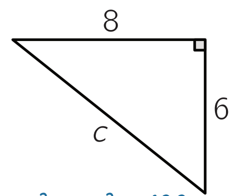
The net force on the toy is 50 newtons. The hypotenuse shows the direction of the force with slope ¾ in the north-easterly direction.

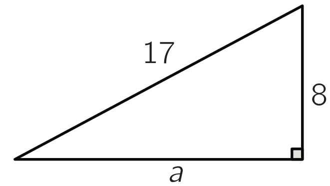
1. Use the Pythagorean Theorem to find the missing side of each triangle.

$5^2 + b^2 = 13^2$ so $b^2 = 144$ and $b = 12$.

$a^2 + 8^2 = 17^2$ so $a^2 = 225$ and $a = 15$.







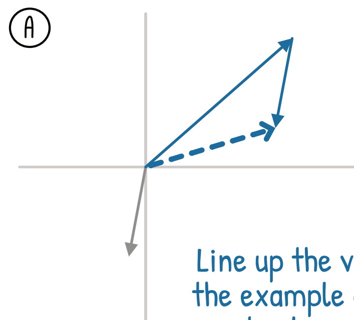
$6^2 + 8^2 = c^2$ so $c^2 = 100$ and $c = 10$.

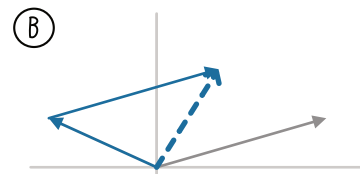
2. A ruler and protractor can be used to add vectors. Draw the net or resultant vector and then record the length & angle below.

Use centimeters and degrees.

A. Magnitude: 2.1 cm, Angle: 17°

B. Magnitude: 1.8 cm, Angle: 58°





Line up the vectors from tip to tail, just like the example on the previous page. To get the exact values of the length and angles, you will need a protractor and ruler.

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?

They need to go 2 mi west and 5 mi south. They would travel downward along the line with slope 5/2 for a distance of 5.39 mi.

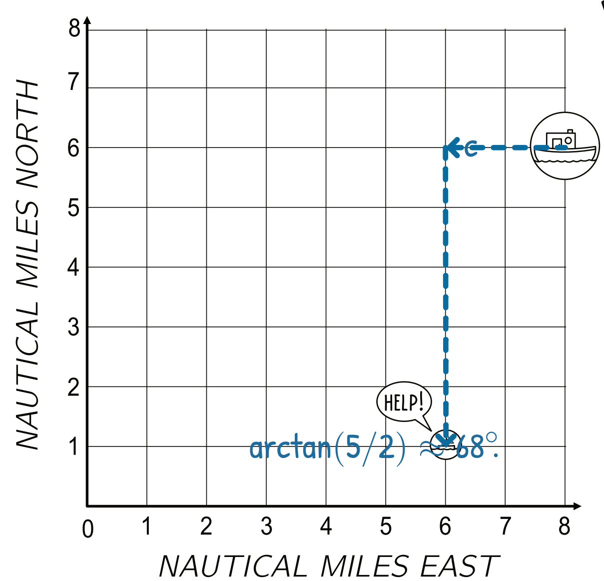
c

To get the exact distance, one can use Pythagorean theorem.

$$^2 = 2^2 + 5^2 \implies \quad = \sqrt{29} \approx 5.39$$

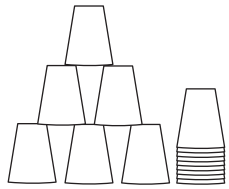
The angle from horizontal can be found using trigonometry or a protractor and compass.

The trig concepts are beyond the scope of this course, but the answer is:

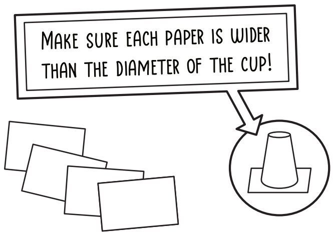


CUP STACK CHALLENGE

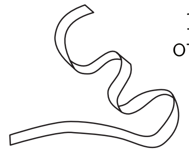
MATERIALS



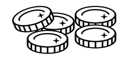
5 or more stackable paper cups



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



15 to 25 coins or other small weights

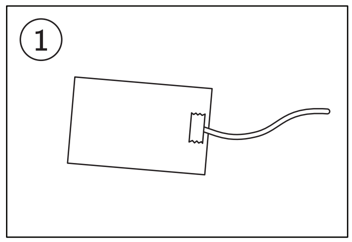
Tape

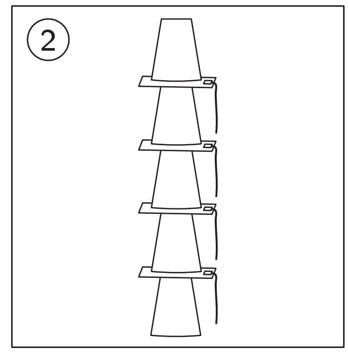
GOALS

- 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

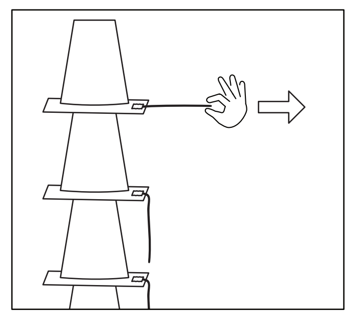
1. Use tape to add ribbon to each card on one side.
2. Stack 5 cups so that each cup is resting on top of a card.





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:



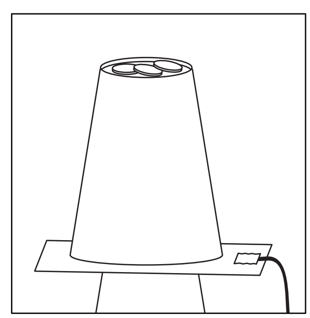
My prediction: ______________________________

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:

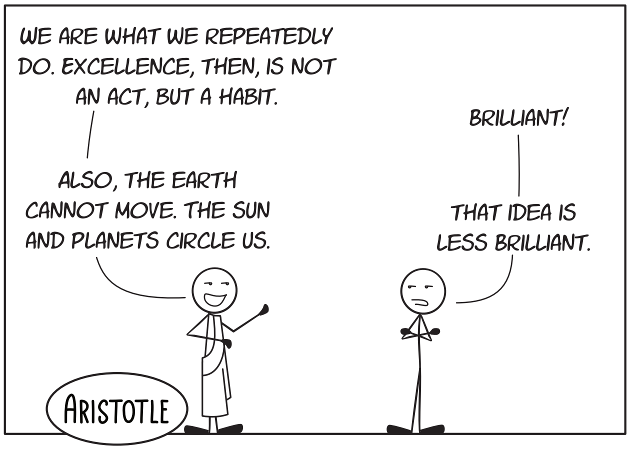


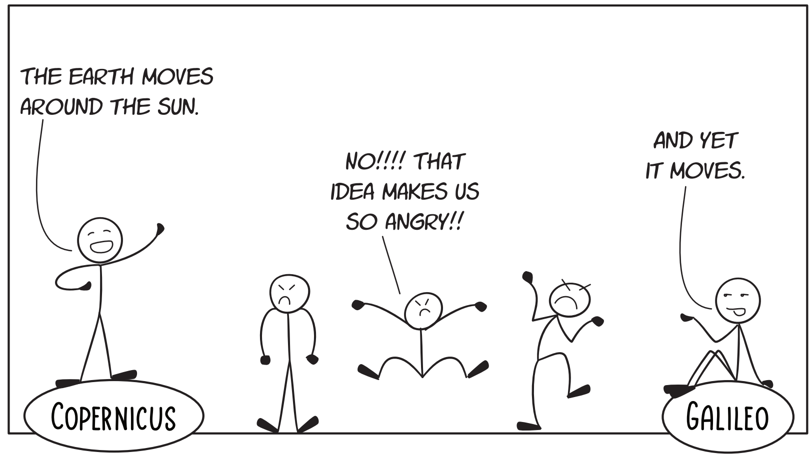
My prediction: ______________________________

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

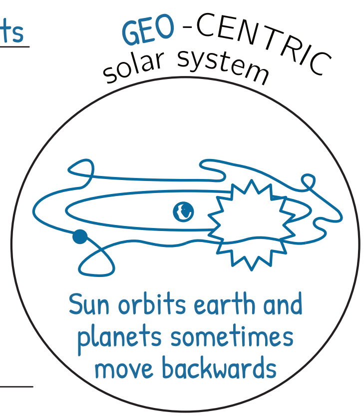
The result: ______________________________

MOVEMENT – IDEAS THROUGH HISTORY

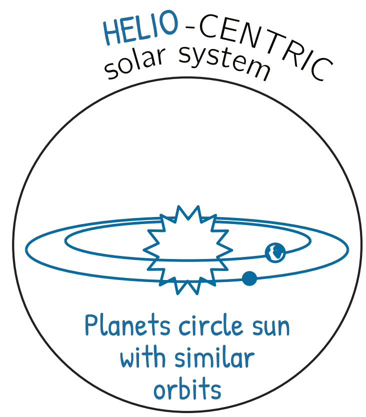




Big ideas: Heavy objects fall faster. Laws of physics are different away from Earth. Similar objects attract each other.

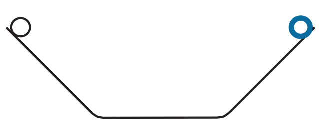


Big ideas: The Earth moves around the Sun. All objects fall at the same rate. Laws of motion are the same in the solar system as on Earth.



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.

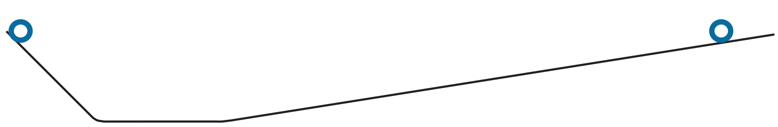


Downward ramp of 45°
Upward ramp of 45°

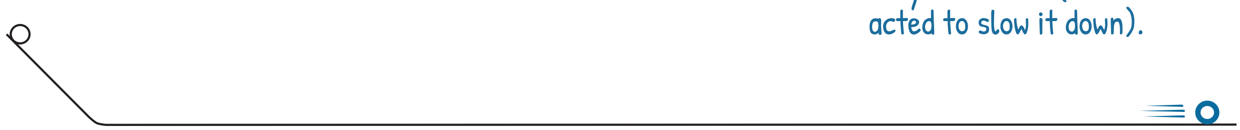
Downward ramp of 45°
Upward ramp of 30°

With no friction, the ball will roll back to its original height.

This is what Galileo observed when he performed this famous set of experiments with ramps. The results led him to conclude that the ball with no upward ramp would stay in motion (unless a force acted to slow it down).



Downward ramp of 45°
Upward ramp of 9°



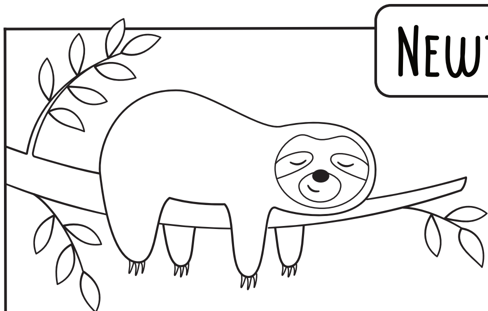
Downward ramp of 45°
No upward ramp

FILL IN THE BLANKS:

perspective inertia changes motion

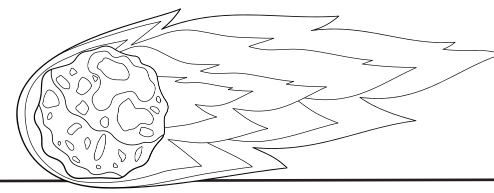
All objects resist changes to their state of motion. We don't know why this happens, but we have a name for this quality of resisting change. It is called inertia. Identifying whether or not an object is moving depends on perspective. One observer's state of rest is another observer's state of motion.

NEWTON'S FIRST LAW OF MOTION



AN OBJECT AT REST TENDS TO stay at rest

AN OBJECT IN MOTION TENDS TO Stay in motion at constant speed and in a straight line unless acted on by an unbalanced force.



MAKE A DIAGRAM!

HOW IS INERTIA INVOLVED IN EACH OF THESE PHYSICS DEMONSTRATIONS?

EXPLAIN IT HERE!

TABLE CLOTH PULL

CLIMBING POTATO

DOG SHAKING OFF WATER

KETCHUP THUMP

TABLECLOTH PULL: The dishes are at rest and tend to stay at rest as the cloth is pulled.

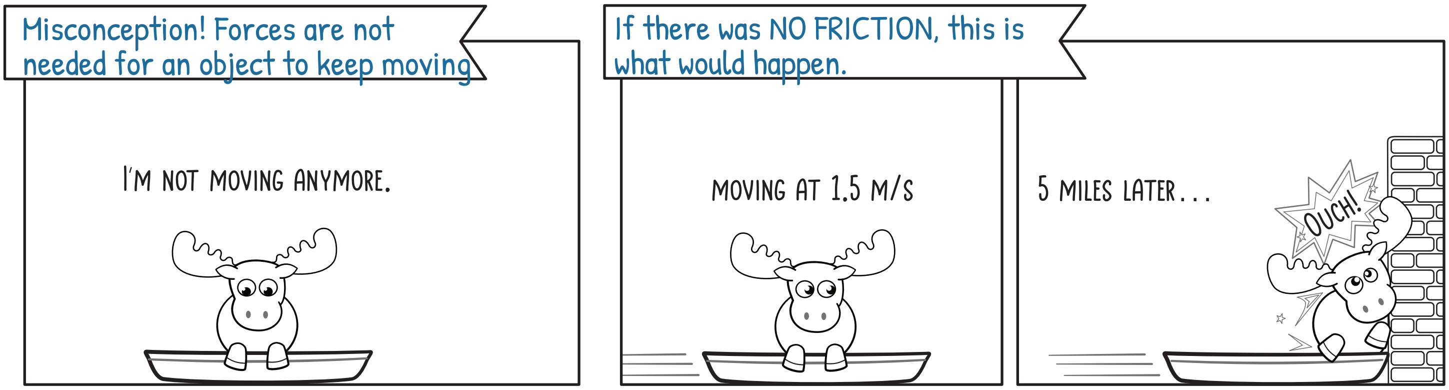
CLIMBING POTATO: The potato stays at rest as knife or skewer is moved fast. Since it moves less with each push or tap, it appears to "climb"

DOG SHAKE: The fast movements of the shake get both the fur and water moving. The water keeps moving when the fur changes directions, which is why droplets fly out from the dog.

KETCHUP THUMP: When the bottle stops, the ketchup stays in motion and moves to the bottom.

A MOVEMENT MISCONCEPTION

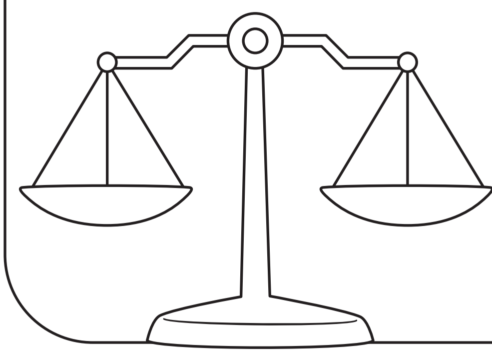
A sled receives a push that causes it to move forward across a flat surface of ice at 1.5 meters per second (about 3 miles per hour). The ice is 5 miles long and ***there is no friction or air resistance***. What will happen? One of the predictions below is accurate. The other is a misconception.



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 =

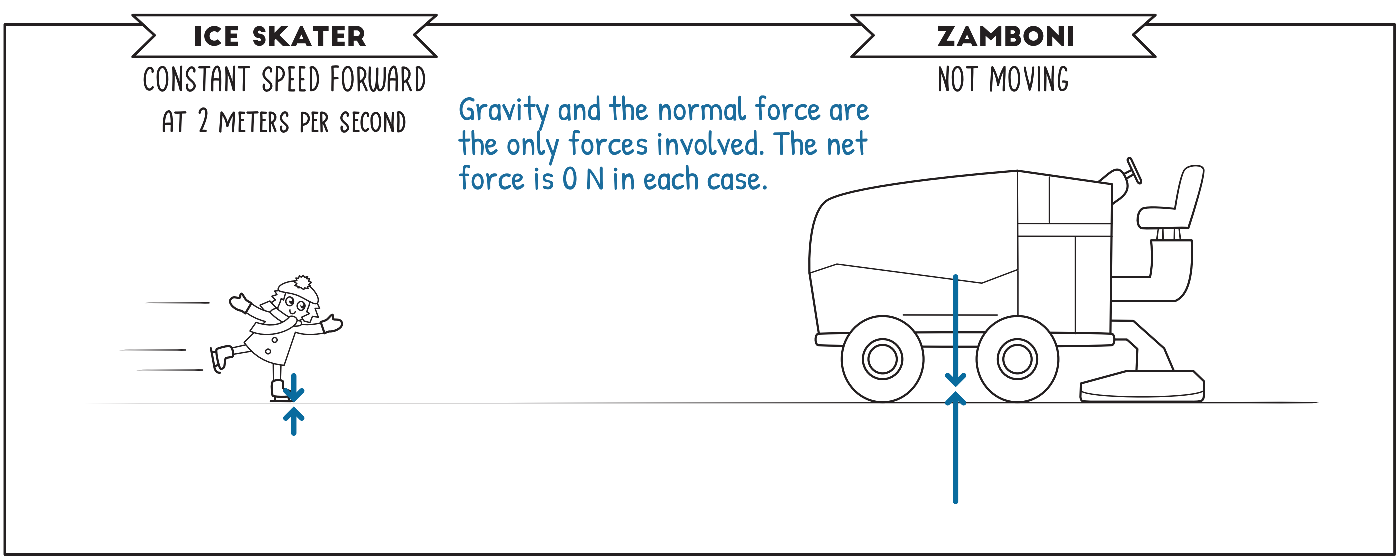


Balanced forces will result in CONSTANT velocity!

Constant or unchanging velocity =

1. No movement (object at rest) OR
2. Constant motion (unchanging speed).

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**?



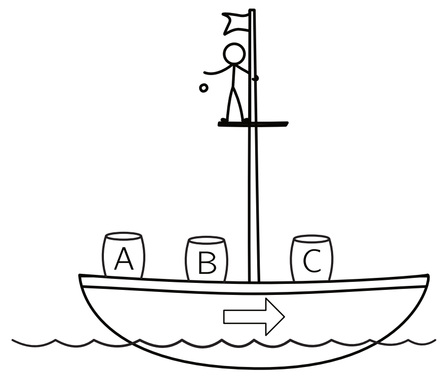
Practice Problems – The Law of Inertia

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

   When the bus is moving, everything inside the bus, including each passenger, is also moving at the same speed as the bus. The passengers tend to stay in motion with the same speed and direction. The lurch forward is the body continuing forward with its previous motion.

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.

   The ball will fall into barrel B. The ball was traveling horizontally with the same speed as the boat, so it will keep its horizontal speed after it is dropped as well.



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.

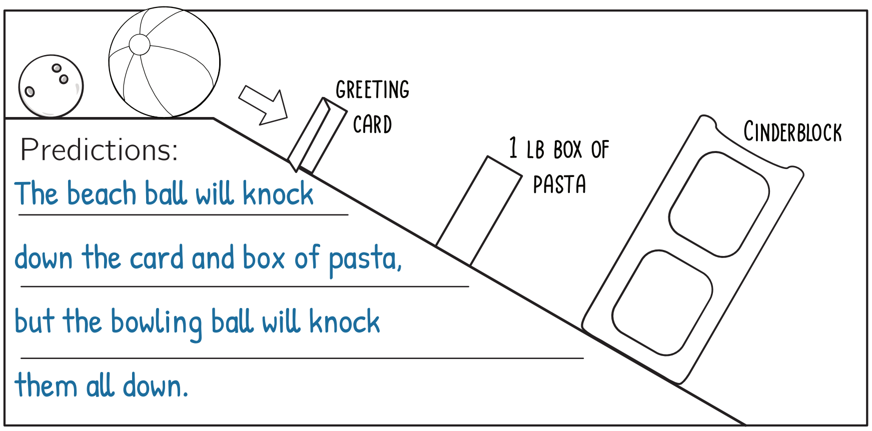
4. What would happen if a mischievous squirrel jumped onto a table that was covered by a slippery and almost friction-less tablecloth? (Assume there are no external forces acting on the tablecloth)
   A. The squirrel would be stuck in place, unable to move.
   B. The squirrel would slide to the end of 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

   Option B is the second best because the stationary cat could stay stationary if it can't exert a net force on the surface.

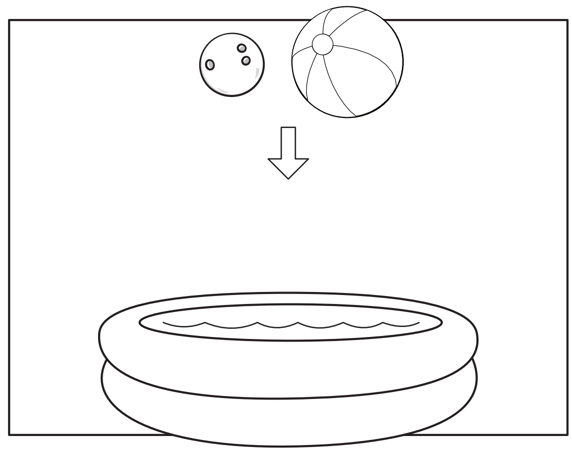
Inertia & Mass

Beach ball vs bowling ball



Predictions:

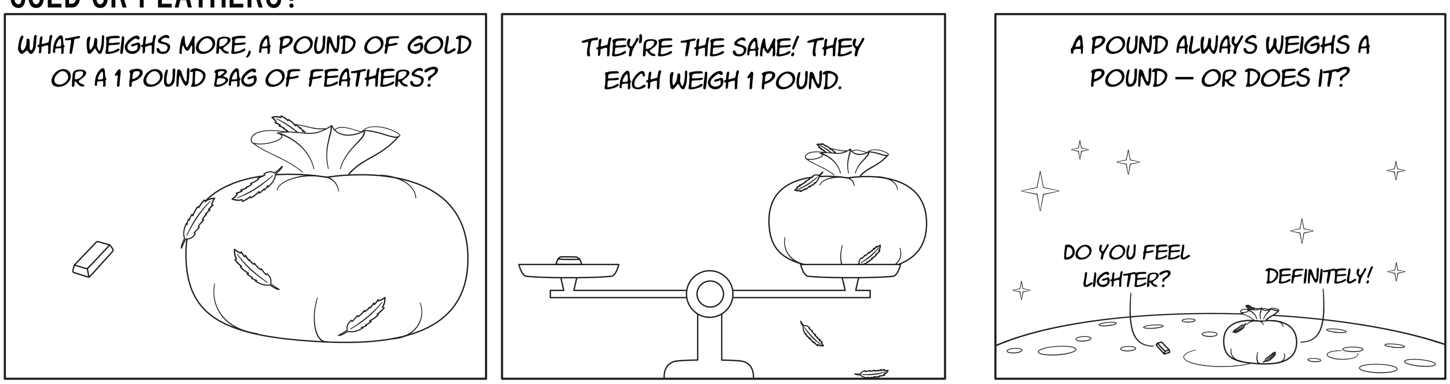
The beach ball will knock down the card and box of pasta, but the bowling ball will knock them all down.



Beach ball results: ______________________________

Bowling ball results: ______________________________

GOLD OR FEATHERS?



MASS vs WEIGHT

MASS

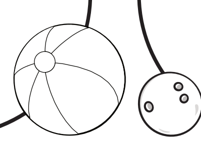
What it is & how it's measured:

Mass is the amount of matter in an object. The amount of mass is the amount of inertia an object has. Mass is measured in kilograms.

WEIGHT

What it is & how it's measured:

Weight is the amount of downward force an object has due to gravity. Weight is measured in newtons. $1\ \text{N} = 1\ \text{kg} \cdot \text{m/s}^2$.



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?

To calculate weight, multiply mass by the force of gravity.

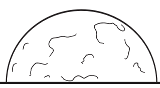
On Mars, the mass is 899 kg and the force of gravity is 3.7 N/kg. To calculate the weight we multiply:

899 kg · 3.7 N/kg = 3,326.3 N.

On Earth, the mass is the same but the force of gravity is 9.8 N/kg.

899 kg · 9.8 N/kg = 8,810.2 N.

The rover weighs more than twice as much on Earth as it does on Mars.



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: 50 kg
Gravity: 9.8 N/kg
Weight:
9.8 N/kg · 50 kg
= 490 N.

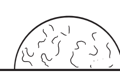
EARTH

Mass: 50 kg
Gravity: 1.6 N/kg
Weight:
1.6 N/kg · 50 kg
= 80 N.

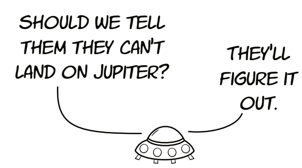
EARTH'S MOON

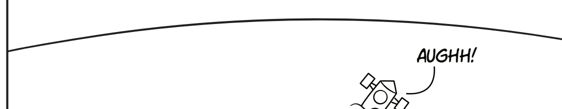
Mass: 50 kg
Gravity: 3.7 N/kg
Weight:
3.7 N/kg · 50 kg
= 185 N.

MERCURY



Mass: 50 kg
Gravity: 24.8 N/kg
Weight:
24.8 N/kg · 50 kg
= 1240 N.



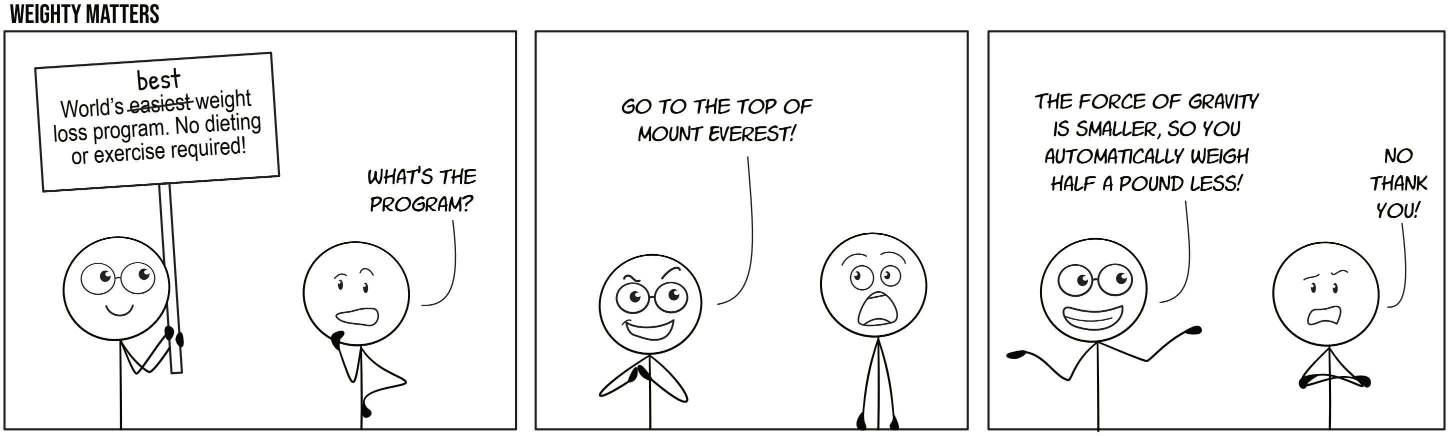


JUPITER

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 the same.
   D. Weight would decrease, mass would stay the 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?

   The boulder will have more inertia because it has a larger mass. It doesn't matter if it is laying still or moving. It will be harder to change the motion of the boulder than it will be to change the motion of the pebble.

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.

   The box stops moving because the force of friction pushes against it while it is motion. An object in motion will retain the same motion until acted upon by a force (like friction).

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.

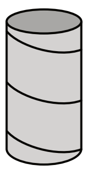
Place them in a location where it would be okay if things accidentally tipped over. Have a towel or rag handy to clean up any messes!

GOALS

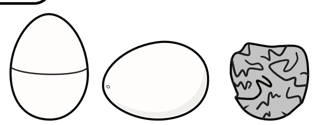
- Better understanding of the concept of inertia.
- See that multiple trials or repeated experiments can improve our understanding

EGG SPLASH

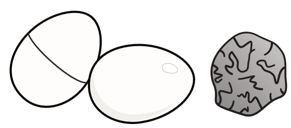
MATERIALS



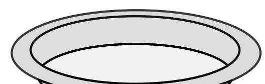
Toilet paper tube



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

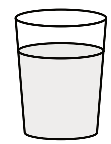


1 OR MORE "HEAVY EGGS"
A plastic egg filled with dough or clay, a hard-boiled egg, or an egg-shaped bundle of coins or rocks wrapped in plastic, paper, or foil



Aluminum pie plate or a piece of cardboard

Rag or towel to clean up any spilled water



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

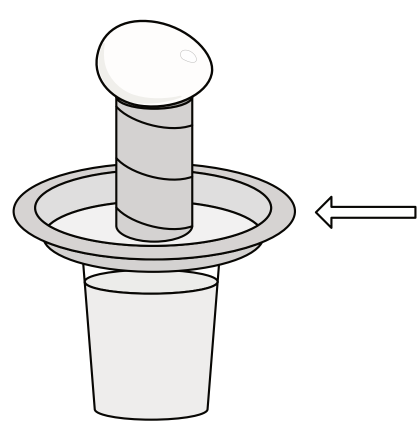
In this experiment you will be attempting to land an egg in a cup. The egg is balanced over the cup, but to get it in you are only allowed to touch the pie pan. No touching the egg or toilet paper roll! BEFORE you try it, make a prediction. Which egg do you expect to be easier to land in the cup?

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

- ☐ The light egg will be 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?

____

____

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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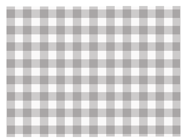
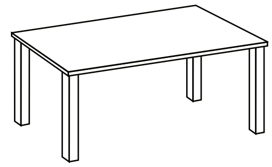
TABLECLOTH PULL

MATERIALS

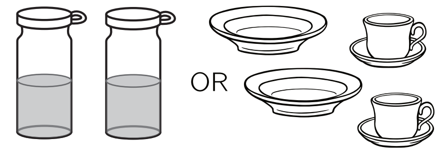


A smooth cloth or scarf made of silk or satin with little or no ridge around the edge

A bath towel



A flat table or counter top



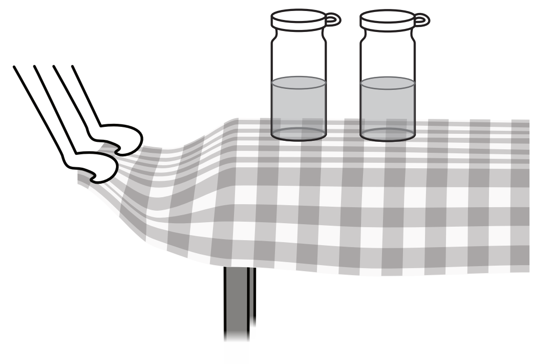
Two water bottles, each half-full of water, OR two unbreakable dishes or cups

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?

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

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.



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
1st attempt		
2nd attempt		
3rd 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?

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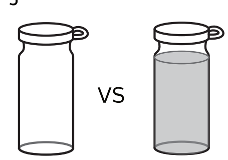
Bonus experiment:

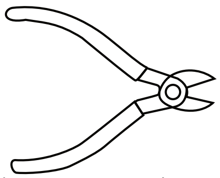
Does the weight of the objects matter? Try the demonstration with objects of different mass!



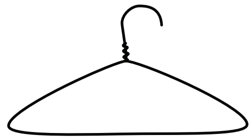
INERTIA HAT

BONUS ACTIVITY!

MATERIALS

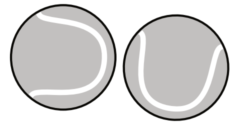


wire cutters and pliers (optional)

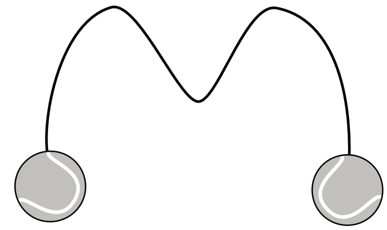


wire hanger

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?*

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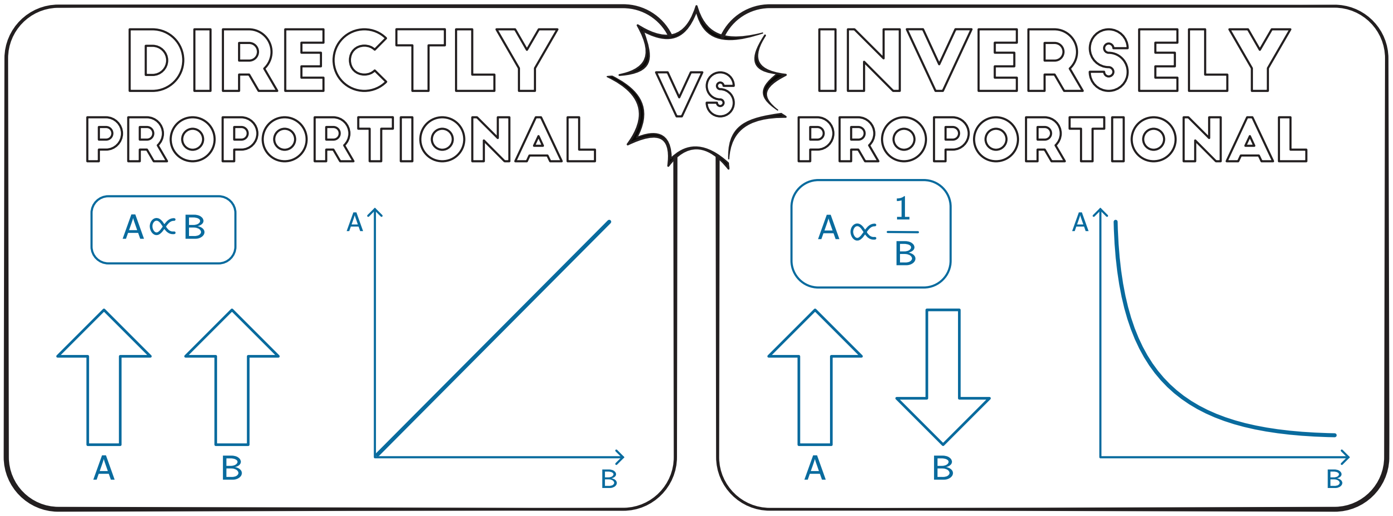
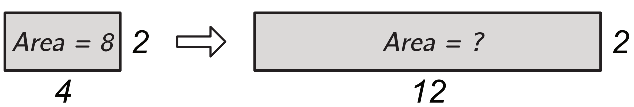
Directly or Inversely Related?

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.



Area = (base)·(height)

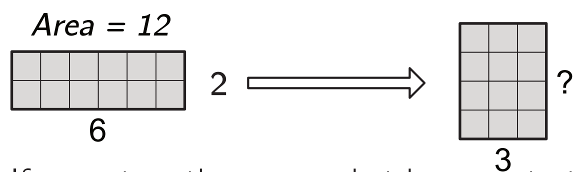


If the **length** of the base is **tripled**, what happens to the area?

The area is also tripled!

$2 \cdot 12 = 24$.

24 (area of the longer rectangle) is 3x larger than 8 (area of shorter rectangle).



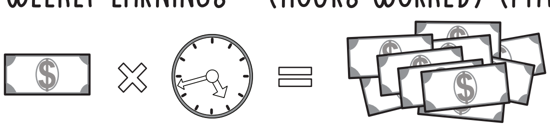
If **area** stays the **same**, what happens to the height when the base length is cut in half?

The height doubles.

If the base length is cut in half (from 6 to 3), then to keep the same area, the height must double (from 2 to 4).

$6 \cdot 2 = 12$ and $3 \cdot 4 = 12$

Weekly Earnings = (hours worked)·(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?

Weekly earnings is also doubled. $20 per hour x 40 hrs = $800

$800 is twice as large as $400.

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?

$40 per hour. When hours are reduced by a factor of 4, hourly pay must increase by a factor of 4 to keep total pay the same. Hours and hourly pay are inversely related. $40 per hour x 10 hrs = $400

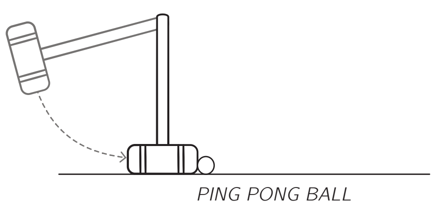
Complete each sentence. Then circle whether it's directly or inversely proportional:

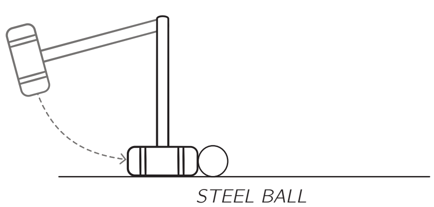
As test scores go down, grades go down.	DIRECTLY	INVERSELY
For brighter flashlight settings, battery life decreases.	DIRECTLY	INVERSELY
As driving speed increases, time spent traveling decreases.	DIRECTLY	INVERSELY
As number of tacos ordered goes up, money spent increases.	DIRECTLY	INVERSELY
More workers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

Experiments with Mass & Force

Experiment One:

Same force, different mass.



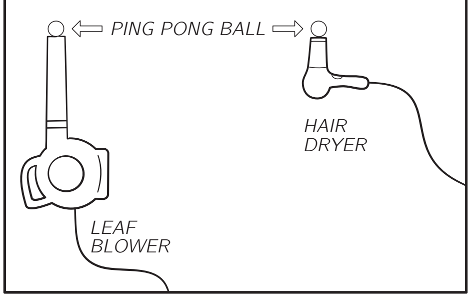


Which ball will accelerate more?

When both experience the same force, the ball with less mass accelerates more.

Experiment Two:

Same mass, different force.

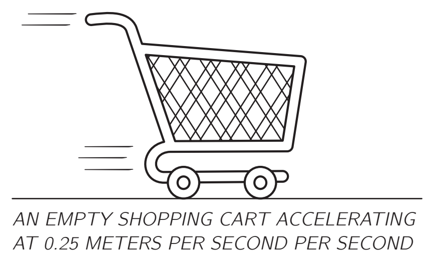


Which ball will accelerate more?

The ball that experiences the larger force (leaf blower) will accelerate more.

Experiment Three:

Same acceleration, different mass



Which requires more force?

The full shopping card requires more force to travel with the same acceleration.

NEWTON'S SECOND LAW OF MOTION

Net force is proportional to both mass and acceleration.

$$F = m \cdot a$$

Force equals mass times acceleration!

The equation can be rewritten in these forms too!

$$\text{Mass} = \frac{\text{force}}{\text{acceleration}}$$

$$\text{Acceleration} = \frac{\text{force}}{\text{mass}}$$

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?

Yes. You would use F=m·a, but then rearrange it to be: acceleration= force/mass.
In this case, 5 N / 10,000 kg = 0.0005 N/kg, but remember newtons are kg·m/s^2, so the kg cancel out and the answer is 0.0005 m/s^2, which is not very fast!

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*

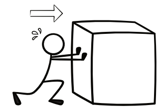
When two quantities are directly proportional, changing or scaling one quantity leads to a corresponding scaling in the other. Anytime you have an equation where quantity A is a multiple of quantity B, A and B will be directly proportional to each other.

If two quantities are inversely 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 inversely proportional, and force and acceleration are directly 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?



   $F = ma$ so $40\ N = 20\ kg \bullet a$. Solving for a yields $a = 2\ m/s^2$.

2. How much force is needed to accelerate a mass of 100 kg at a rate of 20 m/s^2?

   $F=ma$ so $F=100\ kg \bullet 20\ m/s^2 = 2{,}000\ kg \bullet m/s^2 = 2{,}000\ N$.

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

   $F=ma$ so $10\ N = mass \bullet 5\ m/s^2$ so the mass is $(10\ N)/(5\ m/s^2) = 2\ kg$.

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

   $F=ma$ so a and F are directly proportional. Doubling force doubles the acceleration.

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

   Mass and acceleration are inversely proportional. By tripling the mass, you only get 1/3 of 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 m/s^2. What force is needed to slide a bucket of 50 apples with that same acceleration?

   Force and mass are directly proportional. Cutting the mass in 1/2 makes it so you only need ½ of the force to get the same acceleration.

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

   Force and acceleration are directly proportional, so you need 5 times the force to get 5 times the acceleration.

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?

   Acceleration is directly proportional to force but inversely proportional to mass, so 3 times the force and 2 times the mass will multiply the old acceleration by 3/2.

(9) Circle **T** or **F** to mark each statement as either True or False:

$\boxed{\text{T}}$ F Acceleration is a vector quantity.

T $\boxed{\text{F}}$ Mass is a vector quantity.

$\boxed{\text{T}}$ F Force is a vector quantity.

$\boxed{\text{T}}$ 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 directly proportional to your height.
- Liters of gasoline consumed is directly proportional to the distance driven.
- Time until arrival is inversely proportional to speed of travel.
- The number of candy bars purchased is directly proportional to the total paid for candy.
- In the equation $72 = x \bullet y$, the variable x is inversely 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	A skater gliding at a uniform pace on ice with no friction
Tug of war - stalemate	UNBALANCED	Rocket taking off
Rock resting on the ground		Dog sled team slowing down

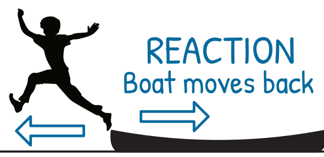
(12) A 100 kg satellite is going to be launched from a space station, but if its going to reach the correct orbit it needs to be launched with an acceleration of 11 m/s^2. How much force is needed to launch it?

$F = ma = (100\text{ kg})(11\text{ m/s}^2) = 1{,}100\text{ kg}\bullet\text{m/s}^2 = 1{,}100\text{ N}$

Newton's Third Law of Motion

Forces between two interacting objects will always occur in pairs that are equal in magnitude and opposite in direction

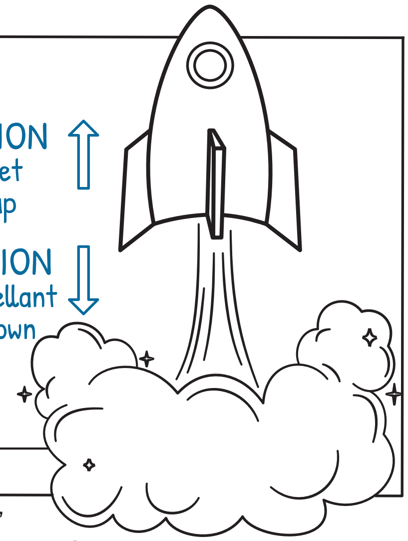
ACTION
Jump forward



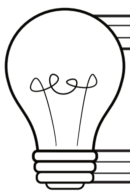
REACTION
Boat moves back

REACTION
The rocket moving up

ACTION
The propellant moving down



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!



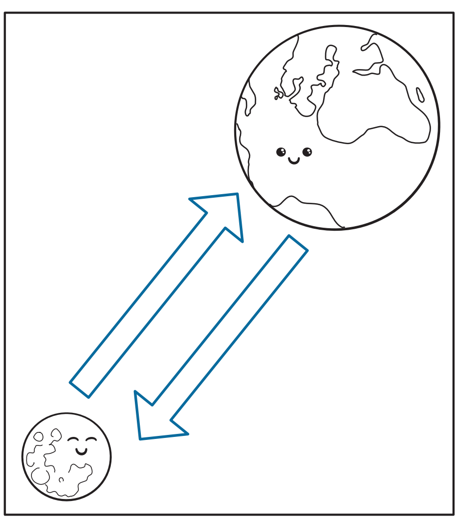
ESSENTIAL CONCEPT

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

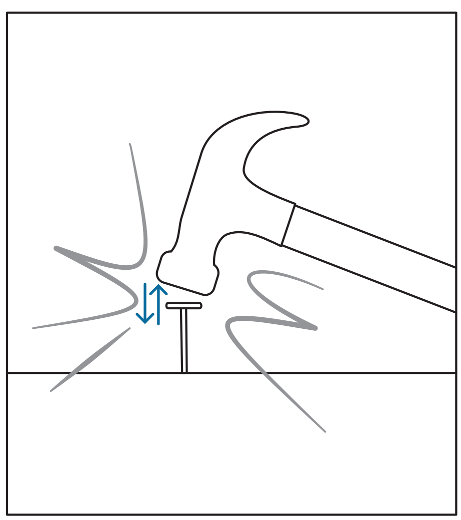
What holds the Moon in orbit around the Earth? GRAVITY

Does the Moon also exert a force on the Earth? Yes – it exerts an equal and opposite force. This is what causes the tides in the ocean.

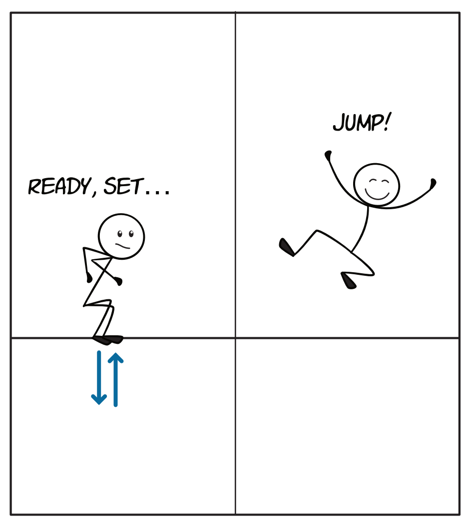
Draw arrows to show the strength and directions of the forces between each pair of objects.



The force of gravity between the Earth and the Moon is found with the equation $F = G(m_1 \cdot m_2)/r^2$. It is approximately $1.982 \cdot 10^{20}$ or 198,200,000,000,000,000,000 newtons.



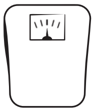
The nail drives the hammer into the wood, but the equal and opposite force from the nail slows the hammer. A rough estimate for this force would be 500 newtons.



The force of the jump pushes down on the ground. The ground exerts and equal and opposite force back, allowing the person to jump into the air. A 64 kg (140 lb) person jumping 46 cm (18 in) would exert about 900 newtons of force.

On average, the Moon is 384,400 km (238,855 miles) away from Earth – that's about the length of 30 Earths!

LET'S TEST IT!



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

1 kg = 2.2 lb = 9.8 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?

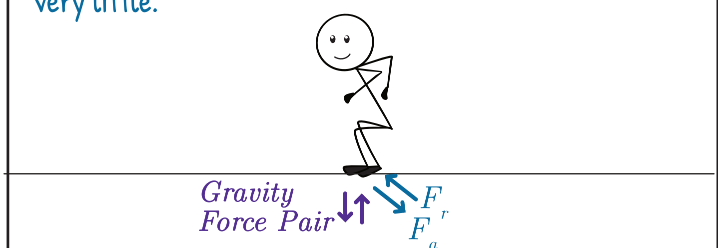
If one scale receives 80 Newtons of force (about 18 pounds) then the other scale will also experience the same force.

Newton's 3rd Law of Motion tells us that the scales will always have identical readings.

IDENTIFY THE FORCE PAIRS IN EACH SCENARIO:

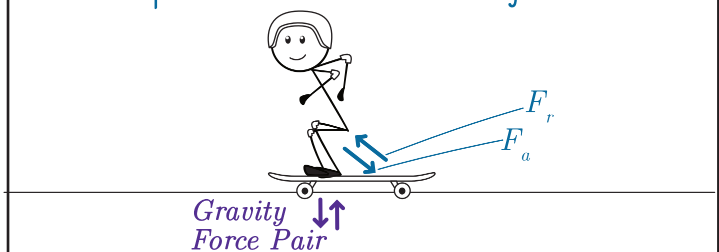
Ignore friction and the normal force - just consider gravity and the force of the push (applied force)

The force of the jump or push (applied force) creates a "reaction force" that pushes the person forward. Since the ground/pavement has so much more mass than the person, the person moves forward while the Earth moves very little.



A PERSON JUMPS FORWARD FROM SOLID PAVEMENT.

The same force applied during a jump will create the same push (F_a for applied force) and an equal but opposite "reaction force" (F_r). But this time there is an opposite relationship between the masses of the objects!



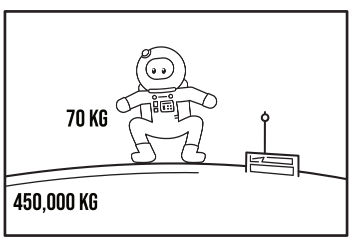
PERSON JUMPS FORWARD WITH THE SAME FORCE AS BEFORE, BUT THIS TIME STANDING ON A SKATEBOARD.

SKATEBOARD JUMP EXPLAINED: The person and pavement experienced the same force, but the mass of the pavement was a LOT bigger than the mass of the person, so the person experienced more acceleration (remember F=ma). With the skateboard, we have the same force pair but the mass of the skateboard is much smaller, so it experiences more acceleration.

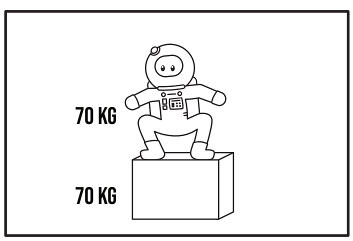
JUMPING IN OUTER SPACE! PREDICT THE FORCE & ACCELERATION IN EACH SCENARIO:

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

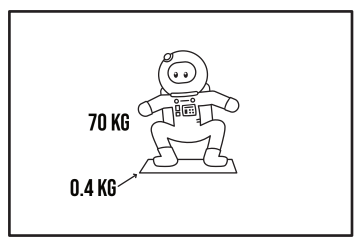
Which object experiences more force or acceleration? Circle the correct answer for each situation.



JUMP FROM ROOF OF LARGE SPACE STATION



JUMP FROM BOX WITH EQUAL MASS

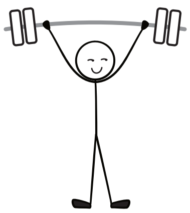


JUMP FROM A PIECE OF THIN ALUMINUM

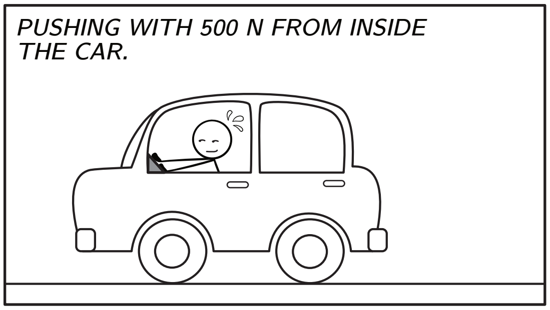
WHICH EXPERIENCES GREATER FORCE?	ASTRONAUT SPACE STATION SAME	ASTRONAUT BOX SAME	ASTRONAUT ALUMINUM SAME
WHICH EXPERIENCES GREATER ACCELERATION?	ASTRONAUT SPACE STATION SAME	ASTRONAUT BOX SAME	ASTRONAUT ALUMINUM SAME

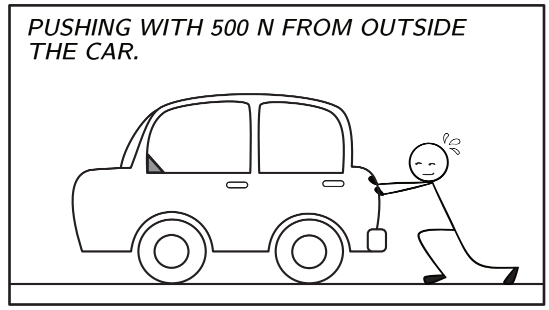
Would it move?

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!



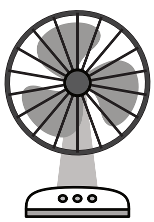


Both cars are in neutral gear. 230 newtons of force could propel them forward if applied correctly.

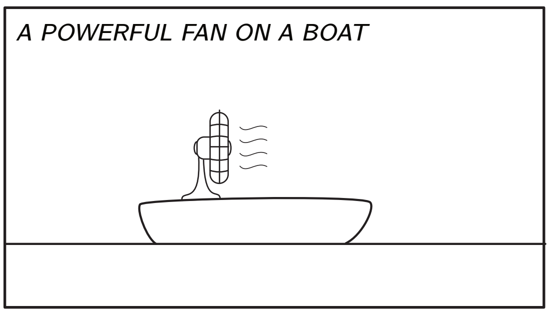
Record what you predict would happen:

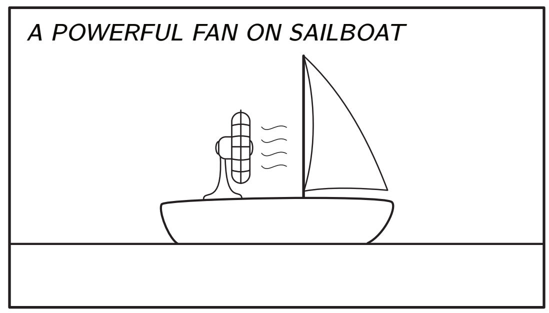
The car would stay in place.

The car would move.



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





Record what you predict would happen:

The boat would move more than the boat with the sail.

Depends on the shape of the sail! With a flat sail, the forces would balance each other out and there would be little to no movement. With a curved sail, there would be movement, but not as much as if the fan was faced in the opposite direction.

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?

As the air rushes out of the balloon, it pushes against the balloon with some force. According to Newton's third law, the balloon pushes back with an equal and opposite force, causing the balloon to fly around the room.

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 only if both push with equal effort
C. No
D. No, unless their mass changes

The same mass and equal but opposite forces will result in equal but opposite accelerations from a velocity of zero m/s. Individual effort does not change the outcome.

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?

F=ma, so the mass and acceleration have the same product with opposite signs. However, the cannon has much more mass, so it has a lower acceleration.

$m\mathbf{a}=-\mathbf{M}a$

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

Yes! Newton's third law guarantees that an equal but opposite force to gravity pulls on the Earth. However, the mass of the Earth is too large to be moved or accelerated by such a force.

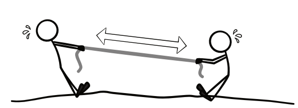
5. A male ice skater and a female ice skater push off of each other. The male has a mass of 100 kg, and the female has a mass of 50 kg. If the male skater accelerates to the right at 2 m/s^2, how quickly does the female skater accelerate?

They experience equal but opposite forces. F=ma, and acceleration and mass are inversely proportional, so the the male skater has twice the weight but half the acceleration. The female skater will accelerate to the left at a rate of 4 m/s^2.

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?

The net force downward is 27 N, so the floor exerts a force (normal force) of 27 N upward.

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. For every force there is an equal and opposite counter force.

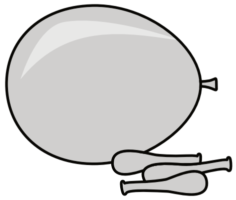
T F Actions and reactions always result in motion.

T F When a bug and a windshield collide, the bug hits the windshield with as much force as the windshield hits the bug.

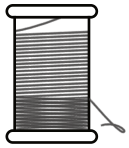
The net force may still be 0 so there might not be any acceleration.

RACING BALLOONS

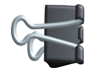
MATERIALS



2 to 4 Balloons

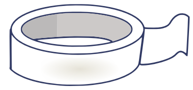


10 or more meters (32+ feet) of thin thread or fishing line

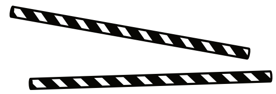


Clip or clothespin (optional)

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



Tape

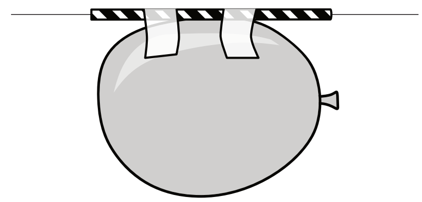


2 straws

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?

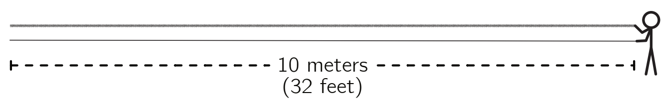
Will the balloon/straws move along the string? If yes, in which direction? Which balloon will move more, the one on thread or twine?

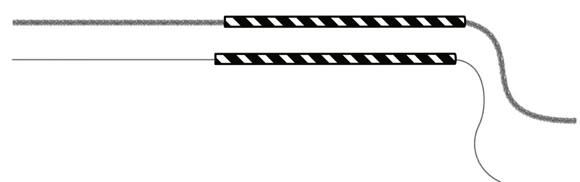
My prediction: ____

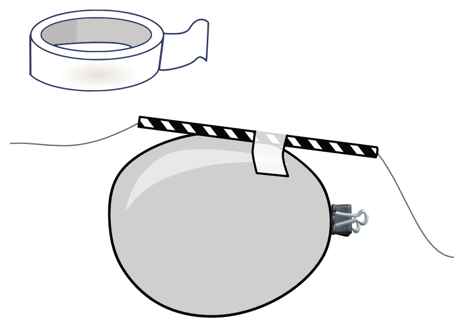
____

____

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.

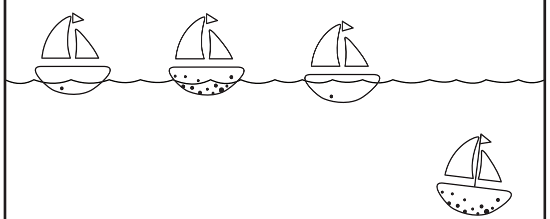
TIPS FOR SUCCESS:

- 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?

____

____

____

____

RACING BALLOONS DATA

Record the distance each balloon traveled

	THREAD or FISHING LINE	TWINE or THICK YARN
1st attempt		
2nd attempt		
3rd attempt		
4th attempt		
5th 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:

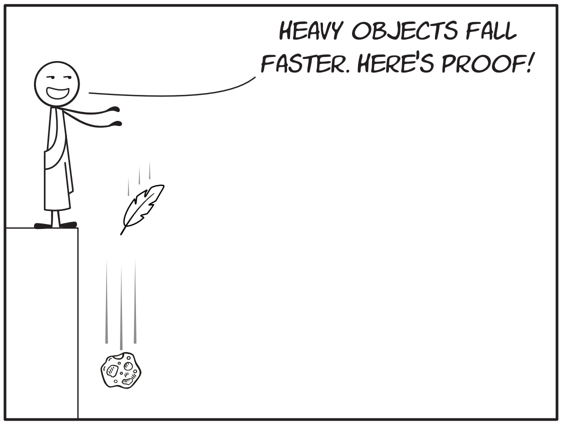
⇨ Change the angle of the string!
Does the balloon move faster if it's going downhill? What about uphill? Can you find the maximum slope where it will still travel to the end of the thread/fishing line?

⇨ 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?

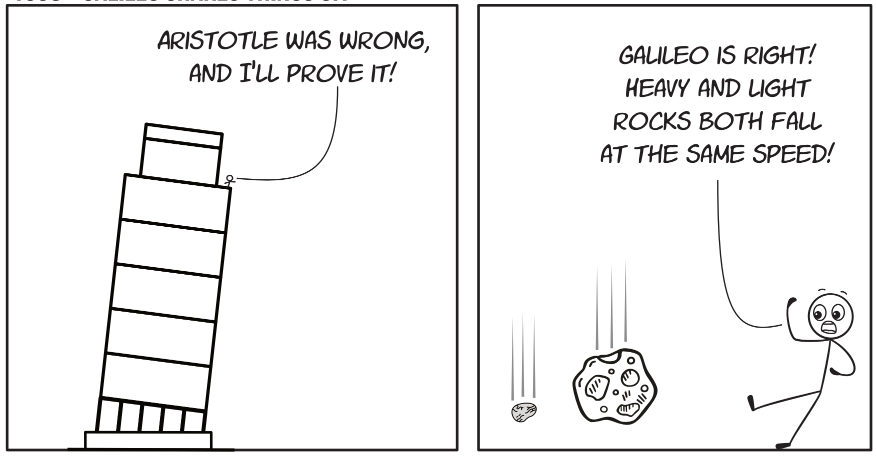
Down to Earth

Understanding The Force of Gravity

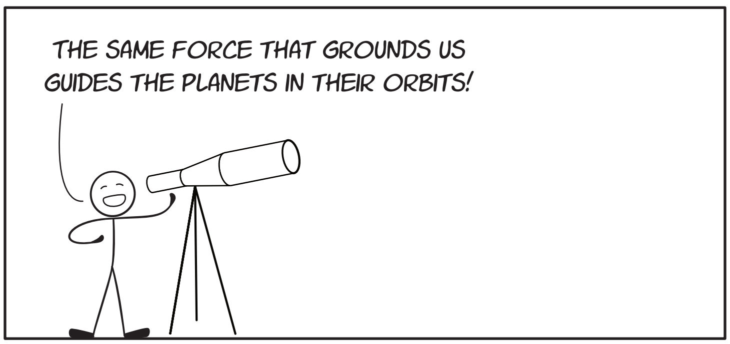
BEFORE 1638 – MANY SIMILAR IDEAS ABOUT GRAVITY EXIST IN VARIOUS CULTURES.



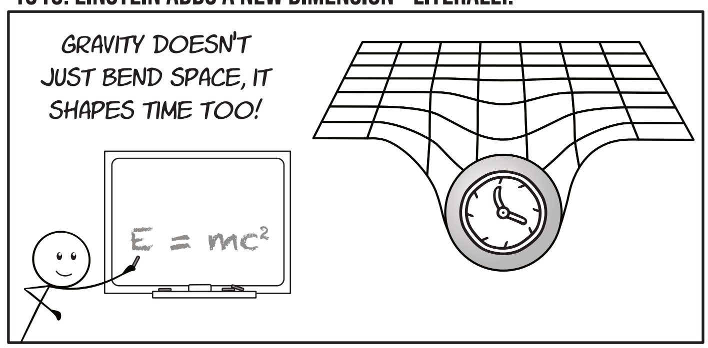
1638 – GALILEO SHAKES THINGS UP.



1687: NEWTON DESCRIBES UNIVERSAL GRAVITATION.

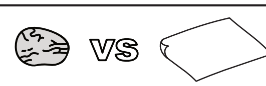


1915: EINSTEIN ADDS A NEW DIMENSION - LITERALLY.



Predict and record the outcome:

A piece of unfolded paper and a rock are dropped at the same time from the same height.



Which will land first, paper or rock?

PREDICTION: Answers will vary

OUTCOME: The rock lands first because air resistance slows the unfolded paper

The same drop is repeated, but this time the paper is crumpled into as small of a ball as possible.

Which will land first, paper or rock?

PREDICTION: Answers will vary

OUTCOME: The rock and paper land at the same time

Free Fall

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

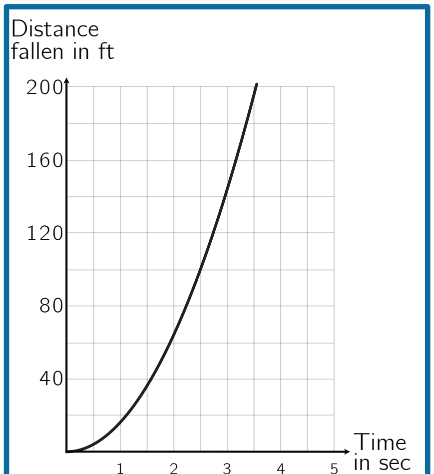
The gravitational constant, g, can be either 32 ft/s^2 or 9.8 m/s^2.

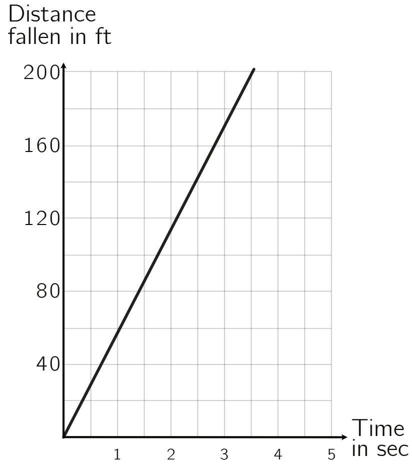
Example: If an object falls for 5 seconds, it will fall a total distance of $h = \frac{1}{2} \cdot 32 \cdot 5^2 = 400$ ft.

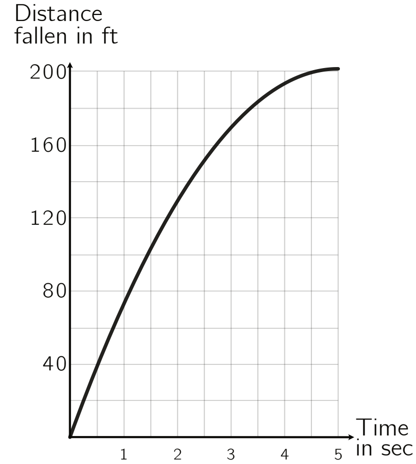
Use the height formula to find the total distance that an object falls for each of the remaining values in the table below:

Total time (in s)	0	1	2	3	4	5
Total distance (in ft)	0	16	64	144	256	400

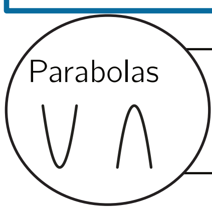
Which of the graphs matches the data in the table?







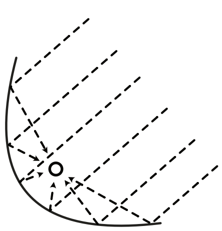
Objects fall slowly at first and then speed up as they fall.



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!

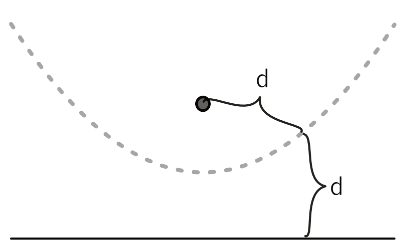
Are these FACT or FICTION? Write your verdict below each statement:

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



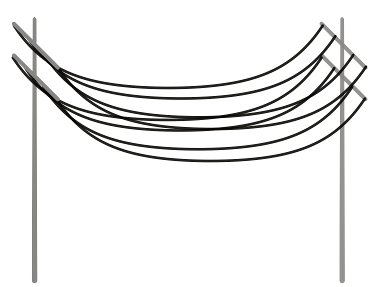
Fact. That's why satellite dishes are based on parabolas.

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



Fact. Those points always form a parabola.

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



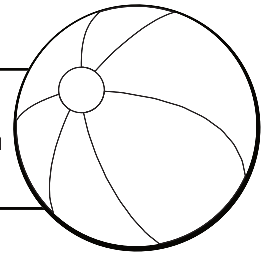
Fiction. They make a different shape called a catenary.

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?

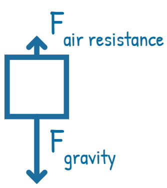
Golf Ball	vs	Steel Ball	vs	Beach Ball
Radius: 2 cm		Radius: 2 cm		Radius: 43 cm
Mass: 1.6 oz		Mass: 18.9 oz		Mass: 1.6 oz



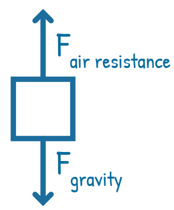
A bigger sphere will experience more air resistance, and a heavier sphere is pulled harder by gravity, so they all fall at the same rate at first, but the beach ball will reach its terminal velocity first, followed by the golf ball and eventually the steel ball. The steel ball has the fastest terminal velocity.

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

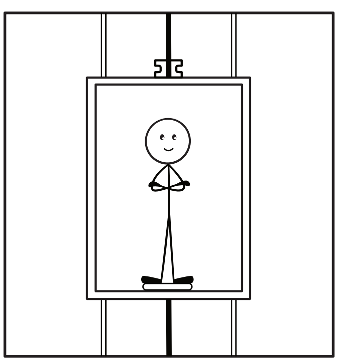
1 second after being dropped



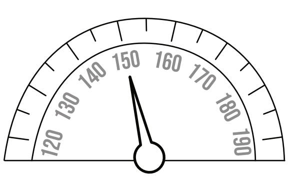
15 second after being dropped

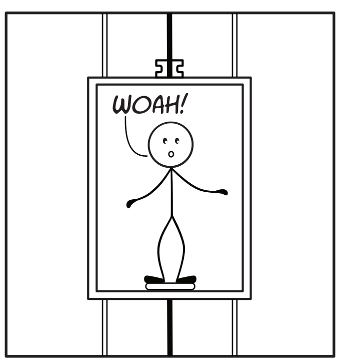


A person who weighs 150 lb (68 kg) is standing on a scale in an elevator. The elevator is stationary in the beginning. Then it accelerates, traveling up to the 20th floor where it slows to a stop. In the situations illustrated below, will the scale show readings that are higher, lower, or the same? Circle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

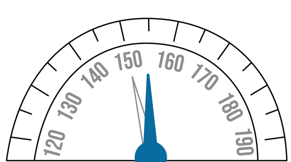


ELEVATOR IS STATIONARY AT GROUND FLOOR

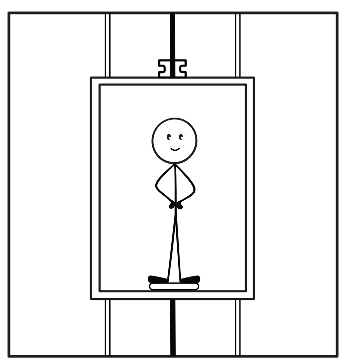




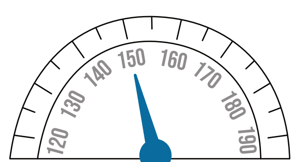
ELEVATOR SPEEDING UP OR ACCELERATING UPWARD



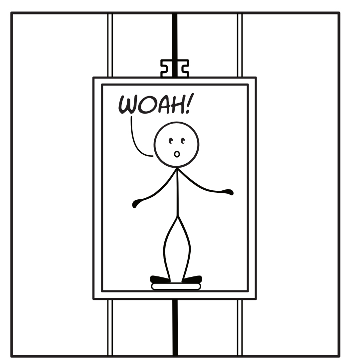
LOWER SAME HIGHER



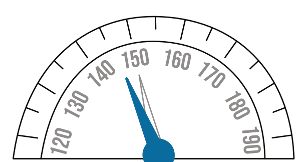
ELEVATOR MOVING AT CONSTANT SPEED TOWARD THE 20TH FLOOR



LOWER SAME HIGHER



ELEVATOR SLOWING DOWN AS IT REACHES THE 20TH FLOOR



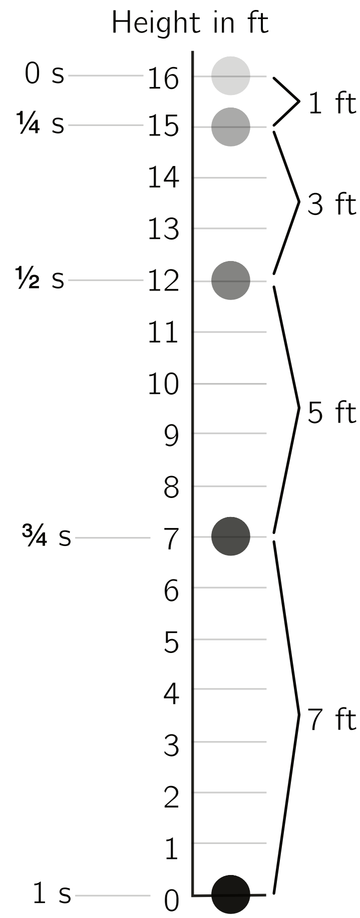
LOWER SAME HIGHER

NOTE: actual values of the scale will depend on how fast the elevator accelerates and decelerates.

Practice Problems – Gravity and Freefall

Use the formula for fall distance: $h = 16t^2$ to find how fall 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)	0	1	4	9	16

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

The numbers in the second row are the perfect squares:

0^2, 1^2, 2^2, 3^2, 4^2.

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

We could use the pattern in the bottom row to answer this. $81=9^2$, so it would appear at the end of 9 time intervals in the table. Since each interval is 0.25 seconds in length, it would take $9 \cdot 0.25 = 2.25$ seconds to fall 81 ft.

Alternatively, one could solve the equation $81=16t^2$ for t.

(4) Explain what terminal velocity is and what causes it.

Terminal velocity is the maximum downward speed an object will reach in freefall. When the force of friction due to air resistance is equal and opposite to the force of gravity, then forces are balanced, and the object will no longer accelerate.

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

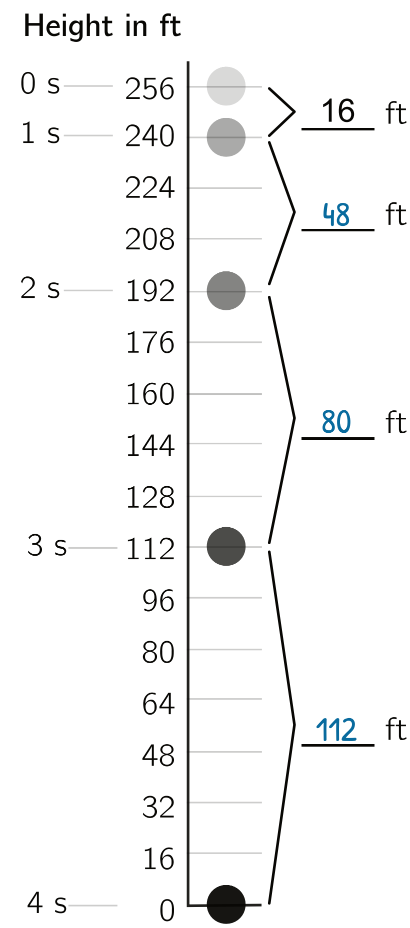
No. Terminal velocity depends on air resistance, so the shape of the object matters. Two objects of the same mass can have very different air resistances if their shape is different. A 1 kg bird will glide, but a 1 kg rock will fall quickly.

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

No. Terminal velocity depends on air resistance. The Moon has no atmosphere, so there is no terminal velocity on the Moon.

Practice Problems – Gravity and Freefall

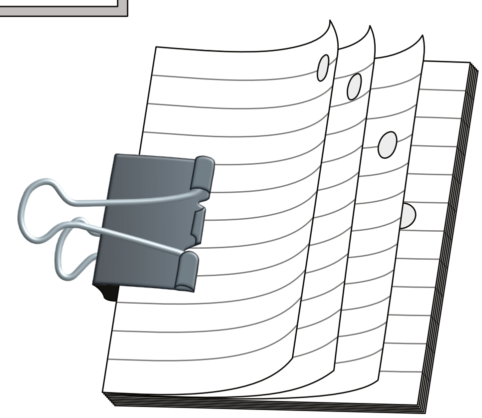
7. An object dropped from a height of 256 ft will hit the ground in 4 seconds as pictured to the left.
   Fill in the table below to record the total distance fallen at each interval.
   Next, fill in the blanks to identify how far the object fell in each 1-second interval.



Total time falling (in s)	0	1	2	3	4
Total distance (in ft)	0	16	64	144	256

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...

BONUS ACTIVITY: FLIP BOOK PHYSICS



1. Cut a stack of 3″×5″ 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 pulls on every other object. This force is directly proportional to each mass and inversely proportional to the square of the distance.

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

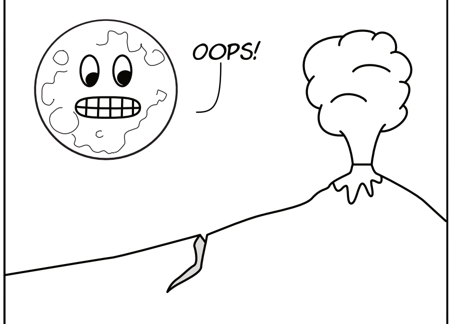
Mass of first object multiplied by the mass of the second object

Distance between the objects squared

Gravitational constant (an extremely small number)

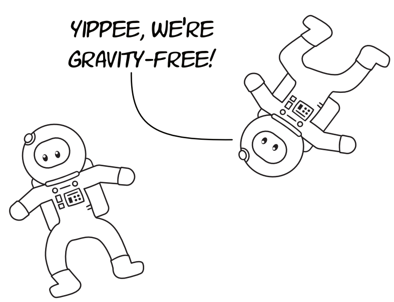
FACT OR FICTION? *Write your verdict below each statement:*

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



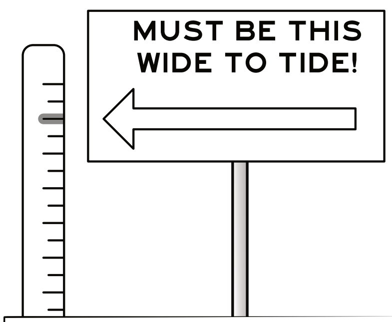
FACT

There is no gravity in outer space.



FICTION

Tides occur in oceans but not in ponds.



FACT

EXPLAIN WHY EACH STATEMENT WAS FACT OR FICTION:

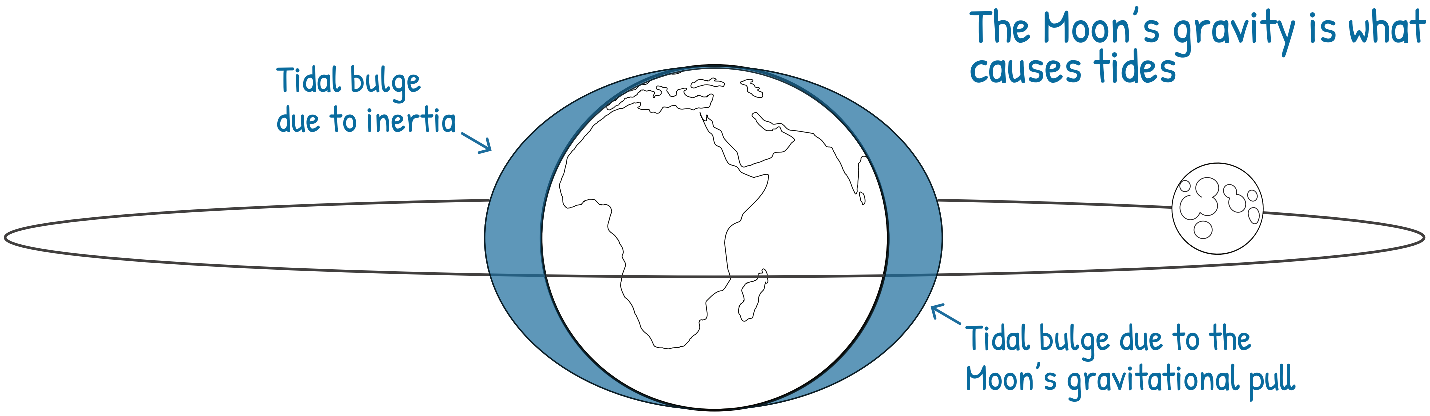
The pull of the Moon's gravity causes tides in the ocean, but it also causes "earth tides" where the solid surface of the Earth moves by as much as ¼ of a meter! As a result, both earthquakes and volcanic eruptions are SLIGHTLY more likely during the spring tides – which occur during each full and new moon.

This is a common misconception! Astronauts feel weightless in space, but they still experience the effects of gravity. If they are in orbit around a planet, then they are in a state of free fall. Far from any large object, the distance could be so great that they don't feel a noticeable effect from gravity. But the force is still there!

Ocean tides are caused by the DIFFERENCE in gravitational attraction between different parts of the ocean.

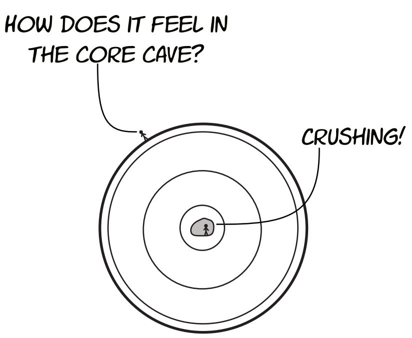
Ponds and people are simply not large enough for there to be a significant difference in the attractive pull of gravity on one side of the pond/person and the other.

Tides and Orbits



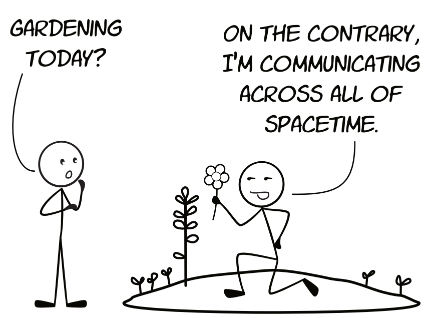
FACT OR FICTION? *Write your verdict below each statement:*

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



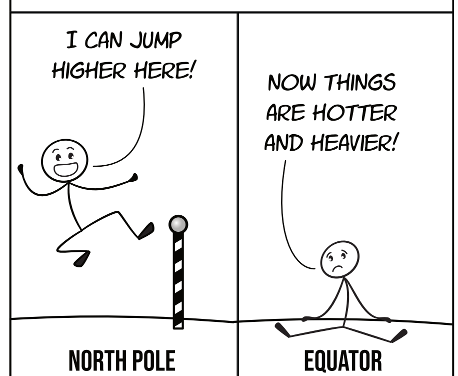
FICTION

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



FACT
(but needs clarification)

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



FICTION

EXPLAIN WHY EACH STATEMENT WAS FACT OR FICTION:

Assuming that it was possible to have a "cave" in the Earth's core, the force due to gravity would be close to zero because the mass of the Earth would be pulling equally in all directions, effectively cancelling each other out.

An object inside a hollow planet would experience no net gravitational pull!

The word "move" in this famous quote is used metaphorically.

The gravitational field of any object, no matter how small, extends through all of spacetime. Amazing, right?! But remember, the strength of a gravitational field decreases rapidly with increasing distance.

So the gravitational field of a flower will not have a measurable effect on any stars.

It's the opposite. For the same elevation above sea level, the force of gravity will be less at the equator than the poles.

Because the Earth is an oblate spheroid (has a squished-shape), points on the equator are further away from the center of Earth's mass than points at the poles. Since d^2 is larger, the overall force of gravity will be smaller.

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?

   As she throws the wrench, the astronaut exerts a force on the wrench, and the wrench exerts a force back. That reaction force is in the direction of the ship (opposite the throwing force) so the astronaut would accelerate back toward the ship. Whether it would work or not all depends on how far the ship drifted and how much force the astronaut can give to the throw.

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?

   You would weigh three times as much. Gravitational force is directly proportional to each mass, so tripling the mass will triple the weight.

4. If the Earth had the same mass but three times the radius, how would your weight on Earth change?

   You would only weigh 1/9 of what you currently weigh. Gravitational force is inversely proportional to the square of the distance between the centers of mass, so multiplying the distance by 3 reduces the weight by a factor of 1/9.

5. If object B has twice the weight of object A, why do both objects fall at the same rate?

   Object B has twice the weight, but it also has twice the mass and that inertia makes it harder to speed up. In terms of Newton's 2nd Law we have: $a = \frac{F}{m} = \frac{2F}{2m}$

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. Greater distance reduces the force of gravity.

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?

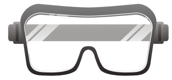
In the next few pages you'll find 3 options for an experiment where you could present your results as a lab report. Choose at least one. Then share your results and conclusions with a family member, friend, or classmate! Which lab(s) will you choose?

- [ ] Water Rocket Lab
- [ ] Fall Time vs Height Lab
- [ ] Horizontal Motion and Gravity Lab

WATER ROCKET LAB

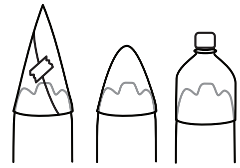
MATERIALS

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

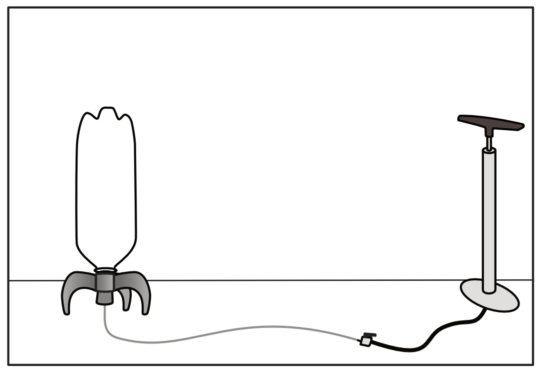
A water rocket is a type of model rocket that uses water and pressurized air to launch a plastic bottle up into the air. Like all rockets, water rockets operate on the principle of Newton's third law of motion: for every action, there is an equal and opposite reaction.

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 m/s^2 (or 32 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 ½ of the* ***hang time*** *or ½ 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.

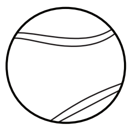
When using a rubber cork or bung, the amount of pressure will vary!

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

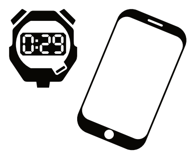
For notes and doodles

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

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

Example.

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

$$h = \frac{1}{2}(9.8\,\mathrm{m/s^2}) \cdot (4\,\mathrm{s})^2 = 78.4\,\mathrm{m}$$

or

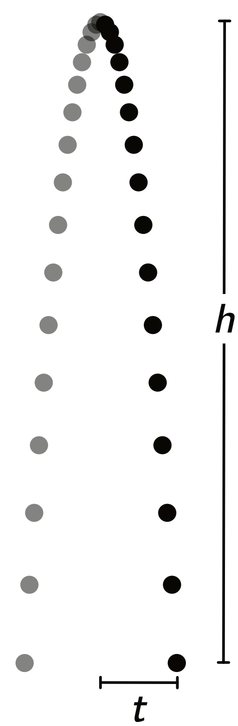
$$h = \frac{1}{2}(32\,\mathrm{ft/s^2}) \cdot (4\,\mathrm{s})^2 = 256\,\mathrm{ft}$$

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 ft/s^2 for g. If your estimation was in meters, use 9.8 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.

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

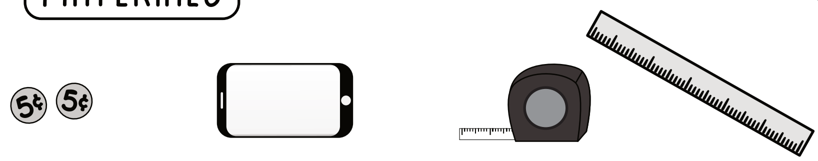


Extensions:

1. How high could you throw a ball on the Moon where g = 1.62 m/s^2 or 5.31 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



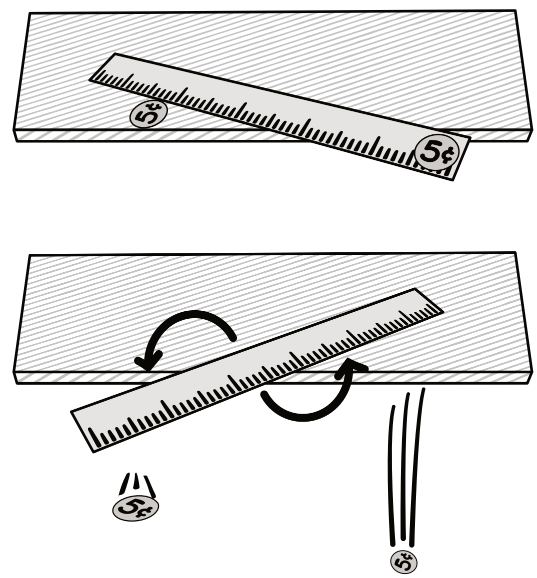
Two identical coins | Camera for timing | Measuring tape | Ruler

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)

	Time for vertically dropped penny *V*	Time for horizontally launched penny *H*	Difference in time *V-H*
AVERAGE:			

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

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

The height equation!

Calculated Height for V penny: ______________________________

Calculated Height for H penny: ______________________________

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?

____

____

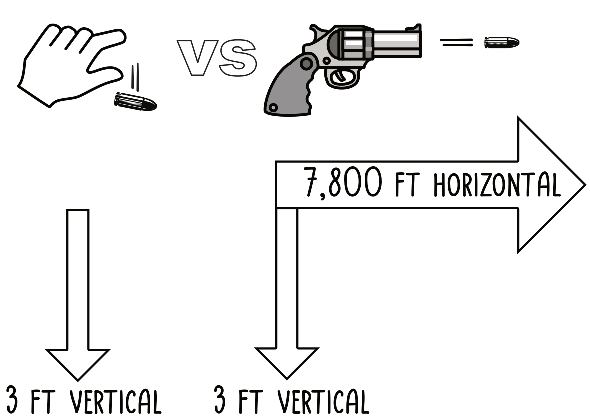
Does your data show a difference in the average fall times between the two coins?

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.

____

____

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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ASSESSMENT

BE SURE TO HAVE A PENCIL AND SCRATCH PAPER!

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

Law of Reaction: 3

Law of Inertia: 1

Law of Acceleration: 2

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 1st Law
B. Newton's 2nd Law
C. Newton's 3rd Law
D. The statement is actually false.

"Acceleration occurs when forces are unbalanced." This is the converse of the 1st law and is described precisely by the 2nd law.

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 1st Law
B. Newton's 2nd Law
C. Newton's 3rd 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^2
B. 24 m/s^2
C. 1.5 m/s^2
D. 0.67 m/s^2

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 1st 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 1st Law
B. Newton's 2nd Law
C. Newton's 3rd Law
D. Newton's 4th 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 m/s². What is the net force acting upon the ball along the slope of the ramp?

A. 1/6 N
B. 2/3 N
C. 3/2 N
D. 6 N

11 What is the mass of an object if a force of 12 N causes it to accelerate at 3 m/s²?

$F = ma$, so $12\ kg \bullet m/s^2 = m \bullet 3\ m/s^2$.

The object has a mass of m=4 kg.

12 What is the acceleration of a 20 kg object if a force of 10 N is applied to it?

$F = ma$, so $10\ kg \bullet m/s^2 = 20\ kg \bullet a$

The acceleration is $0.5\ m/s^2$.

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

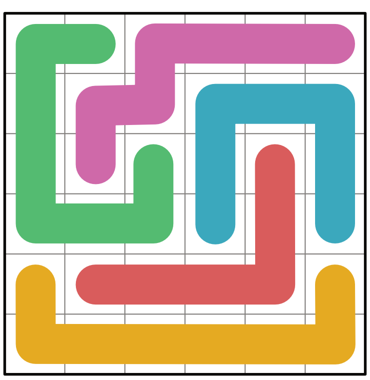
15 Gravity on Earth is 6 times as strong as gravity on the moon. An object with a mass of 12 kg on Earth will have how much mass on the Moon?

A. 0 kg
B. 2 kg
C. 6 kg
D. 12 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

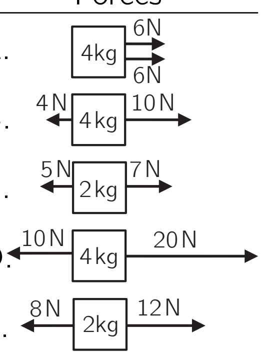
Pipe Flow Matching – Unit 2

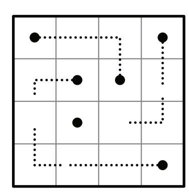


Use Newton's 2nd law to rank the acceleration of objects A-E below from slowest to fastest. Record your answer in the grid by joining the answers with a continuous stroke (pipe). Each square in the grid should be visited by exactly one pipe.

Acceleration rightward — Forces

1. Slowest — A.
2. Slow — B.
3. Medium — C.
4. Fast — D.
5. Fastest — E.

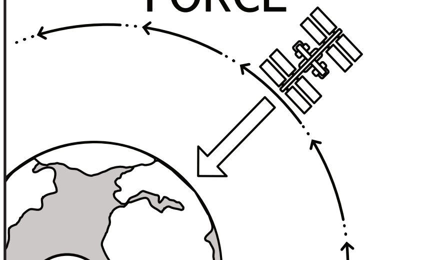




Unit 3: Work, Machines, & More

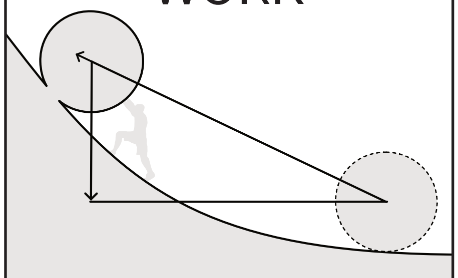
In this unit, we'll learn more about how physics impacts daily life by exploring energy, work, power, rotational motion, and simple machines.

CENTRIPETAL FORCE



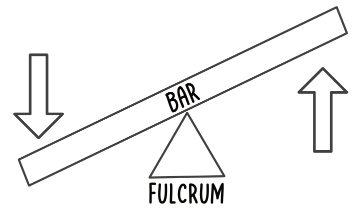
$F_c=\frac{mv^2}{r}$ The inward force causing circular motion

WORK



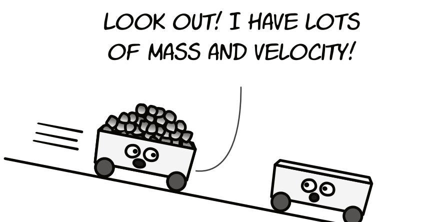
$W=F\cdot d$ Energy transferred when force causes displacement

LEVER



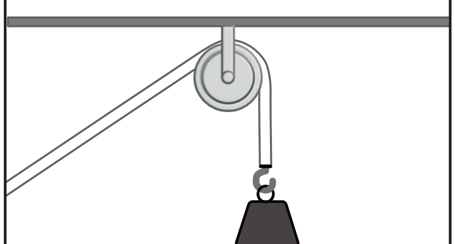
One of the six classic simple machines

MOMENTUM



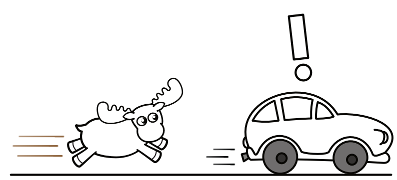
$\vec{p}=m\cdot\vec{v}$ The product of mass and velocity

PULLEY



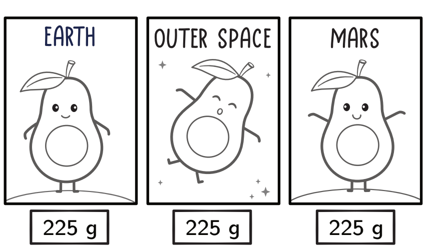
One of the six classic simple machines

KINETIC ENERGY



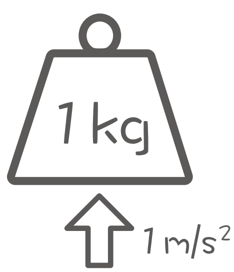
$KE=\frac{1}{2}mv^2$ Energy due to motion

MASS



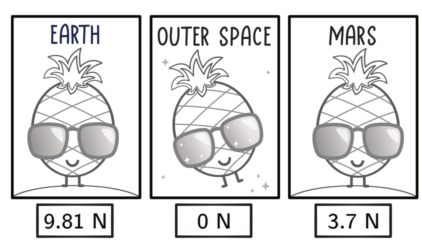
kg or g The amount of matter in an object or particle

NEWTON

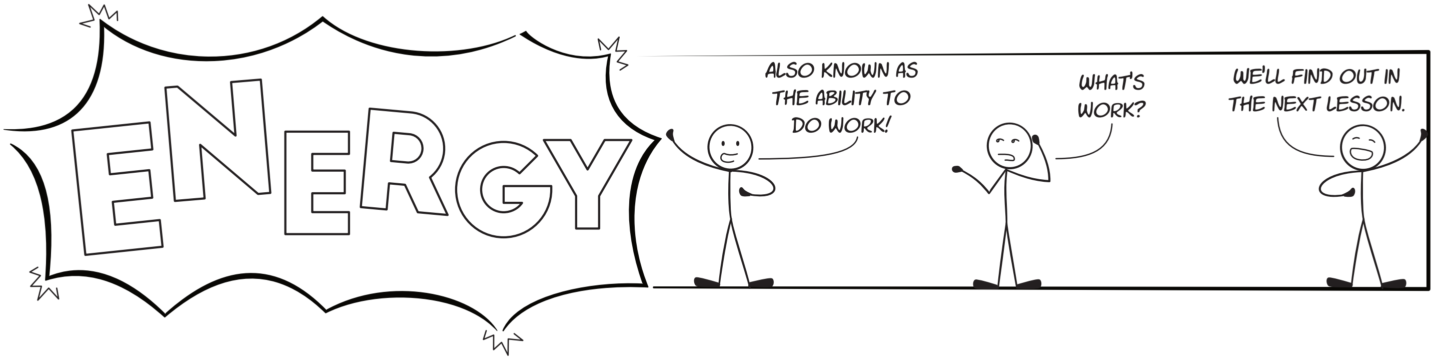


$1 kg\cdot m/s^2$ The force that gives 1 kg an acceleration of 1 m/s^2

WEIGHT



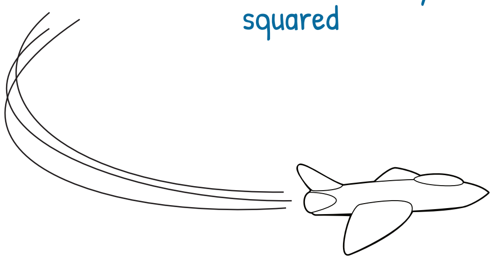
$W=m\cdot g$ The force acting on an object due to gravity



Kinetic Energy

$KE = 1/2mv^2$

Kinetic energy = one half of mass times velocity squared



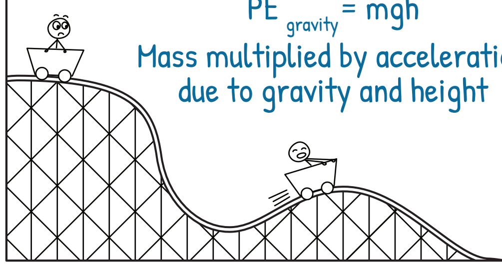
Potential Energy

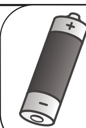
STORED energy – many sources!

$9.8\ m/s^2$

$PE_{gravity} = mgh$

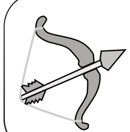
Mass multiplied by acceleration due to gravity and height





Chemical / Electric

Magnetic



Tension

FILL IN THE BLANKS:

stored	*energy*	*joules*	*mass*	*velocity*	*potential*	*height*

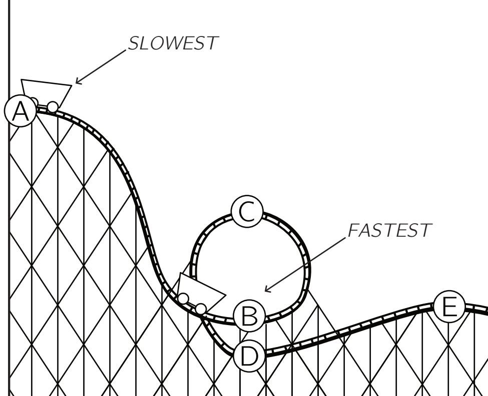
Kinetic _energy_ depends on both the _mass_ and _velocity_ of an object. Potential energy is _stored_ energy, and there are many different types! Gravitational _potential_ energy is calculated using mass, _height_, and gravitational acceleration ($9.8\ m/s^2$ on Earth). Both PE and KE are measured in _joules_.

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

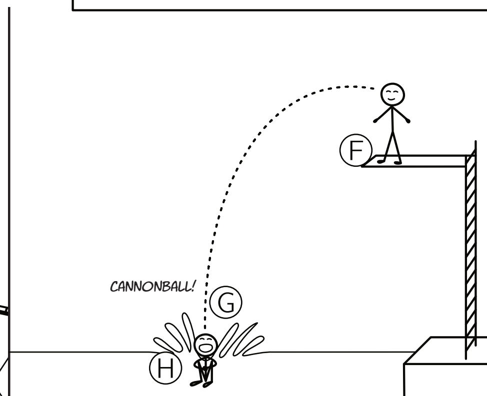
Kinetic Energy:	Potential Energy:
1. Answers will vary but could include objects in motion such as a car driving, bird flying, water flowing etc.	1. Answers will vary but could include food (chemical energy that can be converted into heat and movement by our bodies), water in a reservoir that is at a higher level than the river below (the gravitational energy of a hydroelectric dam), and many other examples.
2.	2.
3.	3.

WHERE IS THE ENERGY?

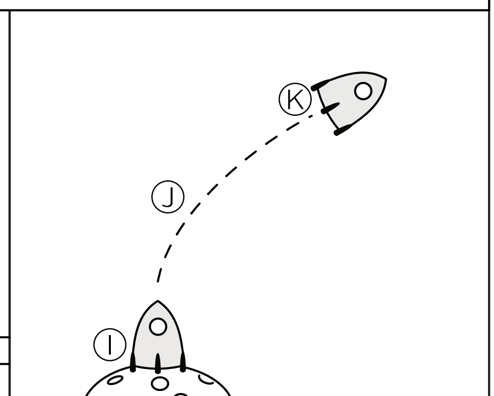
IDENTIFY WHERE THE MOST POTENTIAL, KINETIC, AND TOTAL ENERGY IN EACH SCENARIO.



Cart goes down a track



Person dives into pool



Rocket launches from moon

Maximum PE: A
Maximum KE: B (D w/o friction)
Maximum Total E: All the same

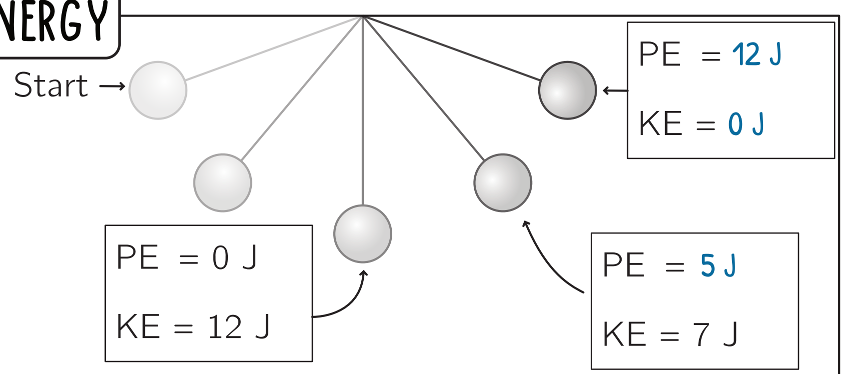
Maximum PE: F
Maximum KE: G
Maximum Total E: All the same

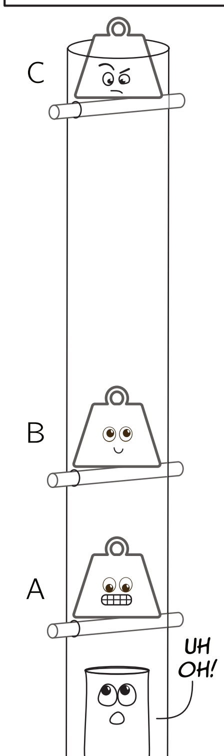
Maximum PE: I
Maximum KE: K
Maximum Total E: All the same
(Note: we're just looking at mechanical energy for these questions)

LAW OF CONSERVATION OF ENERGY

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

$$PE_1 + KE_1 = PE_2 + KE_2$$

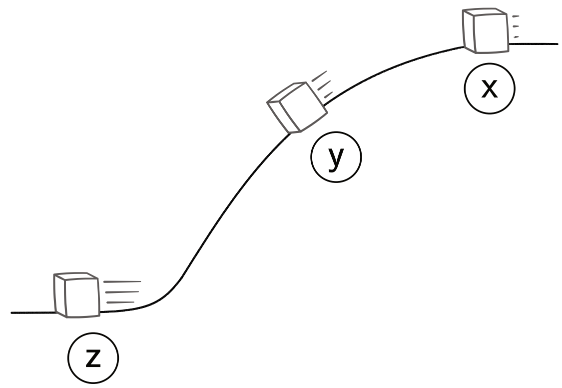




A weight is dropped from different heights onto an empty aluminum can. One weight is just above the can (A). Another is twice as high (B), and another is at the top of the tube (C). Which weight will squish the can the most and why?

Weight C will squish the can the most. C starts with higher potential energy because it is higher up. When each weight falls, the potential energy is converted to kinetic energy so weight C will hit the can at the highest velocity.

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)

Almost all potential energy and just a little bit of kinetic energy

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

At point y it has both potential and kinetic energy.

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

Just kinetic energy (energy of movement) because it's at the bottom of the hill.

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

Trick question! The total energy is equal at all 3 points.

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

A. PE = mgh
B. KE = ½mv^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?

Yes, the expressions contain the same information.

Weight is mass multiplied by g (gravitational acceleration).

Since W= mg, then mgh (mass · g · height) is the same as Wh (weight · height).

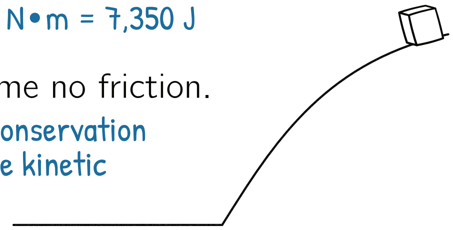
4. What information is needed to calculate kinetic energy?

A. Mass and velocity Remember KE=1/2mv^2
B. Mass, velocity, and height
C. Mass, height, and the gravitational constant
D. Height, velocity, and the gravitational constant

5. There is a 15 kg box sliding down a hill that is 50 meters high.

A. If the box starts from rest at the top of the hill, what is its potential energy at the top of the hill?

Potential Energy = mgh = 15 kg • 9.8 m/s^2 • 50 m = 7,350 N•m = 7,350 J



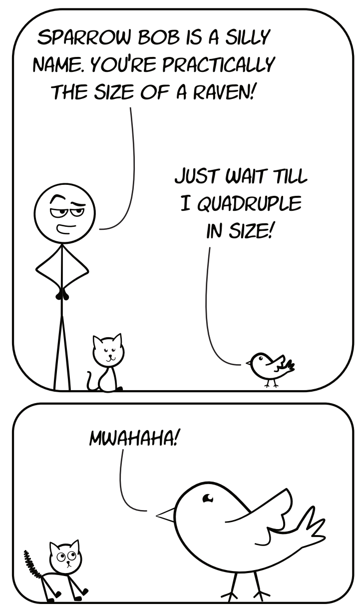
B. What is its kinetic energy at the bottom? Assume no friction.

Kinetic Energy at the bottom = 1/2 mv2, but by the law of conservation of energy, the potential energy at the top will be equal to the kinetic energy at the bottom. Hence it is also 7350 Joules.

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?

Kinetic Energy = 1/2 mv^2 = 1/2 • 0.145 kg • (40 m/s)^2 = 116 kg·m^{2}s^2 = 116 J.

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.



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

Kinetic energy is directly proportional to mass, so quadrupling the mass will quadruple the kinetic energy from 2 J to 8 J.

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

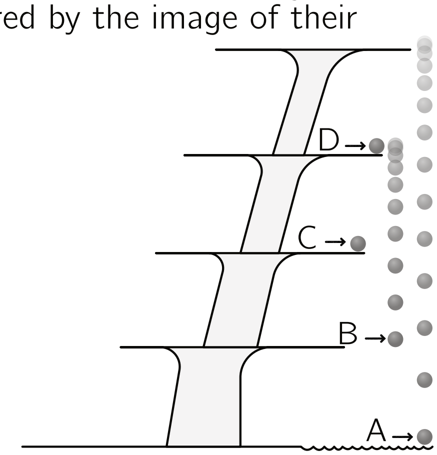
Kinetic energy is directly proportional to the velocity squared, so quadrupling the velocity multiplies the kinetic energy by a factor of 4^2 from 2 J to 32 J.

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

Half the mass cuts the kinetic energy in half, but doubling the velocity multiplies the kinetic energy by 4, so the total kinetic energy goes from 2 J to 4 J.

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.



Potential energy only depends on height. The speed they have is irrelevant for this question!

From least PE to greatest PE we have A, B, C, and D.

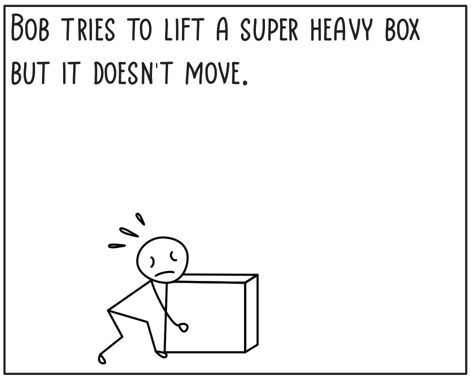
WORK

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

Answers will vary.

Things like picking up books from the floor and putting them on a shelf would be considered work in physics because objects are moved and a force is applied. But other work such as studying might not be work according to physics if nothing is displaced or moved.

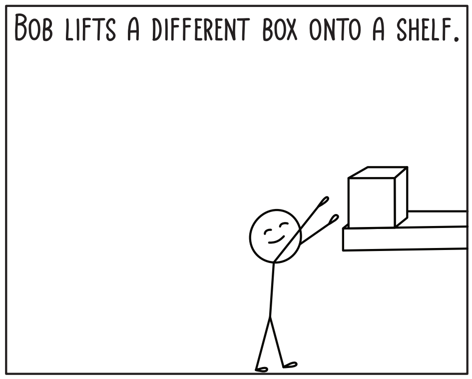
Look at the examples you listed. In physics, **work** occurs when a **force** causes **displacement**. Which examples are also considered work according to physics? Identify the force and displacement for each.



Did Bob do work? Y N

What provided the force?

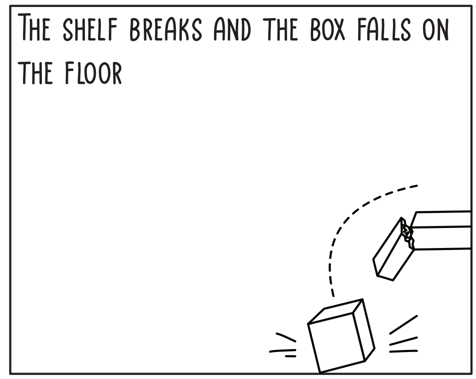
Bob*



Did Bob do work? Y N

What provided the force?

Bob



Did work happen? Y N

What provided the force?

Gravity

*In the case of Bob's quivering muscles, there was both force and movement so work did happen. But only within the muscles. In regards to the box - there was no movement and hence no work.

$$W = Fd$$

Work equals force multiplied by displacement*

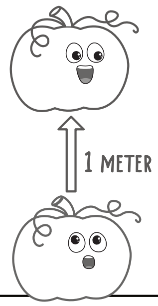
If the force does not cause displacement, then work (according to physics) didn't happen.

A force is always involved when work is happening. Can be gravity, a push, a pull, friction, any force will work! (pun intended)

*Note: Force and displacement must be acting along the same line of motion!

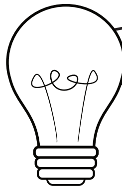
You can't have work without displacement, even if there is a force applied. Also, just because something is moving, that doesn't mean work happened! If there was no force applied (remember inertia) then no work happened. In physics, for work to have happened we need BOTH displacement and force.

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



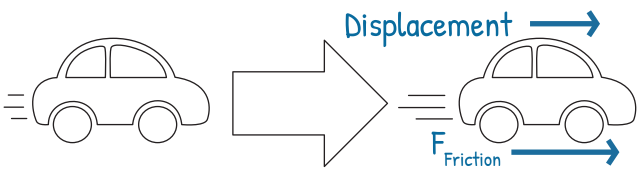
ENERGY VS WORK

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.

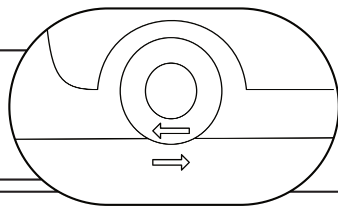
When work is done on an object, energy is transferred to or from that object.

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
- [x] West

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

- [ ] East
- [x] West

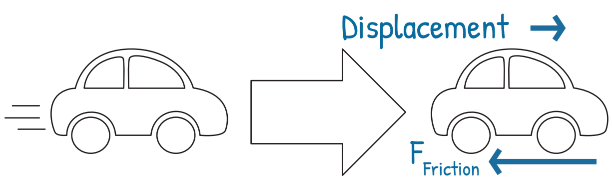
The net force and displacement are happening in the SAME direction, so work is positive.

Is the kinetic energy of the car increasing or decreasing?

- [x] Increasing
- [ ] Decreasing

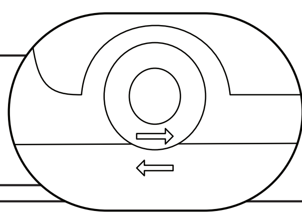
The car has greater speed (more kinetic energy) after accelerating.

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
- [x] West

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

- [x] East
- [ ] West

The net force and displacement are happening in OPPOSITE directions, so work is negative.

Is the kinetic energy of the car increasing or decreasing?

- [ ] Increasing
- [x] Decreasing

The car is slowing down and therefore has less kinetic energy than before.

+ POSITIVE WORK

When force is in same direction as displacement, we say the work is positive. Positive work results in an increase in energy.

− NEGATIVE WORK

When force is in opposite direction as the displacement, we say the work is negative. Negative work results in a loss of total energy.

Practice Problems – Work

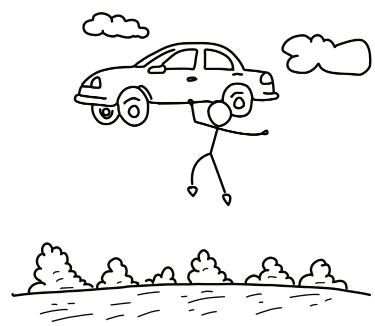
1. If you push a shopping cart with a force of 10 newtons for a distance of 5 meters, how much work did you do?

   Calculate work using the formula W = Fd.
   Substitute 10 N for force and 5 m for distance:
   W = 10 N•5 m = 50 J.

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)?

   By using the formula W = Fd and rearranging it to read: $d = \frac{W}{F}$
   In this case, 10,000 J = 500 N•d
   Divide both sides by 500 N. 10,000 J / 500 N = 20 meters

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?
   The work done is W = Fd. Substituting the given values,
   W = 10,000 N•20 m = 200,000 joules.



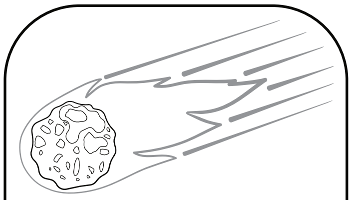
4. If a teacher pushes a desk across the room with a force of 100 newtons and does 500 joules of work, how far did the desk move?
   From the work formula W = Fd, we can solve for distance: d = W/F. Substituting the given values, d = 500 J / 100 N = 5 meters.

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?
   From the work formula W = Fd, we can solve for force (weight) by using F = W/d. Substituting the given values, F = 28,000 N / 20 m = 1,400 newtons, or about 315 pounds.

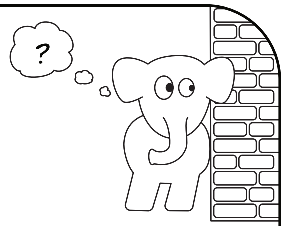
6. A hockey puck is moving at constant speed across a frictionless ice rink. Is work being done on the hockey puck?
   No because there is no force being applied.

Work & Power

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



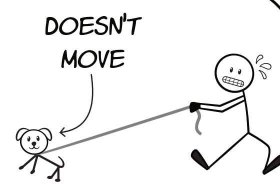
A Comet zooms through space at constant speed



An elephant leans against a wall, which does not move

Positive work / increase in energy

A person pedals their bike, accelerating to 10 mph



A person holds leash so a dog can't jump forward

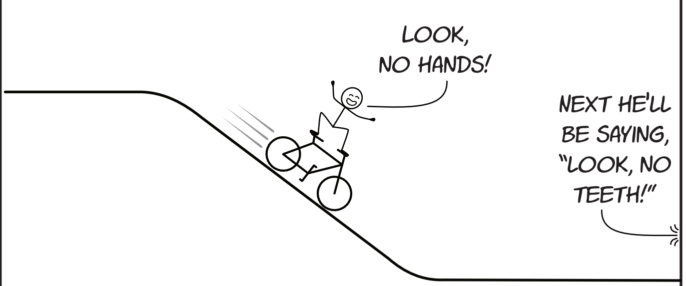
NO WORK HAPPENED

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: $\Delta KE = F \cdot d = Work$



When Diego rides a bike downhill, why does his speed increase without pedaling?

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

Speed increases without pedaling because of the conversion of potential energy (due to height) into kinetic energy (movement).

In a frictionless system, yes, the height could be calculated because the kinetic energy at the bottom of the hill would be equal to the potential energy at the top, so $mgh = \frac{1}{2}mv^2$

By substituting in the mass, acceleration due to gravity (9.8 m/s), and the velocity, we could calculate height.

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?

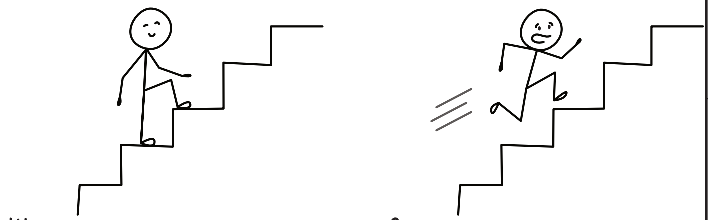
The energy to move the cart came from Tala. She did work on the cart which was transferred to KE.

$KE = \frac{1}{2}mv^2 = \frac{1}{2} \cdot 15\ kg \cdot (2\ m/s)^2 = 30\ kg \cdot m^2/s^2 = 30\ J.$

$Force = Work / Distance = 30\ J / 2\ m = 15\ N.$

So, Tala applies a force of 15 newtons to accelerate the cart to a speed of 2 m/s over a distance of 2 meters.

WHO DID MORE WORK?



The same amount of work occurs regardless of the speed! From bottom to top, the net force of starting and stopping is the same in both cases, and the distance is the same, so the work is also the same.

The reason it takes more effort to sprint up stairs than walk up them is because it requires more POWER to sprint than walk.

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

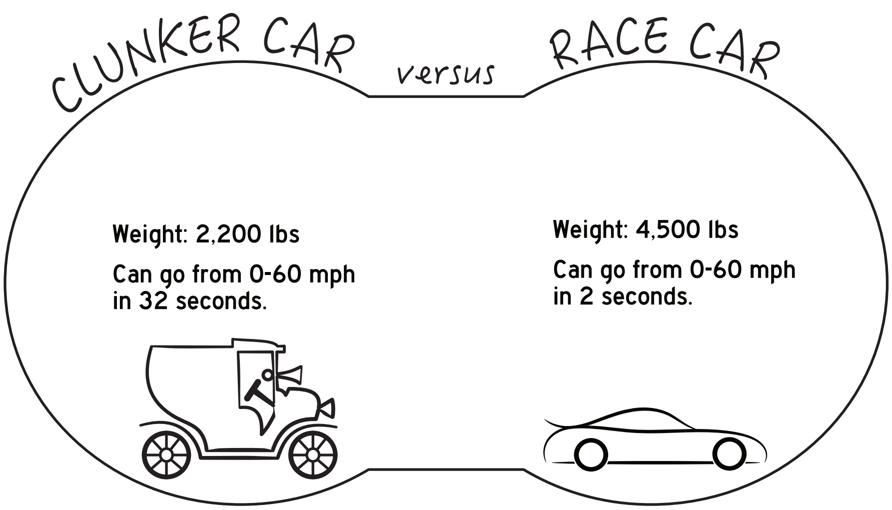
$$\text{power} = \frac{\text{work}}{\text{time}}$$

Power is the amount of energy transferred or converted per unit of time.

(Power = work divided by time).

WHAT ARE THE UNITS?

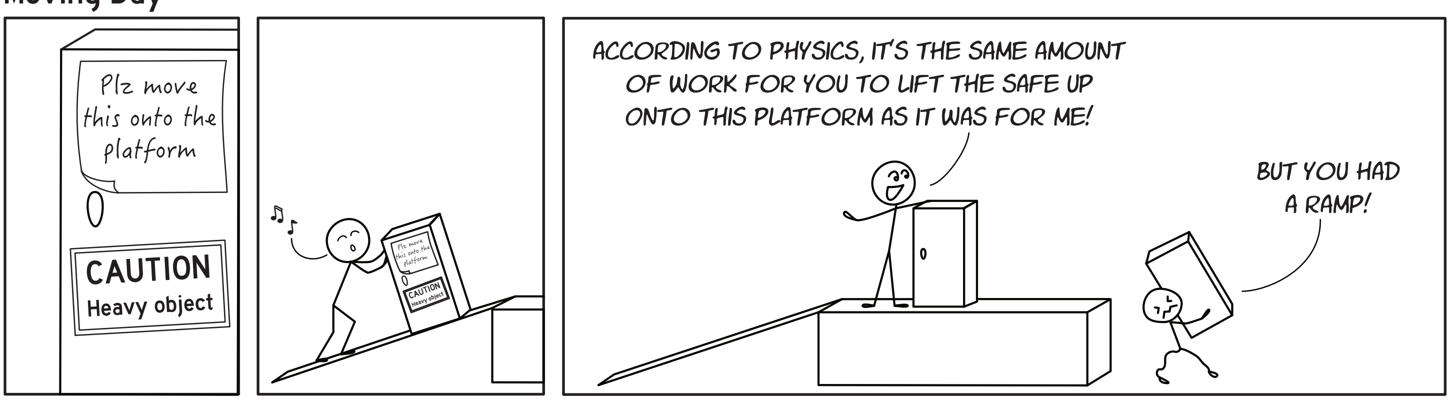
The SI unit of power is the watt (joule per second)



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

The race car has more power. Power is the rate at which work is done or energy is transferred. Despite being heavier, this car accelerates to 60 mph much faster. It transfers a greater amount of energy in less time, thus it has more power.

Moving Day



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.

Useful Equations:

$W=Fd$
$F = W/d$
$D = W/F$
$P=W/t$
$PE = mgh$
$KE = \frac{1}{2}mv^2$
$PE_1+KE_1 = PE_2+KE_2$
$\Delta KE = Fd$
$g = 9.8\ m/s^2$

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

   Variable we want to know: work (W)

   Formula: Work = Force x Distance or $W=F \cdot d$

   Work = 50 N x 15 m = 750 joules.

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?

   Variable we want to know = distance (d)

   Distance = Work / Force So, the work done is:

   Distance = 150 J / 30 N = 5 m.

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

   What we want to know = force (F)

   Force = Work / Distance. Thus, the force Maria applies is:

   Force = 1000 J / 20 m = 50 N.

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

   What we want to know: Power output (P)

   Power = Work / Time. Therefore, Tom's power output is: Power = 300 J / 20 s = 15 W.

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?

   What we want to know: force (F). We know distance (d) but not work (W). But we know the change in KE (from 0-30 m/s) so we want to use the equation:

   $\Delta KE = F \cdot d$

   The work done on the car equals the change in its kinetic energy. So, Work = $\Delta KE = 0.5mv^2 = 0.5 * 1000\ kg * (30\ m/s)^2 = 450{,}000$ Joules. Work is also force times distance, so Force = Work / Distance = 450,000 J / 200 m = 2250 N.

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 $g = 9.8\ m/s^2$)

   We want to know power (P)

   First, we need to calculate the work done, which in this case is the gravitational potential energy gained by the load, using the formula:

   Work = mass x gravity x height = 200 kg x 9.8 m/s^2 x 10 m = 19600 joules.

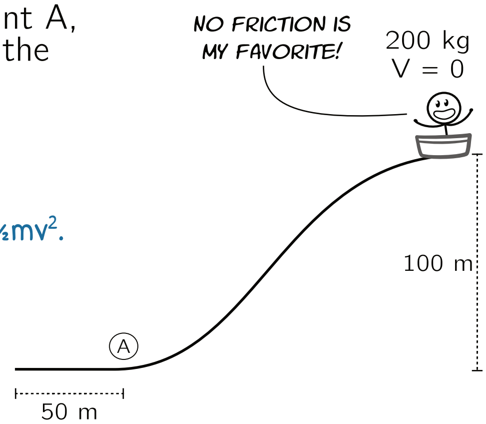
   Then, we can calculate power using Power = Work / Time, so the power used by the motor is:

   Power = 19600 J/ 5 s = 3920 W

Challenge Problem

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.



The formula for total energy at the top of the hill will be PE = mgh.

The formula for total energy at the bottom of the hill will be KE = $\frac{1}{2}mv^2$.

Because of the conservation of energy, the values for PE at the top of the hill (where KE is zero) and KE at the bottom of the hill (where PE is zero) will be equal to each other (ignoring all friction):

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

$(200\ kg)\cdot(9.8 m/s^2)\cdot(100\ m) = \frac{1}{2} \cdot (200\ kg)\cdot(v^2)$

$v^2 = 2 \cdot 9.81\ m/s^2 \cdot 100\ m$

$v = 44.3\ m/s$

So Nancy has a velocity of 44.3 m/s when she encounters friction at point A.

Nancy comes to a stop (0 m/s) after 50 meters and the only force acting on the sled to stop its motion is friction. The work-energy theorem states that the work done on an object is equal to its change in kinetic energy, so:

Change in KE (ΔKE) is equal to work, and W = F·d. Therefore, ΔKE = F·d

$\Delta KE = KE_{final} - KE_{initial}$

$0 - 0.5mv^2 = -0.5 \cdot 200\ kg \cdot (44.3\ m/s)^2 = -196202\ kg{\cdot}m^2/s^2$

Remember that $kg{\cdot}m^2/s^2$ = joules, so the change in KE is 196202 J. (The – sign just indicated direction)

Now we can use the value for ΔKE and the value for distance (50 m) to solve the equation ΔKE = F·d and find the value of the force.

$F = \Delta KE/d$

$F = 196202\ J / 50\ m$

$F = 3924\ J/m$

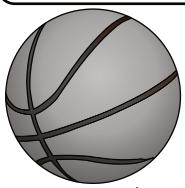
Remember that $J = kg{\cdot}m^2/s^2$, so $3924\ J/m = 3924\ kg{\cdot}m/s^2$

Remember that $kg{\cdot}m/s^2$ = newtons

Force of the friction that stopped Nancy's sled = 3924 N

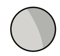
DOUBLE BOUNCE DEMO

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

Note: this experiment should be performed outside.

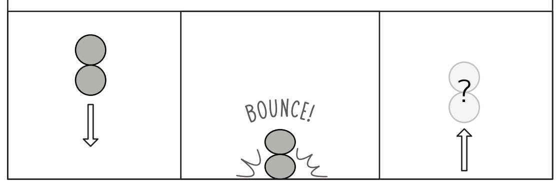
Prepare and Make Predictions:

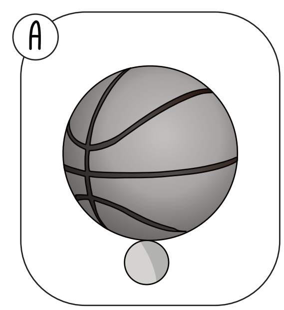
1. Measure the bounce height of each ball by dropping them from chest height on a flat and firm surface. Be sure to *drop* the ball. Don't throw it or push it down! Use a tall reference object such as the side of a building, streetlight, or tree to estimate the height of each bounce. Drop each ball at 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:

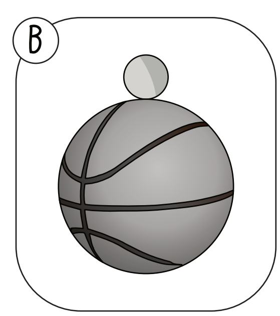
1. Hold the small ball atop the large ball at chest level. Release them both at the same time so they fall together for a "double bounce." Step back quickly as soon as you drop them! If the balls are not lined up straight, the top ball can bounce unpredictably. If the small ball rolled off the large 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!

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





WHICH WILL BOUNCE HIGHER?

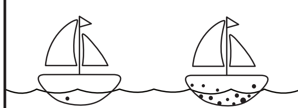
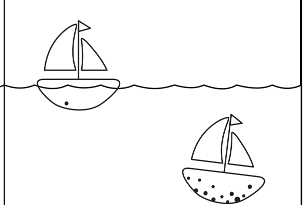


TYPICAL BOUNCE HEIGHT & PREDICTIONS

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	Answers will vary depending on surface, ball, and reference being used to measure height,
Smaller ball	but both balls should bounce to a lower level than where they were dropped.

	PREDICTIONS FOR DOUBLE BOUNCE	RESULTS FOR DOUBLE BOUNCE
Small on top of large	All predictions are valid so long as there is solid reasoning or logic attached to them. It is 100% okay if your prediction is different than the observed results! A surprising or unexpected outcome can result in better learning.	
Large on top of small		

INDEPENDENT What is changed or controlled	DEPENDENT What is measured	REMEMBER: For best results, keep all factors as identical as possible except for the independent variable!
 NUMBER OF HOLES IN BOAT	 HOW FAST BOAT SINKS	What was the **independent variable** in this experiment? The orientation of the balls (large on top of small or visa versa) What was the **dependent variable** in this experiment? How high the top ball bounced

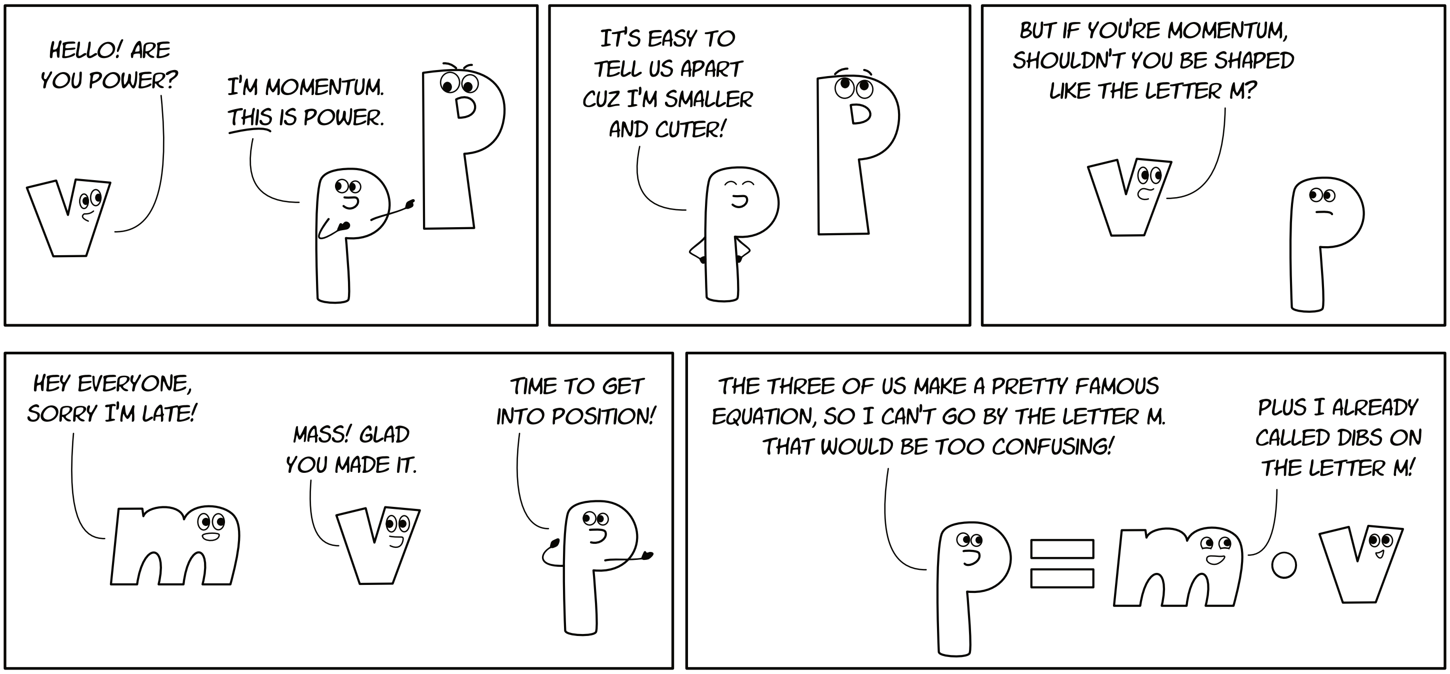
Describe the results! Use the words velocity and mass in your description.

Results can vary depending on surface and the type of ball used. Hopefully, when the balls were stacked and dropped you observed that the ball with less mass bounced far higher than before. The large ball, on the other hand, did not bounce as high. It appeared that the velocity and energy of the large ball was transferred to the small ball when they bounced.

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



DRAW ARROWS ABOVE THE QUANTITIES THAT ARE VECTORS:

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

Momentum is inertia in motion.

It can be thought of as a measure of how hard it is to stop something.

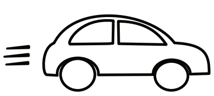
Momentum is the product of mass and velocity!

THE UNITS FOR MOMENTUM:

Kg·m/s

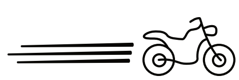
Which vehicle has more momentum and why?

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



VS

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



The car has more momentum. Multiplying the mass and velocity we see that the car has a momentum of 5,000 kg·m/s. The motorcycle has a momentum of 3,750 kg·m/s.

ANOTHER WAY OF LOOKING AT NEWTON'S 3RD LAW:

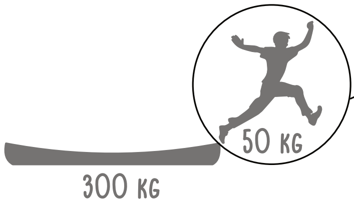
THE CONSERVATION OF MOMENTUM!

In a closed system without external forces, the total momentum BEFORE an event occurs is equal to the total momentum AFTER the event.

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

Before the jump, the total momentum of the non-moving boat and person system is zero

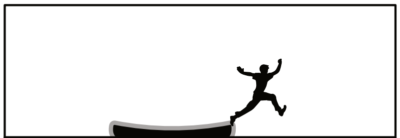
After the jump, the momentum of the moving person (+) and moving boat (-) will be equal and opposite. Added together, total momentum is still zero.



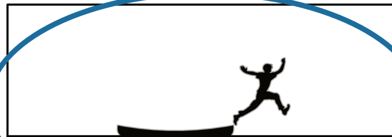
Calculate the momentum of the jumping person:

Velocity and mass are needed to calculate momentum. For the person, 50 kg multiplied by 2 m/s = 100 kg·m/s

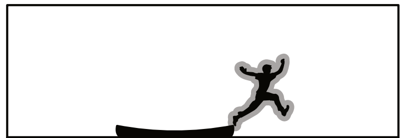
According to the conservation of momentum, the boat will have (circle the correct answer):



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·v

velocity = ?

mass = 300 kg

momentum = -100 kg·m/s

We know the boat has a momentum of -100 kg m/s because it will be equal and opposite to the momentum of the person. Substituting the values in p = m·v gives us:

-100 kg·m/s = 300 kg · v

To find v, divide both sides of the equation by 300 kg.

The boat moves with a velocity of -0.3 m/s.

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:

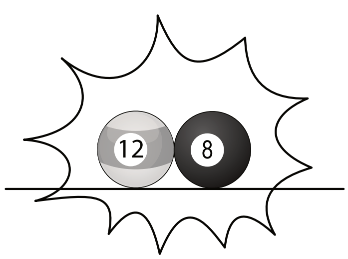
v = 4 m/s v = 0 m/s

The momentum of each ball = mass · velocity. The total momentum for the system (two billiard balls on a pool table) will be the same before and after the collision.

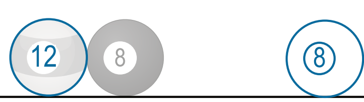
For the #12 ball. p=m·v

p= 0.2 kg· 4 m/s = 0.8 kg·m/s

The velocity of the #8 ball is 0 so the momentum for that ball is also 0. Total momentum for the system is 0.8 kg·m/s



AFTER COLLISION:



The total momentum before the collision is equal to the total momentum after the collision.

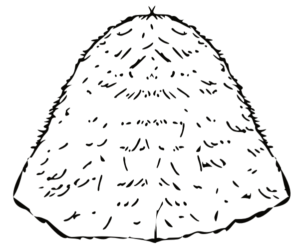
In the case of the pool balls, the KE of the #12 ball is transferred to the #8 ball, which continues forward at 4 m/s.

How to Change Momentum

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

$$\Delta p = Ft$$

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.

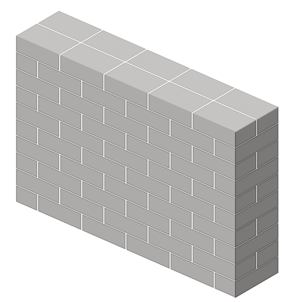


◆ How much momentum will the driver lose in the crash?

The momentum of the car is $p = mv = 80\text{ kg} \cdot 30\text{ m/s} = 2{,}400\text{ kg·m/s}$.

The momentum dropped to 0 kg·m/s, so the change is 2,400 kg·m/s.

A collision with the brick wall will lasts 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?

For the haystack collision, we get

$2{,}400\text{ kg·m/s} = Ft = F \cdot 0.8\text{ s}$.

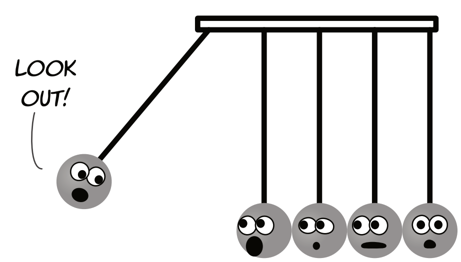
Divide by 0.8 s to get $3{,}000\text{ kg·m/s}^2 = 3{,}000\text{ N}$ of force.

For the brick wall collision, we get

$2{,}400\text{ kg·m/s} = Ft = F \cdot 0.1\text{ s}$.

Divide by 0.1 s to get $24{,}000\text{ kg·m/s}^2 = 24{,}000\text{ N}$ of force.

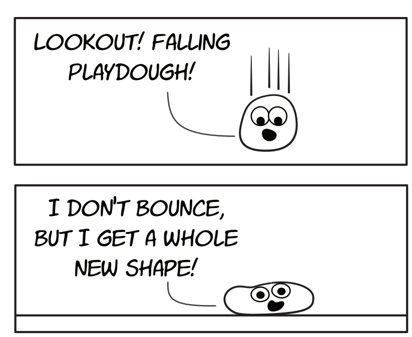
A **collision** happens when objects exert forces on each other over a short time period. Collisions are defined by the exchange of momentum and energy.



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?

Before pushing off, the momentum was 0 kg•m/s. Momentum is preserved, so doubling the mass means cutting the speed in half. The lighter skater moves at twice the speed of the heavier skater after the push-off.

(2) What is the difference between an elastic and inelastic collision?

In an elastic collision, both momentum and kinetic energy are conserved. In an inelastic collision, only momentum is conserved, not kinetic energy. In a perfectly inelastic collision, the objects stick together and move as one after the 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.

Since momentum is conserved, the total momentum before the collision will be equal to the total momentum after the collision. Before the collision, the total momentum is (3 kg • 2 m/s) + (2 kg • 0 m/s) = 6 kg•m/s. Therefore, the total momentum after the collision is also 6 kg•m/s.

(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?

$$\underbrace{m_1 v_1 + m_2 v_2}_{\text{total momentum before}} = \underbrace{m_1 v_1' + m_2 v_2'}_{\text{total momentum after}}$$

$$\underbrace{0\ \text{kg} \cdot \text{m/s}}_{\text{total momentum before}} = \underbrace{(20\ \text{kg})(10\ \text{m/s}) + (30\ \text{kg})v_2'}_{\text{total momentum after}}$$

Solve to discover that:

$$v_2' = -20/3\ \text{m/s}$$

The negative sign indicates that the second piece is moving left (in the opposite direction to the first piece).

(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?

Kyle lost a momentum of p=mv=50 kg•5 m/s=250 kg•m/s. We use the change in momentum formula (impulse formula) Δp=Ft.

When Kyle used his arms, the equation is 250 kg•m/s=F•0.5 s. To solve for F, we divide by 0.5 s. F = 500 kg•m/s^2 = 500 N.

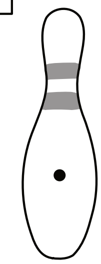
When Kyle doesn't use his arms, the equation is 250 kg•m/s=F•0.1 s. To solve for F, we divide by 0.1 s. F = 500 kg•m/s^2 = 2 500 N.

Without using his arms, Kyle is in serious danger of breaking a bone.

Center of Mass

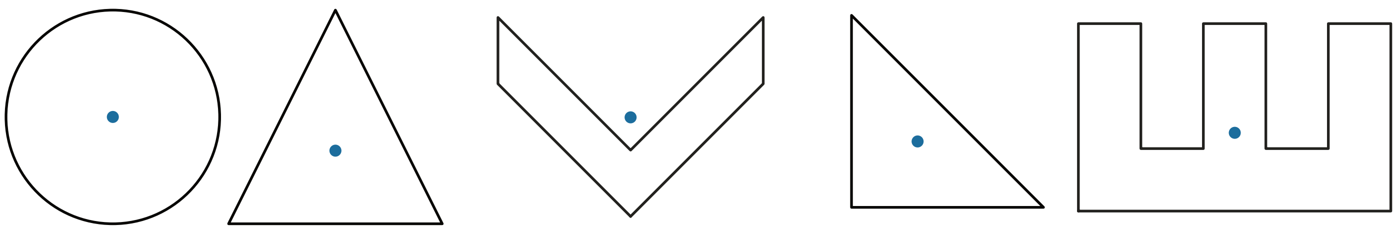
Fill in the blanks:

concentrated *position* *center* *balance* *gravity*



The center of mass of an object is the average position of the objects mass. It's the point where the entire mass of an object can be considered to be concentrated. For a symmetrical object, it's the geometric center. If gravity 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 balance 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?

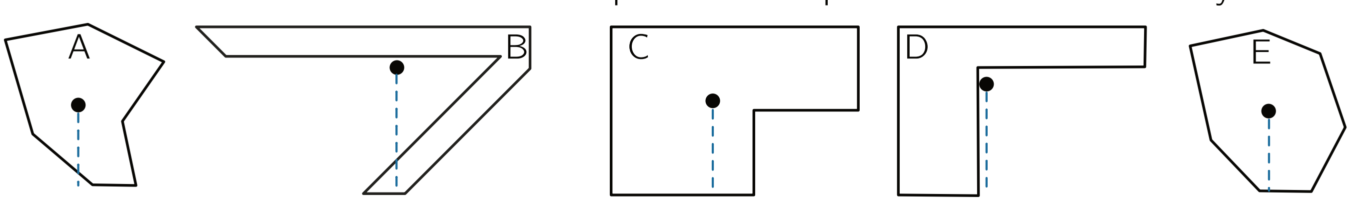
Stand with your left shoulder and foot against a wall. Can you lift your right foot?

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?

Most people will find these challenges impossible! When we bend over, stand on one foot, or stand up we naturally extend our body out so that the center of our mass is directly over our support base (feet or foot). In each of these challenges, we are asked to move without readjusting our center of mass.

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



Shapes A and D would fall over because the center of mass is not above the base, so gravity causes torque. The other three shapes would stay upright.

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?

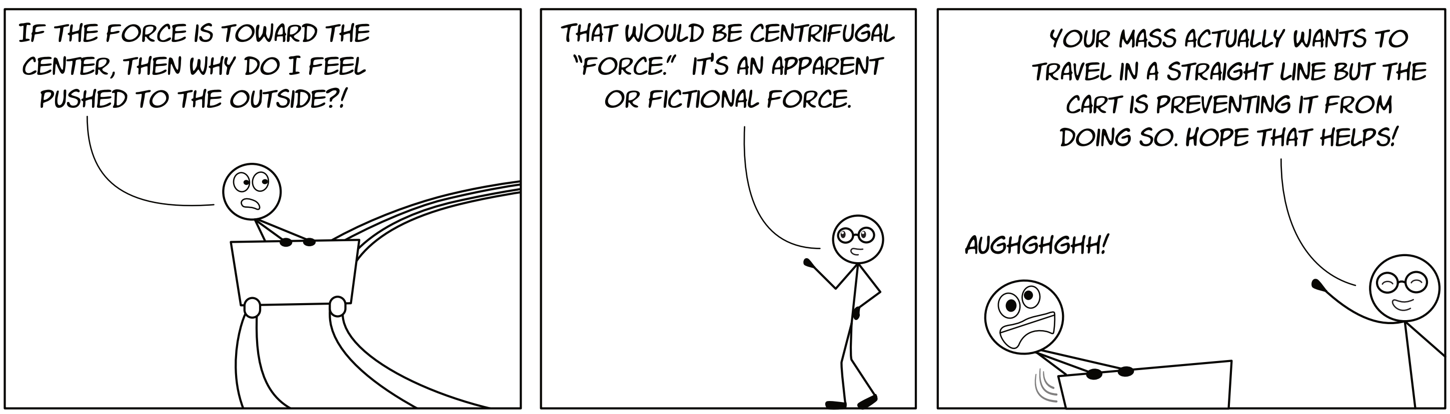
The bucket stays in its circular path due to the centripetal force from the tension of the string.

What keeps the water in the bucket?

The water tries to travel in a straight line, but the bucket forces it to turn. This happens before the gravity can accelerate the water downward.

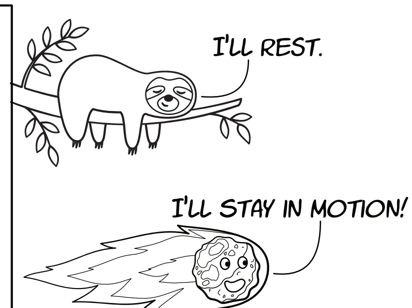
Centripetal Force

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



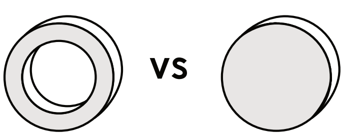
Remember the Law of Inertia?

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

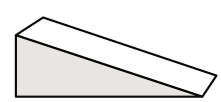


Rotational Inertia:

- Resistance to a change to its state of rotation
- Measured in $kg \cdot m^2$
- Determined by the distance to the axis of rotation. More mass further from the center = more rotational inertia.



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.

The solid cylinder will win because it has less rotational inertia. When the mass is further from the axis of rotation, it has a higher rotational inertia.

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?

   The centripetal force caused by the tension of the string keeps the ball in a circular motion.

2. If you swing it faster, does the force increase, decrease, or stay the same?

   The centripetal force increases. As the rotational speed increases, the force required to keep the ball moving in a circle also increases.

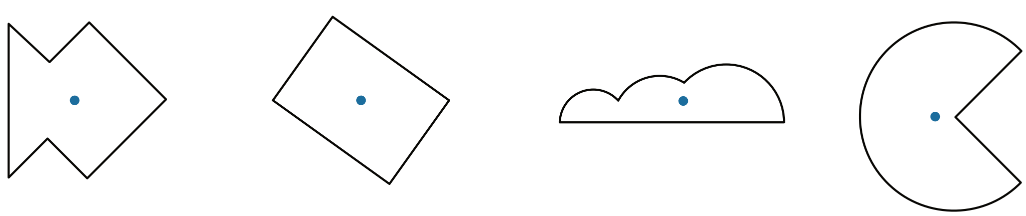
3. What would happen to the motion of the Earth if the Sun disappeared?

   Without the Sun's gravitational pull, there is no more centripetal force. The planet would continue on in a straight line.

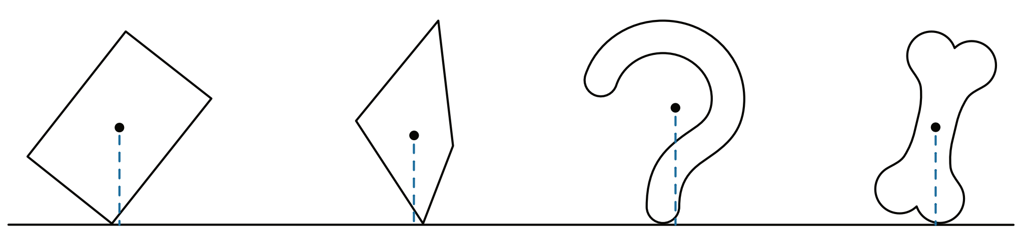
4. A person on a spinning merry-go-round is holding a ball. If they let go of the ball, what will happen to the ball?

   The ball seems to fly outward due to the apparent centrifugal force. From the viewpoint of the person on the merry-go-round, the ball may seem to fly straight out from the center, but it's actually just continuing in a straight line (due to inertia) while the merry-go-round spins away underneath it.

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.

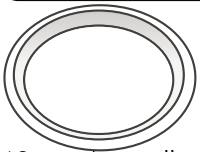


Right | Left | Right | Left

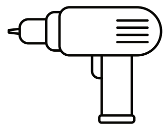
The shape responds to the force of gravity based on the center of mass. If the center of mass is to the left of the base point, the shape will lean left due to the torque caused by gravity.

RACING WHEELS

MATERIALS

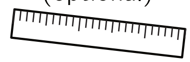

12 sturdy small paper plates OR 6 cardboard circles


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 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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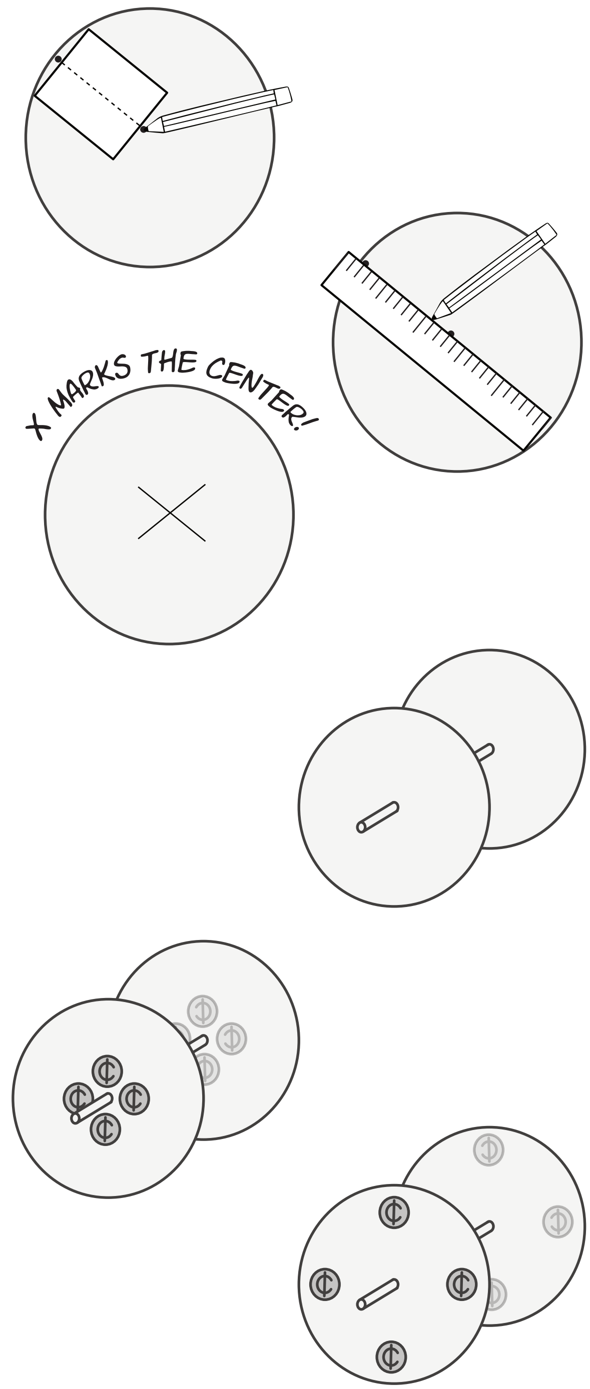

6. Set up a table or board on an incline so that it makes a ramp.
7. Roll the wheels down the ramp and record which is the fastest.

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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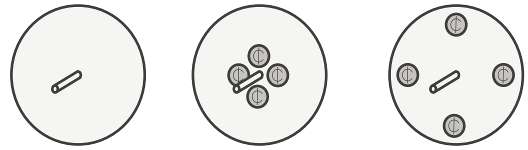

	NO WEIGHT	INSIDE WEIGHT	OUTSIDE WEIGHT
1st attempt			
2nd attempt			
3rd attempt			
4th attempt			
5th attempt			
AVERAGE RESULT			

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: ______________________________________

____

____

To make the slowest wheels: ______________________________________

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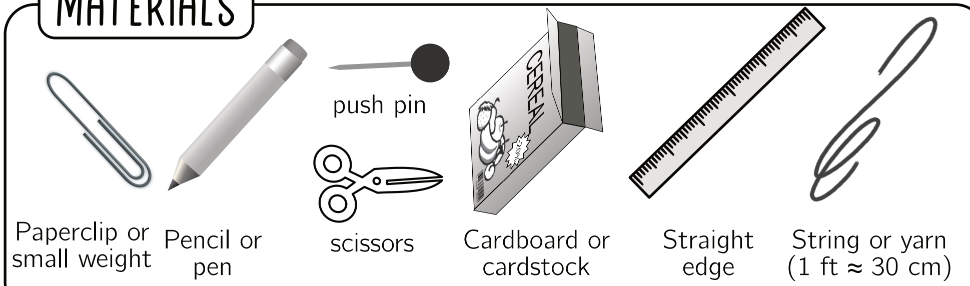
CENTER OF MASS

MATERIALS

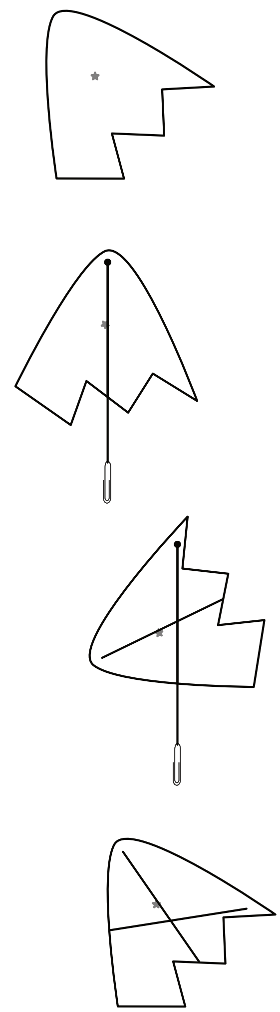


GOALS

- ☆ 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.

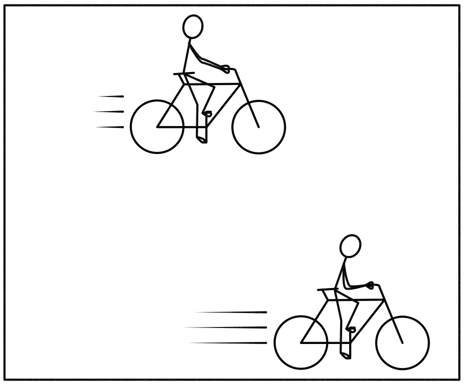
Repeat this process for each of the different shapes.

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?

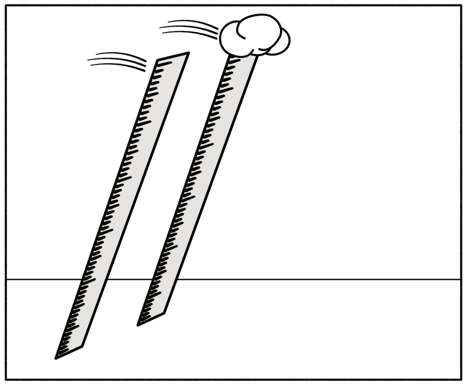
What do you think would happen if you repeated steps 4 through 6 again and drew a third line on the shape?

Rotational Motion



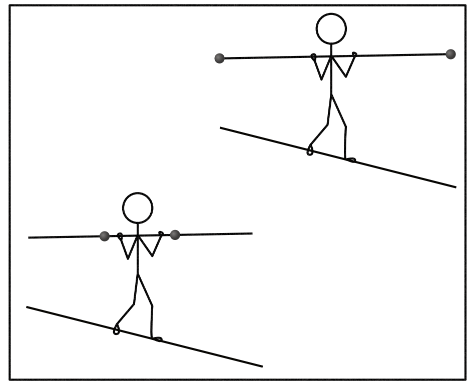
Is it easier to balance on a bike when riding a bike slowly or quickly?

Angular momentum is conserved when the wheels keep their motion.



Which will tip over faster: a ruler or a ruler with a weight of clay at the end?

Weight increase rotational inertia or a resistance to a change in rotation.



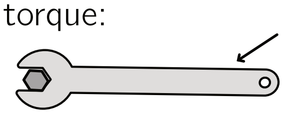
Which pole will help the tightrope walker balance better? The top one

Torque - the measure of force that can cause an object to rotate about an axis.

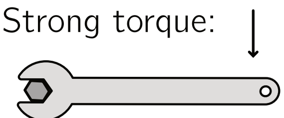
Torque depends on 3 things.

1. the angle at which the force is applied -

Weak torque:

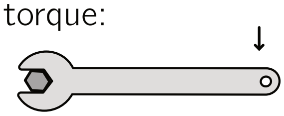


Strong torque:

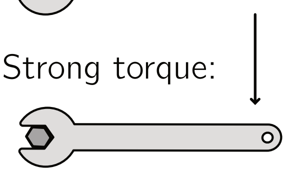


2. the force applied -

Weak torque:

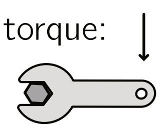


Strong torque:

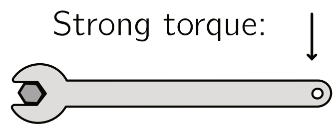


3. the distance from the axis -

Weak torque:



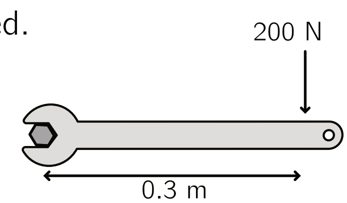
Strong torque:



Torque is measured in newton-meters (N·m).

Torque = (arm length)·(perpendicular force) = rF

Calculate the torque on the bolt using the distance and force indicated.



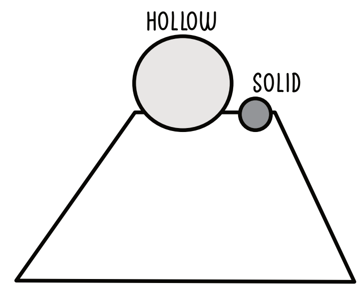
The torque is rF = 0.3 m • 200 N = 60 N • m.

If you want to open a heavy door, would it be easier to push near the hinges or at the handle? Why?

It is easier to push at the handle because less force is required to get the same amount of torque. By pushing at the handle, you are using a larger "arm length" in your torque formula.

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.

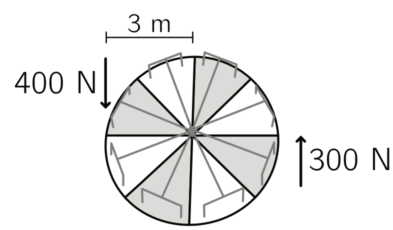


The hollow sphere has more rotational inertia because its mass is further from the center.

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.

Holding the wrench closer to the bolt decreases the distance from the force to the center of rotation, so more force would be required to loosen the bolt than if you hold the wrench further from the bolt.

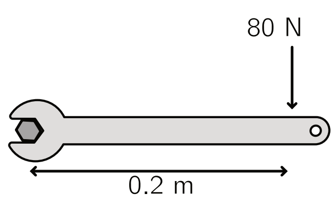
3. Two kids are spinning a merry-go-round as pictured. How much torque is created by their pushes?



Add up the individual torques of the two students since they are applying torque in the same direction.

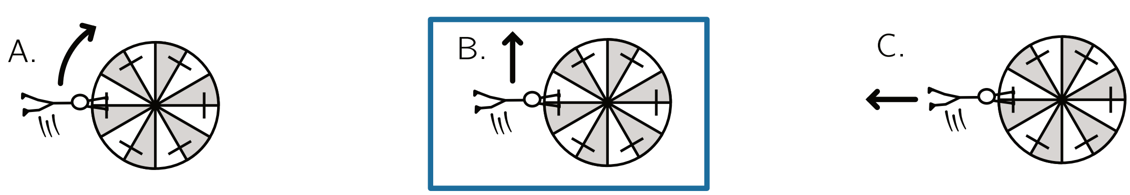
The torque is rF = 400 N•3 m = 1200 N•m and rF = 300 N•3 m = 900 N•m for a total of 2100 N•m

4. Find the torque on the bolt in the diagram below.



The torque is rF = 80 N•0.2 m = 16 N•m

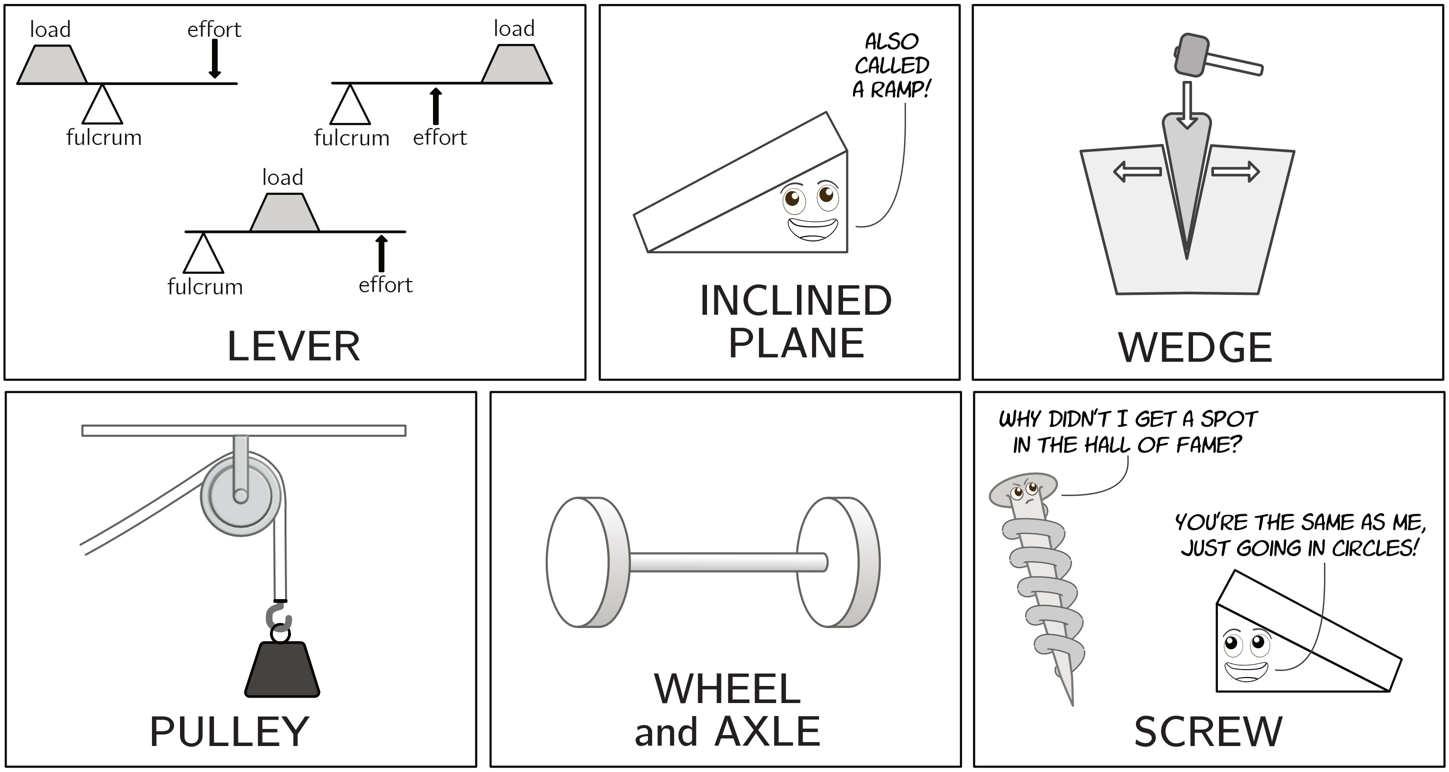
5. Rose is hanging on for dear life onto a rapidly rotating merry-go-round. Fortunately, the merry-go-round is surrounded by a large gymnastics pit filled with foam blocks. If Rose lets go from the position shown below, what will her path of travel look like? Explain.



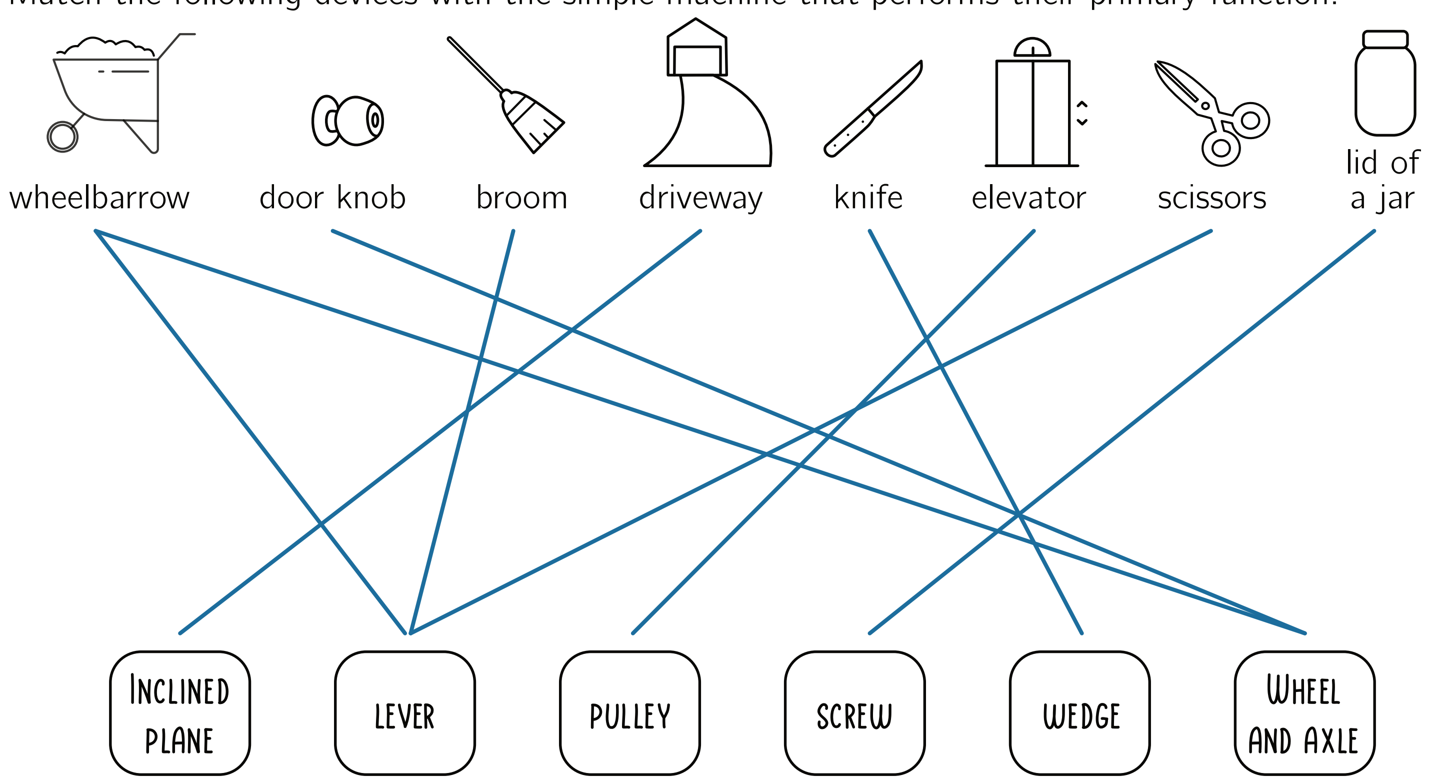
Once Rose lets go, gravity is the only force acting on her, so her circular motion will stop and she will travel in a straight line in the direction she was traveling when she let go. Gravity will accelerate her down toward the pit of foam blocks as she flies.

Simple Machines

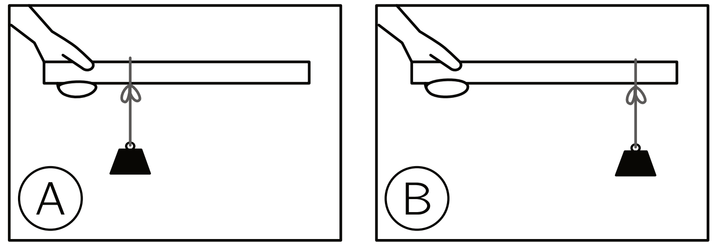
Simple machines are devices that change the direction or magnitude of a force to make work easier. They use leverage to change the force or distance involved. When these simple machines are combined they form complex or compound machines. Renaissance scientists identified six simple machines:



Match the following devices with the simple machine that performs their primary function:



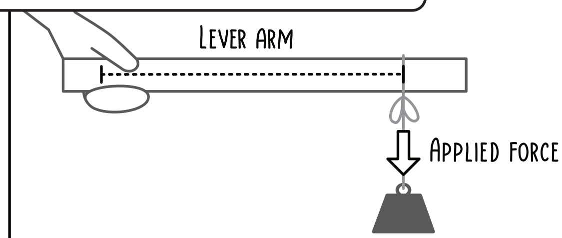
Holding a ruler with a weight hanging from it will feel different depending on whether the weight is hanging close to the hand (A) or further away (B).



Mark which things are the same and which are different when considering situations A and B:

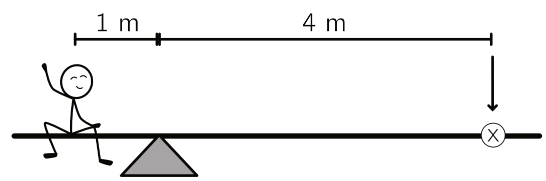
	SAME	DIFFERENT
MASS OF RULER AND WEIGHT	✓	
FORCE ACTING ON HAND	✓	
HOW 'EASY' IT IS TO KEEP THE RULER FROM TWISTING OR DIPPING DOWN		✓
THE DISTANCE FROM THE HAND TO THE STRING HOLDING THE WEIGHT		✓

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.)

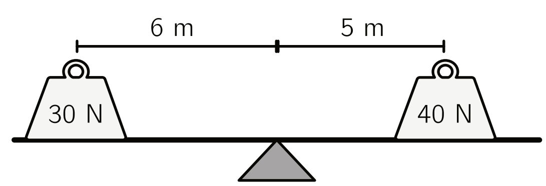


The downward torque on the left side is 1 m • 400 N = 400 N • m.

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).

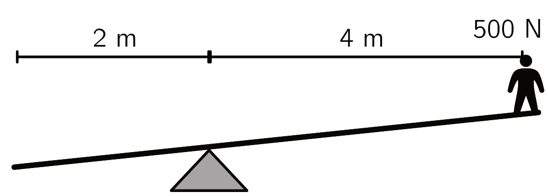
The downward torque on the left side is 1 m • 400 N = 400 N • m. The downward torque on the right side is 4 m • F . A force of 100 N (22.4 lbs) would balance the seesaw. Any additional weight would lift Bob.

Two weights are placed on opposite sides of a seesaw as pictured. Will the seesaw tip down to the left or right? Explain.



The downward torque on the left side is 6 m • 30 N = 180 N • m. The downward torque on the right side is 5 m • 40 N = 200 N • m. The right side has greater downward torque, so the seesaw will tip to the right.

How much weight can the pry bar lift (assuming no mass to the bar)?



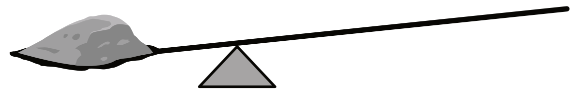
The torque on the right side is 4 m • 500 N = 2000 N • m. Set the torque on the left (2m • F) equal to 2000 N • m to see that the lever can lift anything up to F=1000 N

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?

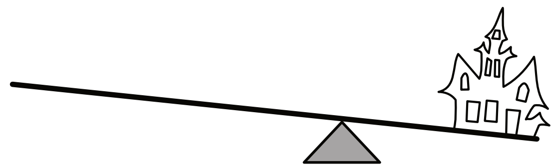
The torque on the rock arm is 0.5 m•300 N=150N•m. The torque on the other arm is 1.5x N•m, so x must be 100 N.

We could also just note that the arm is 3 times longer and divide the force by 3.



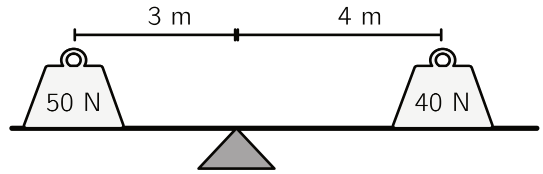
2. A house weighs 10,000 kg. A fulcrum is placed 10 m from the house. How long does the other side of the lever need to be for a 100 kg person to lift the house?

The torque on the house arm is 10 m•10,000 N =100,000 N•m. The torque on the other arm is 100x N•m, so x must be 1,000 m.



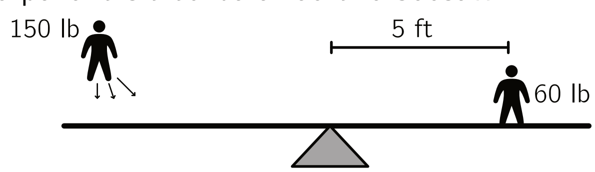
3. A 40 N weight is 4 m to the right of the fulcrum of a lever, and a 50 N weight is 3 m from the fulcrum on the left arm of the lever. Which side of the lever will descend?

The torque on the left arm is 3 m•50 N =150 N•m. The torque on the other arm is 4 m•4 N =160 N•m, so the weight will tip to the right.



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?

We need to match force times distance on each side. 150x=5•60=300, so x=2. The parent should sit 2 ft from the fulcrum on the opposite side.

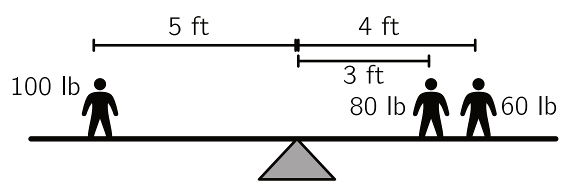


5. Three people are sitting on a seesaw. On the left side, a 100 lb person is 5 ft the left side of the fulcrum, while an 80 lb child is 3 ft to the left of the fulcrum and a 60 lb child is 4 ft to the right. To which side will the seesaw tip?

On the left the torque is 5 ft•100 lb=500 ft•lb. On the right, the torque is

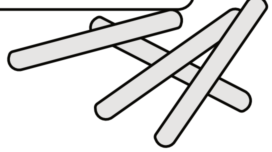
3 ft•80 lb + 4 ft•60 lb=480 ft•lb.

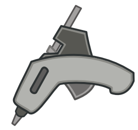
So the seesaw will lean to the left side.

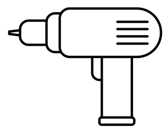


TENSEGRITY TABLE

MATERIALS


Popsicle sticks (at least a dozen)


Glue gun

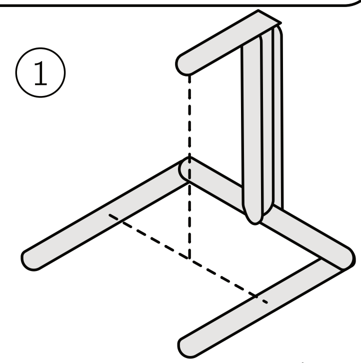

A drill


About 60 cm (2 ft) of yarn or string

GOALS

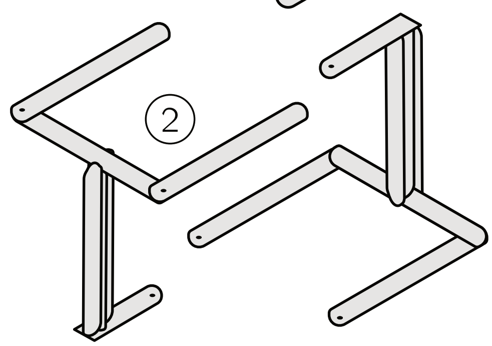
- Create a structure that is supported entirely by tension.
- Diagnose and troubleshoot engineering difficulties.

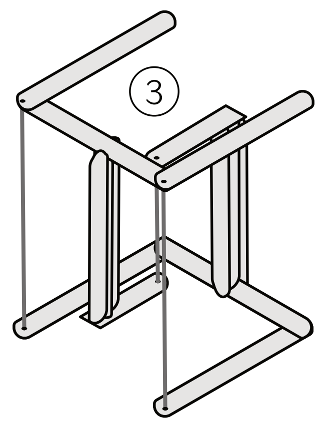
A tensegrity table is a unique and fascinating structure that utilizes the principles of tension and compression to create a “floating” tabletop. The term "tensegrity" is derived from the words "tension" and "integrity," reflecting the balance of forces that hold the structure together. In a tensegrity 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.)

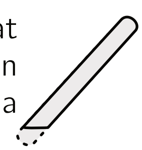
1. Glue a U-shape of three popsicle sticks that will act as a base.
2. Add a vertical support to the bottom of the U-shape. Use plenty of glue. It might help to cut or flatten the popsicle sticks.
3. Break a stick so that it is about 60% of its original length. Then glue this arm to the top of the vertical 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.

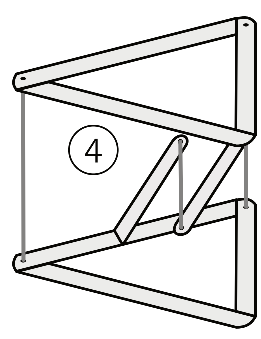




Variant 2 - Steps.

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?

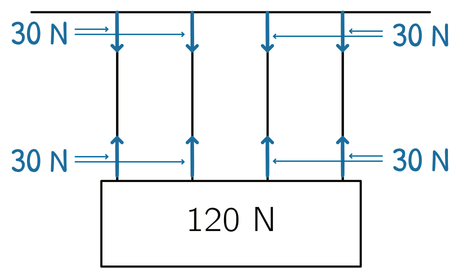
PULLEY

FILL IN THE BLANKS USING THESE WORDS:

heavy	cable	direction
wheel	force	multiple

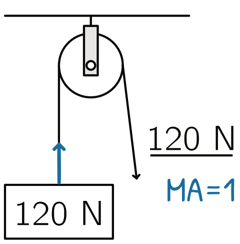
A pulley is a simple machine that consists of a ___wheel___ with a groove along its edge, designed for a rope or ___cable___ to move within it. It is used to change the ___direction___ of an applied force or to significantly decrease the amount of ___force___ required to lift or move a load. When ___multiple___ pulleys are used together in a system, you can lift ___heavy___ loads with much less effort. In a balanced pulley system, the force downward is equal to the force upward.

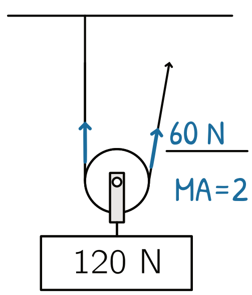
A box with a weight of 120 N is attached to the ceiling with 4 cables as pictured below. Identify and label the forces applied by each rope.

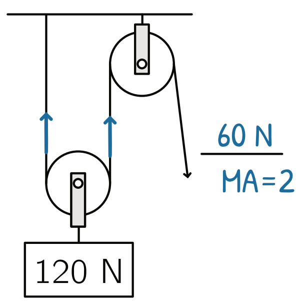


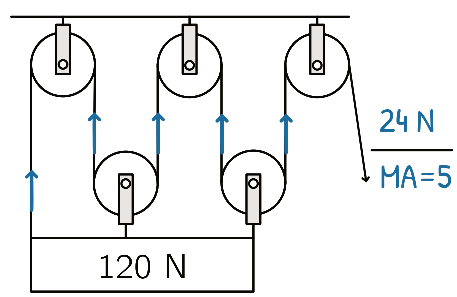
The forces are spread out evenly. The box pulls each rope downward with 30 N, and the bottom of each rope pulls up with a force of 30 N. At the ceiling, each rope pulls down with a force of 30 N, while the ceiling pulls up with a force of 30 N.

A 120 N weight is suspended. Calculate the force needed to keep the weight stationary. (Assume there is no friction.)

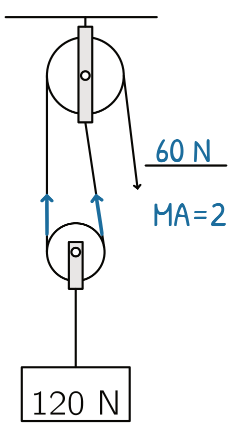


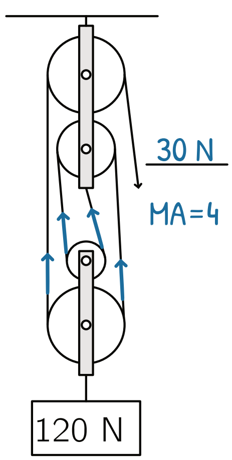


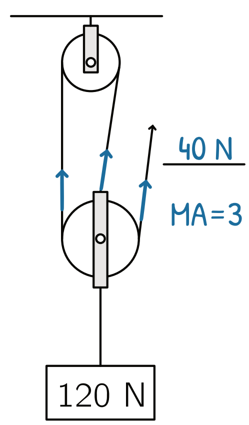


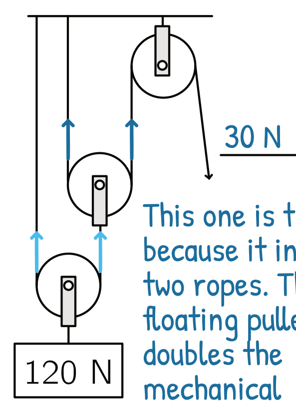


If the pulley only has one string, you can find the mechanical advantage by counting the lines connected to the weight that act against the downward force of gravity.







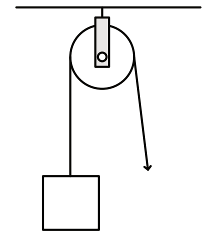


This one is tricky because it involves two ropes. The floating pulley doubles the mechanical advantage. MA=4

See the appendix to learn more about the other simple machines and their mechanical advantage!

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.

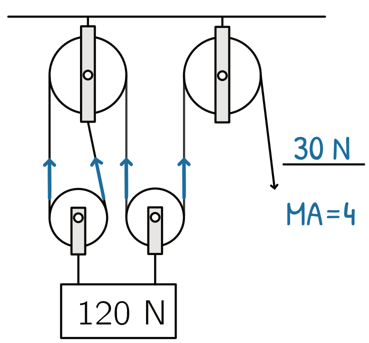
2. A certain simple machine has a mechanical advantage of 8. How much force of effort is required to lift a weight of 120 N?

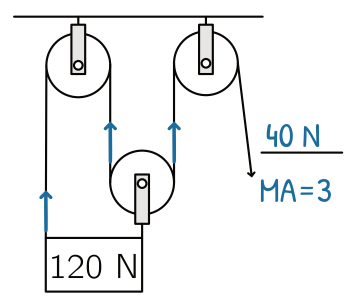
   120/8=15, so 15 N of effort is required to lift a weight of 120 N

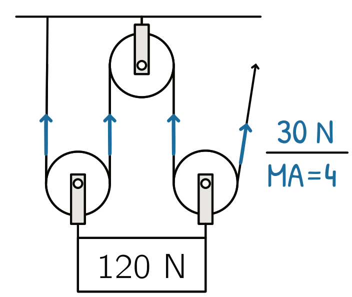
3. Most physics textbooks make a distinction between **ideal** mechanical advantage and **actual** mechanical advantage when it comes to simple machines. Explain the difference between these two ideas. Which idea is more useful?

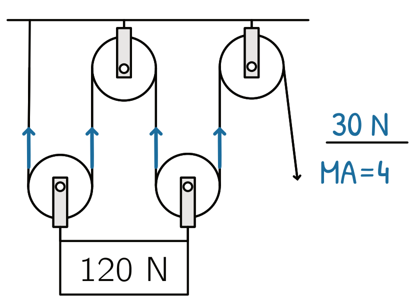
   The ideal mechanical advantage doesn't take into account any of the energy lost to friction, but the actual mechanical advantage does. In most cases, the actual mechanical advantage is more useful because it reflects what actually happens when using a simple machine.

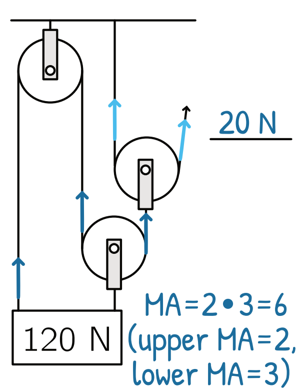
4. A 120 N weight is suspended. Calculate the force needed to keep the weight stationary. (Assume there is no friction.)

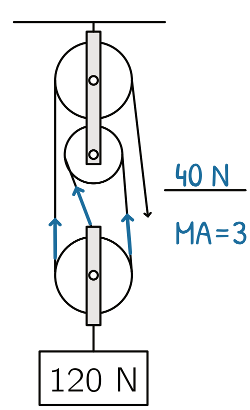


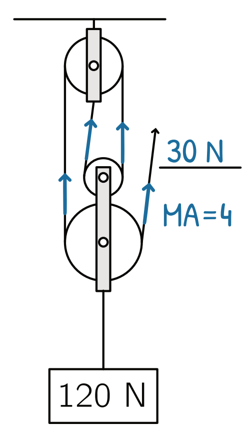






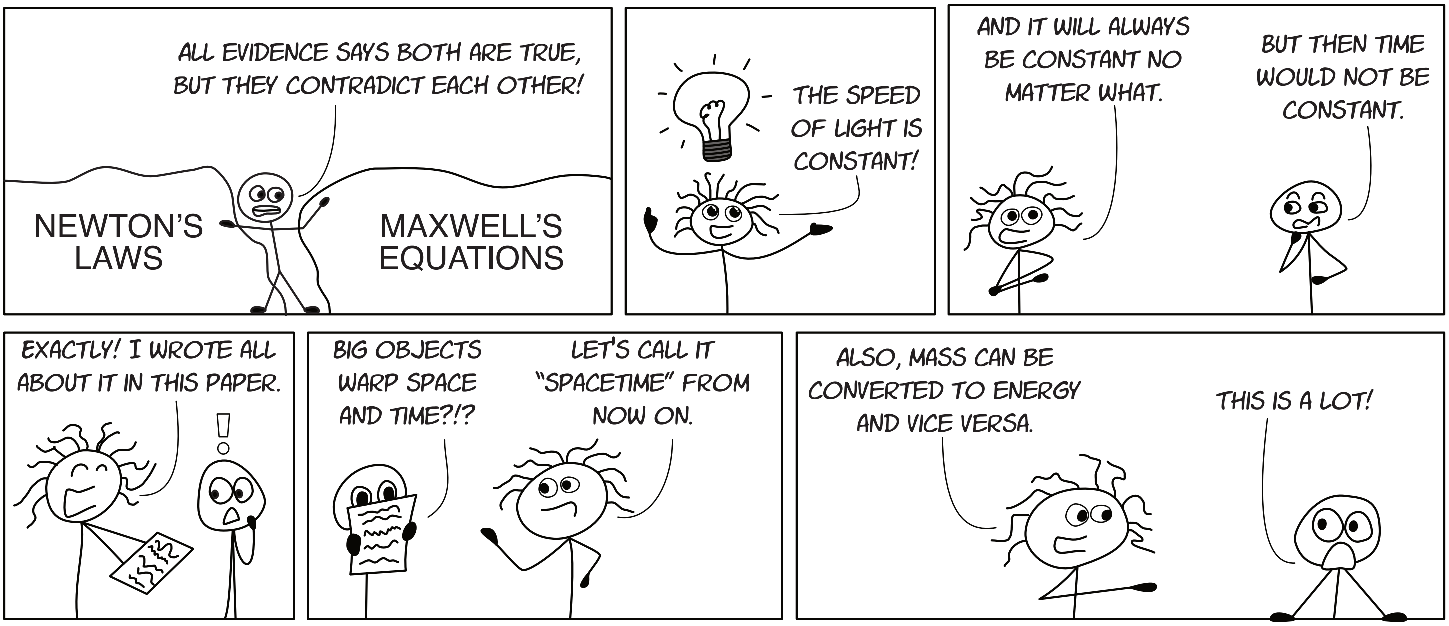






RELATIVITY

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

Time passes at different rates for observers in different frames of reference.

- Two events that are simultaneous in one frame of reference might not be simultaneous in another frame.
- The twin paradox. A twin could stay on Earth and age 10 years while their twin could fly away and return after aging only 5 years.

LENGTH CONTRACTION

Objects appear shorter when they pass by an observer when traveling near the speed of light.

- A meter stick traveling at relativistic speeds would look shorter to an outside observer

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.

$$E = mc^2$$

Energy
There are lots of ways to talk about energy (heat, kinetic, potential etc) but mass-energy equivalence is one of the most important! Energy is equal to mass times the speed of light squared.

Mass
How much matter there is in something. Made of atoms (protons, neutrons, and electrons)

Speed of Light
Light cannot travel faster than this speed, which is 299,792,458 meters per second. That's fast enough to go around the equator 7.5 times in one second!

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!

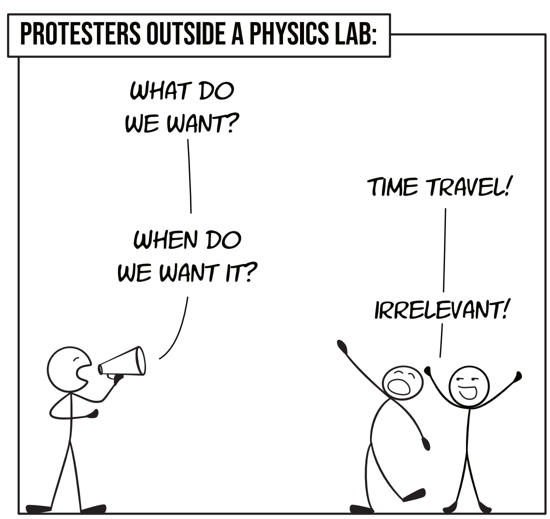
COMIC
Artwork will vary - we hope you enjoyed creating a comic!

How would you describe relativity to a friend who had never heard of it before?

Answers will vary

What part of relativity do you find most surprising?

Answers will vary



Practice Problems – Relativity

1. What is the principle of relativity?

   The laws of physics are the same for all observers in any inertial frame of reference

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.

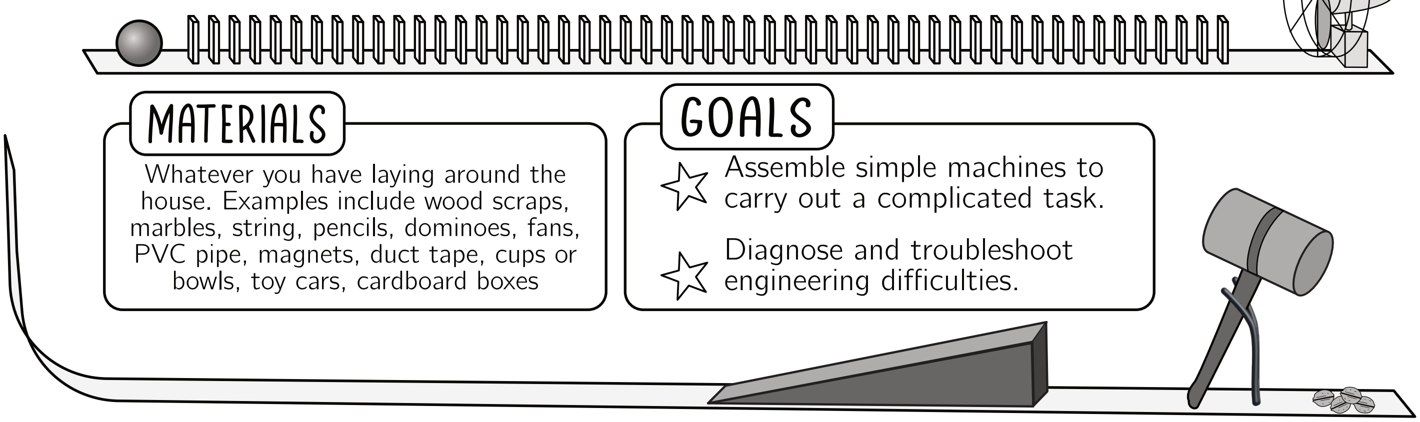
5. What is a key prediction made by general relativity?

   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.

   You couldn't tell uniform motion from rest, but you could distinguish accelerated motion from rest because the surface of the water in an accelerating train would not be level.

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 $kg \cdot m^2/s^2$?
   A. Watts
   B. Joules
   C. $N \cdot m$
   D. Ampere

   $N = kg \cdot m/s^2$
   $W = kg \cdot m/s^3$

2. Which quantities below use the units $kg \cdot m^2/s^2$?
   A. Momentum
   B. Energy
   C. Torque
   D. Work

   Torque and work both use a force times a distance ($N \cdot m$).

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

   $PE = mgh = 2\ kg \cdot 9.8\ m/s^2 \cdot 2m$

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

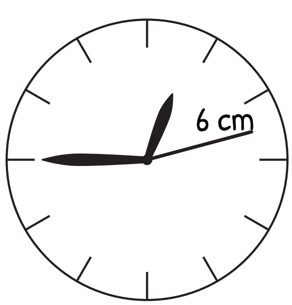
   $KE = \frac{1}{2}mv^2 = \frac{1}{2} \cdot 2\ kg \cdot (0\ m/s)^2$

6. What is the momentum of a 6 kg ball rolling east at a rate of 3 m/s.
   A. $2\ kg \cdot m/s$ east
   B. $9\ kg \cdot m/s$ east
   C. $18\ kg \cdot m/s$ east
   D. $36\ kg \cdot m/s$ east

   $p = mv = 6\ kg \cdot 3\ m/s$

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

   1 rotation every 60 seconds. The length of the clock hand makes no difference.



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.
    KE depends on velocity too.

11. T F The amount of potential energy an object has depends on its height and mass, not its speed.
    $PE = mgh$

12. T F Power is defined as the rate at which work is done or energy is transferred.
    $W = J/s$

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.
    $p = mv$

14. T F The distribution of mass will affect an objects rotational inertia.

15. T F Pulleys have a greater mechanical advantage than levers.
    Only sometimes. Depends on the setup

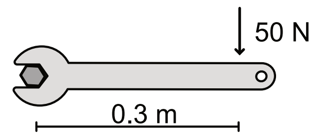
16. T F Simple machines are able to lift heavy objects by doing less work.
    They do the same work.

17. T F Power and energy are the same thing.
    Power is the rate energy is transferred.

18. Which of the following statements about energy conservation in a closed system is TRUE?
    A. Energy can be created and destroyed.
    B. The total amount of energy in the system changes over time.
    C. Energy can change forms, but the total energy remains constant.
    D. Energy is always lost as heat.

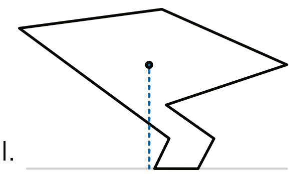
19. If an object is lifted to a greater height, what happens to its potential energy?
    A. It decreases.
    B. It increases.
    C. It remains the same.
    D. It changes into kinetic energy.

20. 50 N of force are applied perpendicular to a wrench that is 30 cm long. How much torque is applied to the bolt?
    A. 15 N•m
    B. 150 N•m
    C. 166.7 N•m
    D. 1500 N•m



T = rF = 50 N • 0.3 m

21. The center of mass of the shape below is marked with a circle. Which direction will it tip?
    A. Left
    B. Right
    C. It won't tip.
    D. There is no way to tell.



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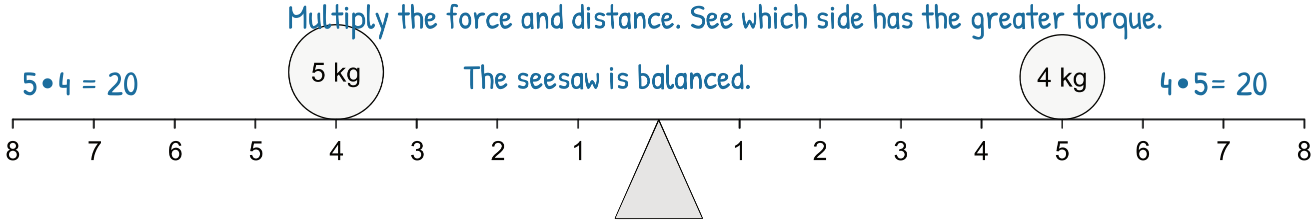
22. Weights are placed on a seesaw as pictured. Which direction will the seesaw tip?

Multiply the force and distance. See which side has the greater torque.

5•4 = 20

The seesaw is balanced.

4•5 = 20

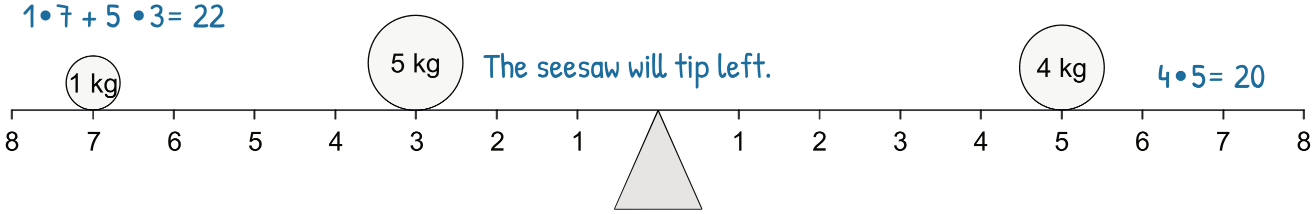


23. Weights are placed on a seesaw as pictured. Which direction will the seesaw tip?

1•7 + 5•3 = 22

The seesaw will tip left.

4•5 = 20

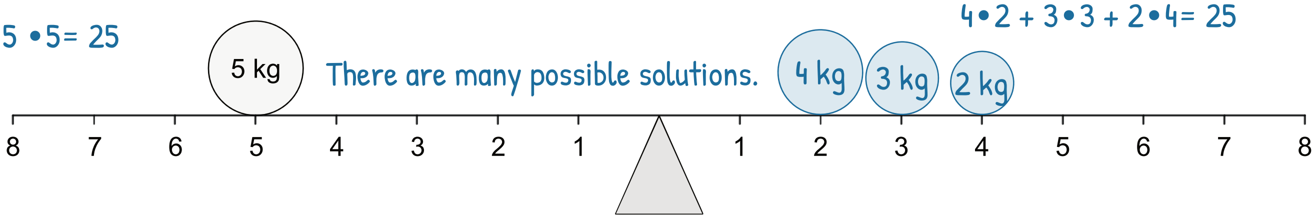


24. Place weights with mass 2 kg, 3 kg, and 4 kg on the seesaw below so that it balances.

4•2 + 3•3 + 2•4 = 25

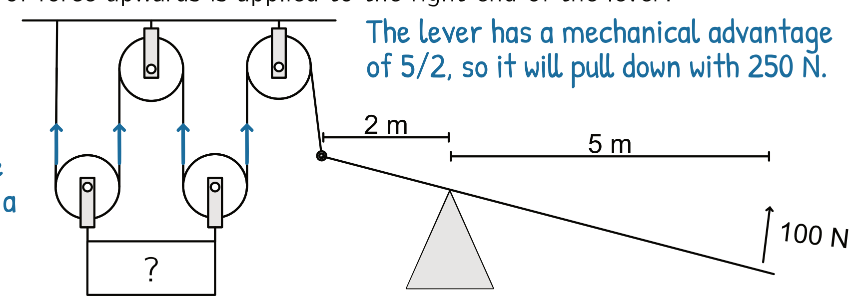
5•5 = 25

There are many possible solutions.



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?

The lever has a mechanical advantage of 5/2, so it will pull down with 250 N.



The pulley has a mechanical advantage of 4, so the pull of 250 N will result in a pull of 1,000 N.

25 Circle T or F to mark each statement True or False.

T $\boxed{F}$ If an object is accelerating at a constant rate of acceleration, then the forces acting upon the object are balanced.

T $\boxed{F}$ An object will be at rest when there are no forces acting upon it.

$\boxed{T}$ 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 $\boxed{F}$ When no net force is applied to a moving object, it still comes to rest because of its inertia.

T $\boxed{F}$ 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 $\boxed{2}$ 3 A light cannon ball launches faster than a heavy cannon ball from the same cannon.

1 2 $\boxed{3}$ A cannon is pushed backwards when it fires a cannon ball.

1 $\boxed{2}$ 3 Force equals mass times acceleration.

$\boxed{1}$ 2 3 While making a right turn in your car, your body is pushed to the left.

$\boxed{1}$ 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

$\boxed{\text{D. 30 N}}$

Newton's 3rd laws declares that equal but opposite forces will be applied.

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

$\boxed{\text{D. 98 N}}$

$F=ma=10\ kg \cdot 9.8 m/s^2=98\ N.$

29 Which option below has the most inertia?

A. A cow

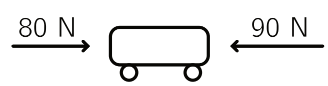
B. A car

$\boxed{\text{C. A blue whale}}$

D. A wheelbarrow

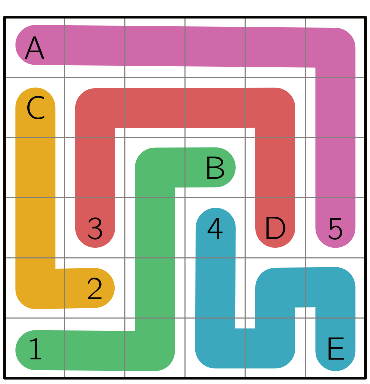
The blue whale has the most mass.

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?



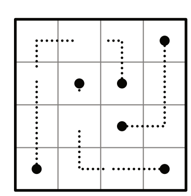
The net force to the left is 10 N. Using F=ma, we get 10=130a, so a=1/13. The cart will accelerate to the left at a rate of 1/13 m/s^2.

Pipe Flow Matching - Unit 3



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. m/s^2
2. momentum	B. $kg \cdot m^2/s^2$
3. power	C. $kg \cdot m/s$
4. force	D. $kg \cdot m^2/s^3$
5. acceleration	E. $kg \cdot m/s^2$

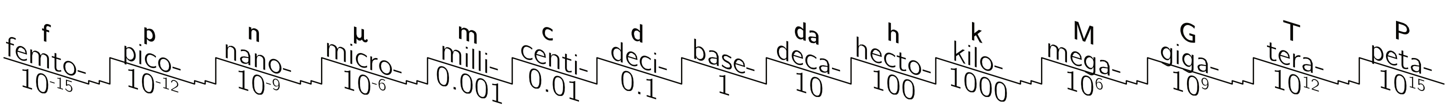


APPENDIX

-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
zetta	Z	10^{21}	1 000 000 000 000 000 000 000
exa	E	10^{18}	1 000 000 000 000 000 000
peta	P	10^{15}	1 000 000 000 000 000
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	μ	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

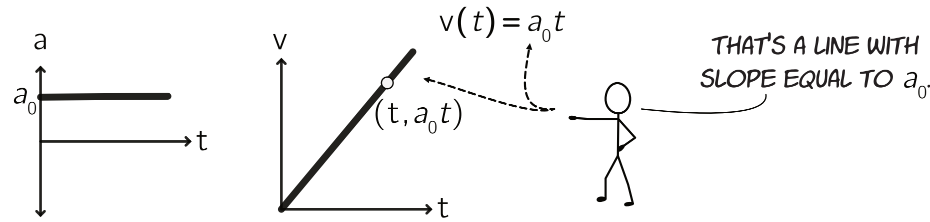


Any time a constant net force is acting on an object of constant mass, the acceleration will also be a constant (represented as a_0). Newton's 2nd law says that $F = ma$. Since force and mass are constant, then so is acceleration.

When the force is gravity, a_0 is denoted by the letter g. ($g = 9.8$ m/s^2 for acceleration)

Velocity. (Constant acceleration from a standstill)

> If an object starts with velocity 0 m/s and then accelerates at a_0 m/s^2 for t seconds, its velocity will be $v(t) = a_0 t$ m/s. (For example: If your speed started at 0 m/s and increased by 3 m/s for 10 seconds, then you speed would have increased to $3 \bullet 10 = 30$ m/s in total.)

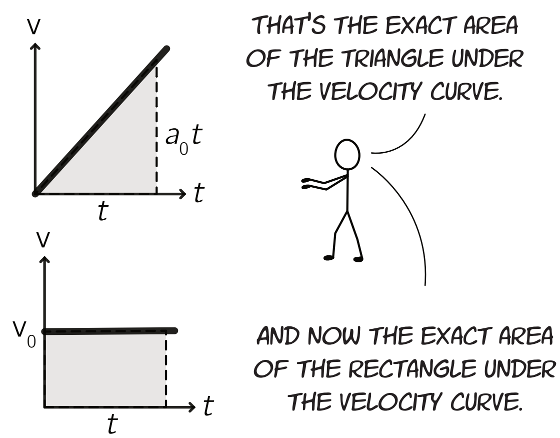


Displacement. (Constant acceleration from a standstill)

> If an object uniformly accelerates from 0 m/s to $a_0 t$ m/s, in t seconds, then the average velocity is $\frac{1}{2} a_0 t$ m/s. Multiply the average velocity by t seconds to get the displacement of $d(t) = \frac{1}{2} a_0 t^2$ m.

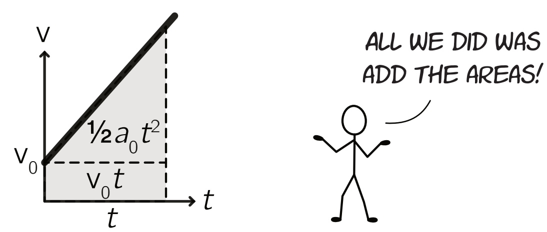
Displacement. (Constant velocity and no acceleration)

> If an object travels at a uniform velocity v_0 m/s for t seconds, then we can multiply the rate and time to get the total displacement of $d(t) = v_0 t$ m.



Displacement. (Constant acceleration)

> If an object has a starting velocity of v_0 m/s and travels at a constant acceleration of a_0 m/s^2 for t seconds, then the total displacement will be $d(t) = \frac{1}{2} a_0 t^2 + v_0 t$ m. This formula adds the displacement due to starting speed to the displacement due to acceleration.



Example.

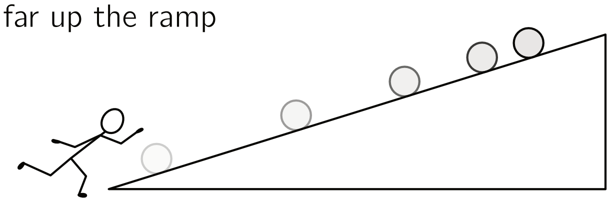
A bowling ball is rolled up a ramp that is sloped so that the net acceleration upward is -2 m/s^2. The initial velocity upward is 6 m/s. How far up the ramp relative to the release point is the ball after 4 seconds?

Solution.

Use $a_0 = -2$ m/s^2 and $v_0 = 6$ m/s in the displacement formula.

$d(t) = -t^2 + 6t$. When $t = 4$ s, we get the displacement

$d(4) = -(4)^2 + 6(4) = 8$ m, so the bowling ball is 8 m up the ramp after 4 seconds.

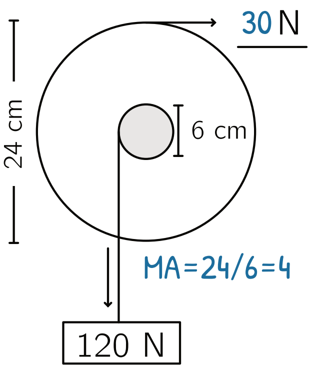


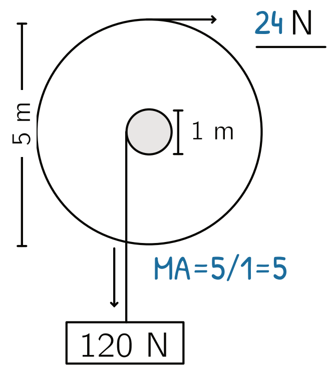
Mechanical Advantage of Simple Machines

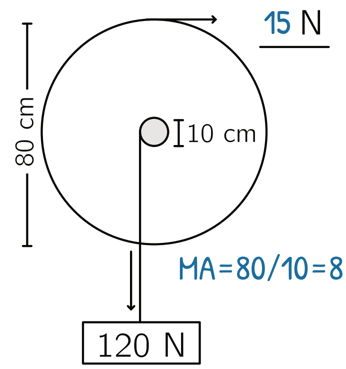
Wheel and Axle

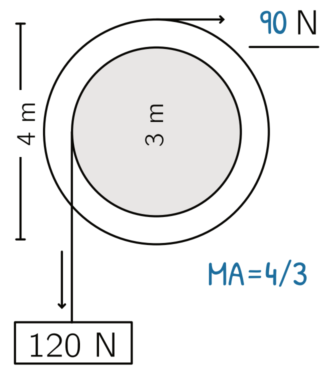
A simple machine that reduces friction and multiplies force. It consists of two connected parts of different diameters.

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.

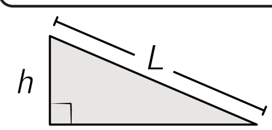








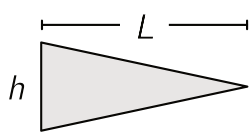
Inclined Plane



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



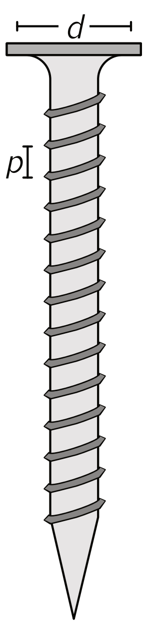
As labeled, the mechanical advantage for an inclined plane and a wedge is

$$\frac{\text{distance of effort}}{\text{distance of resistance}} = \frac{L}{h}.$$

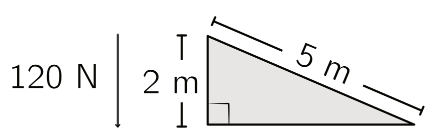
Screw

For a screw, the mechanical advantage is

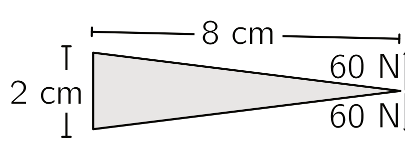
$$\frac{\text{distance of effort}}{\text{distance of resistance}} = \frac{\text{screwdriver circumference}}{\text{pitch (height of one thread)}} = \frac{d\pi}{p}.$$



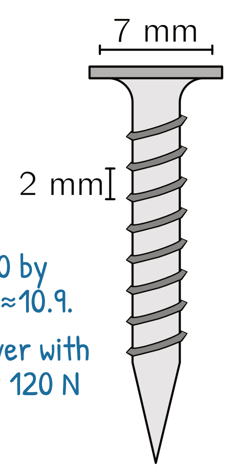
How much force does each simple machine need to match 120 N of resistance?



MA=5/2=2.5. Dividing 120 N by 2.5 yields 48 N. 48 N of force directed up the ramp will match the upward force of 120 N.



MA=8/2=4. Dividing 120 N by 4 yields 30 N. A force of 30 N to the right will apply 120 N vertically.

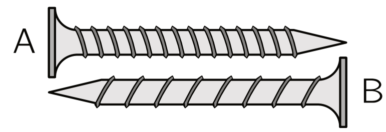


MA=7π/2. Dividing 120 by 7π/2 yields 240/(7π)≈10.9.

So twisting a screwdriver with 11 N of force will apply 120 N of force to the screw.

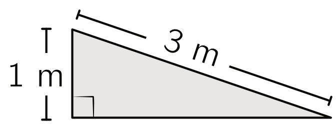
More Practice Problems – Mechanical Advantage

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?



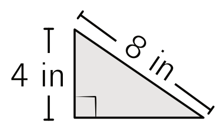
Screw A has twice the mechanical advantage of screw B because it only moves the load half as far with each rotation.

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.)



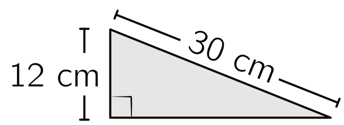
MA=3/1=3

120/3 J = 40 J



MA=8/4=2

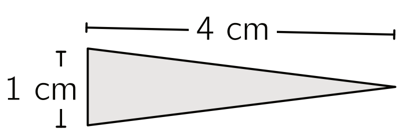
120/2 J = 60 J



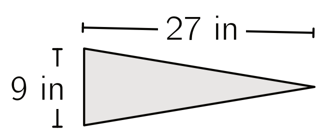
MA=30/12=2.5

120/2.5 J = 48 J

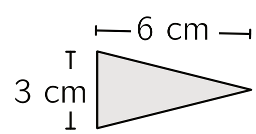
3. Find the mechanical advantage for each wedge below. Which wedge requires the least force to do the same amount of work? Why would anyone use a wedge that requires more force?



MA=4/1=4



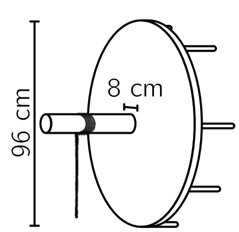
MA=27/9=3



MA=6/3=2

The left wedge has the greatest mechanical advantage, so it requires the least force. The disadvantage is that it requires you do push a larger distance to accomplish the same work.

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?



MA=96/8=12

120/12=10, so it would only take 10 N of force to support the weight.

Laws of Motion

Physics Man

Serge Ballif

Billy Joel

Useful Formulas

Distance

d = distance, r = rate, t = time

$$d = rt$$

Weight

w = weight, m = mass, $g = 9.8\,m/s^2$

$$w = mg$$

Newton's 2nd 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, $G = 6.674 \times 10^{-11}\ m^3/(kg \cdot s^2)$, 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, $g = 9.8\,m/s^2$, 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

τ = torque, r = radius, F = force

$$\tau = rF$$