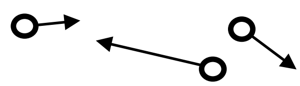
Activity #2: DO THE SMALL PARTICLES OF MATTER MOVE? IF SO, HOW?

Purpose: *We have been developing a model of matter that involves small particles. We have explored the size and the structure of these particles. In this activity, you will explore their motion.*

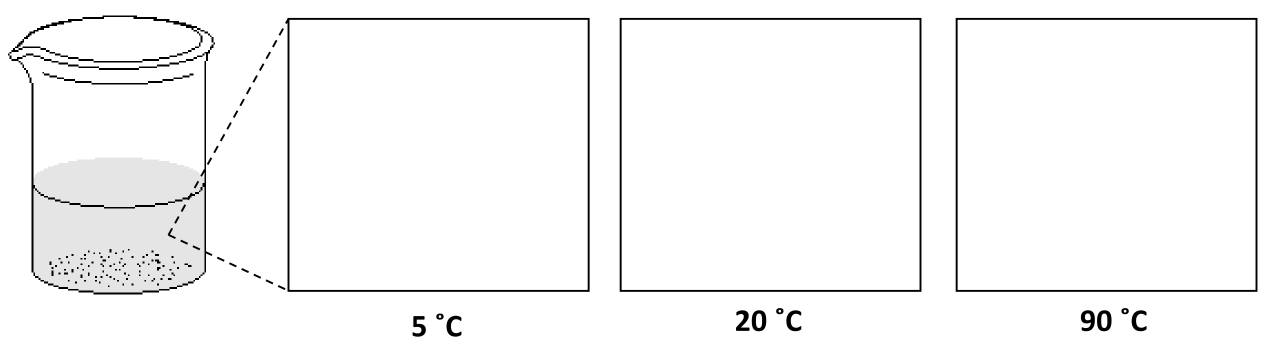
Initial ideas

1. Do you think small particles move, or are stationary? Or, do you think they sometimes move and are sometimes stationary? Consider each of the three phases of matter (solid, liquid, gas) in your answer. What evidence from everyday phenomena supports your ideas?

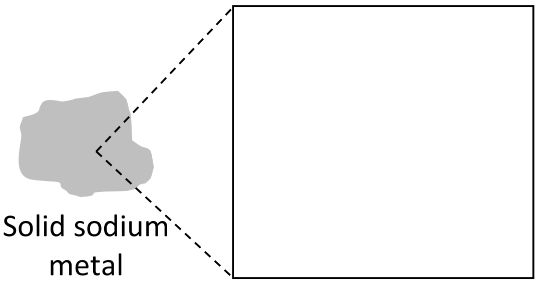
Now that we are discussing how small particles move, we need a way to represent that in our drawings. A good way to do this is to draw arrows coming off your small particles to represent speed; the larger the arrow, the higher the speed.



2. Below is a picture of water in a beaker. Imagine you could see water on a submicroscopic scale at three different temperatures: 5 °C (just above freezing), 20 °C (room temperature) and 90 °C (just below boiling). Draw pictures of what you would see below.

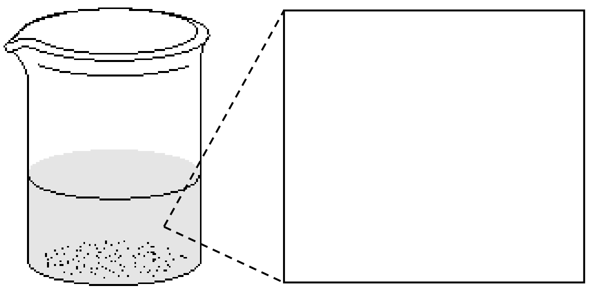


3. Below are three different substances, all at room temperature (20 °C). Noting that each substance is made of small particles of approximately the same mass, draw representations comparing their motion, if any, below.



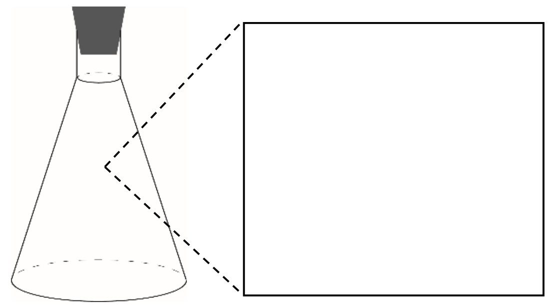
Solid sodium metal

20 ˚C



Water

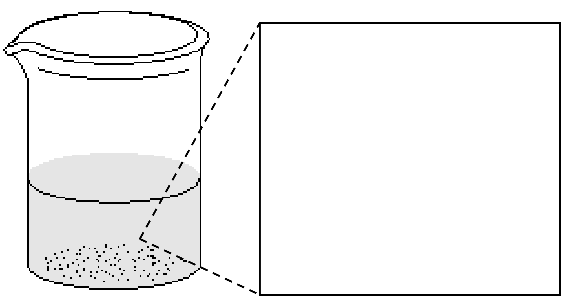
20 ˚C



Neon gas

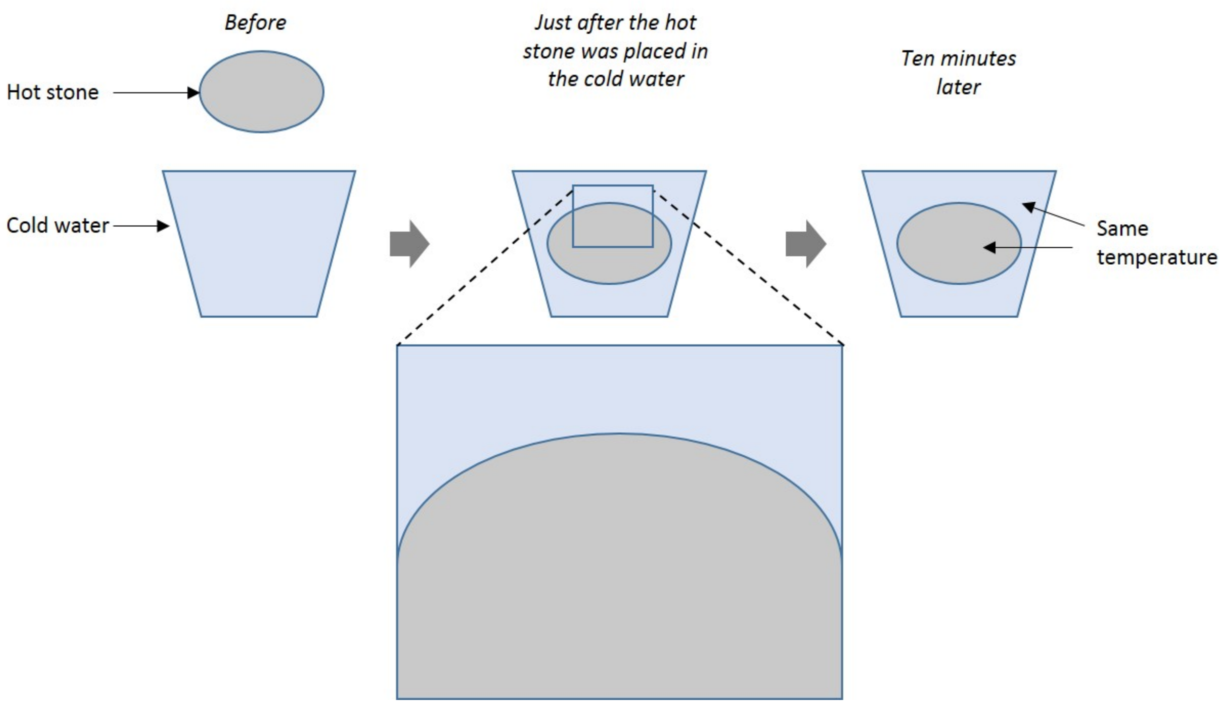
20 ˚C

4. Imagine a “corner” of the universe in which it is colder than any other part of the universe. Draw a submicroscopic representation of water in this corner of the universe.



Coldest corner of the universe

5. Now consider a situation where a hot stone is placed into a bucket of cold water. The stone is warm because it has just been taken off of the ground on a sunny day, and the water in the bucket is ice cold. After ten minutes of the stone being in the water, both the stone and the water are at room temperature. Below, draw a small particle representation explaining how the temperatures of the stone and water came to be equal and approximately midway between the original temperatures of the two substances. Focus your drawing on the areas where the rock and water touch.



6. Below, provide a written description to accompany your drawing above.

Collecting and interpreting evidence

You will need:

- Computer with internet access

View the following two videos:

a) A magnified image of fat vesicles in water. (A vesicle is simply a spherical aggregation of millions of fat molecules. The fat molecules associate with each other because they are not soluble in water.) *http://www.youtube.com/watch?v=9fszHle5D6A*

b) A magnified image of smoke particles in air when illuminated with red laser light. *http://www.youtube.com/watch?v=apUl_baT_Kc*

1. Below, describe the motion that you observe in each video.

a)

b)

Now view a simulation of a smoke particle in air. This simulation is an approximation of the video that you just watched.
http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/Brownian/brownian.html
The large blue circle represents a smoke particle. The small red circles represent air particles. Note these representations are not to scale. The smoke particle is actually millions of times larger than air particles. Additionally, there would be far more air particles than are depicted in the video. Watch this animation for a minute or so and then answer the following questions.

2. What is causing the movement of the smoke particle?

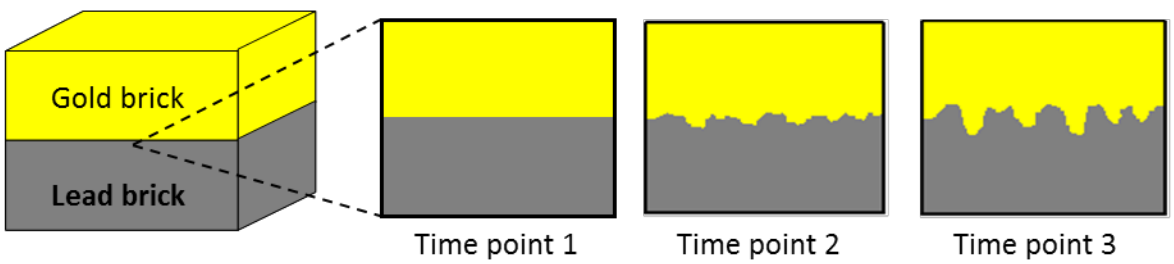
Brownian motion and diffusion

The two videos were examples of a phenomenon called *Brownian motion*, which is defined as "random **movement** of microscopic particles suspended in liquids or gases resulting from the impact of molecules of the surrounding medium" (Merriam-Webster dictionary). Note that microscopic particles are different from small particles – they are much larger. The fat vesicles and the smoke particles are examples of microscopic particles. Each is made up of millions of submicroscopic particles; (we are calling these submicroscopic particles "small particles" – also known as atoms or molecules). The microscopic particles are being moved around by submicroscopic particles (molecules of water or molecules of air), which are jiggling randomly and colliding with them. Tracing the motion of an individual microscopic particle is almost impossible; however, over any period of time all of the microscopic particles move about with average random speeds, in all directions, changing only because the small particles make millions of collisions with them during that time. The observation of anything in motion means it has some motion energy (kinetic energy). The jiggling of the smoke particle is macroscopic evidence that we can see, and we can then infer that the submicroscopic air particles are causing the larger particle to jiggle. Because the smoke particle moves randomly, with no overall specific direction, we can then infer that all of the submicroscopic air particles also move randomly with no overall specific direction. The explanation for this random motion is that air particles are colliding with the smoke particle from all different directions and the energy from the collisions tend to cancel each other out. The same line of evidence is the same for fat vesicles jiggling in water, except the fat particle is in liquid water. The concept of energy will come up later in our studies, but for now it is a useful way to think about all of that aimless jiggling that is responsible for the Brownian motion. This random motion of small particles constitutes an important part of their behavior, one that we will be incorporating into many explanatory models of matter henceforth.

1. Which of the videos at the beginning of this activity serves as evidence in support of the claim that small particles in the *gas* phase move? What about the *liquid* phase? Which small particles move in each case? Complete the table below. Recall that fat vesicles and smoke particles are *microscopic* particles.

CLAIM	Video providing evidence in support of the claim:	What are the small particles (submicro) that are moving randomly?
Small particles in GAS phase move		GAS-phase particles are?
Small particles in LIQUID phase move		LIQUID-phase particles are?

You have collected evidence of small particle motion in the gas and liquid phases, but what about solids? Consider the following example: A gold brick is placed upon a lead brick. At three different times, a microscopic picture is taken of the interface between the two bricks. These pictures are shown below.



This phenomenon is called *solid state diffusion*, where the small particles of one solid "seep into" another solid, and vice-versa. An example of this phenomenon in nature can often be seen in minerals. The photo below is a macroscopic view (note the lens cap, providing the scale) showing how diffusion of components from garnet (red) into gabbro (black+white speckled) produced a "reaction rim" on the garnet consisting of new minerals (plagioclase [white] and hornblende [black]).

Photo: Ron Schott

2. Below, explain how solid state diffusion is evidence of random small particle motion in the solid phase (hint: think whether the lead-gold diffusion or the mineral reaction rim could happen if the small particles *didn't* move.)

3. In order for submicroscopic particles to be able to move randomly and collide with other particles (both microscopic and submicroscopic), what, if anything, must be in between two small particles of any substance? ______________________

Random motion of small particles turns out to be very important in describing how matter behaves. Therefore, it's important to find a way to observe and measure this motion on a macroscopic scale. You will do this in the next investigation.

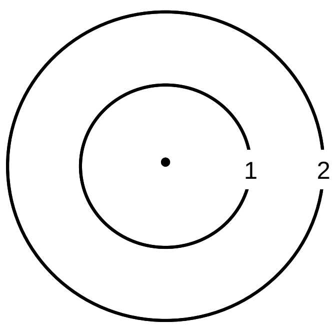
Investigation 1: Small particle motion and temperature

You will need:

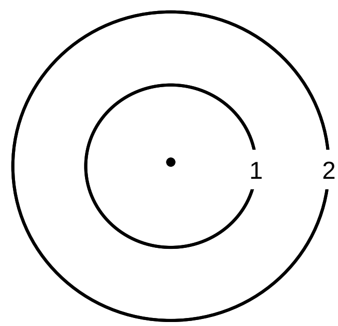
- 2 petri dishes
- 1 bottle of food coloring
- 2 narrow-tipped disposable pipettes
- Hot and cold water
- 2 timers

Procedure

1. Carefully fill two Petri dishes about halfway with water – one cold and the other hot. Center the Petri dish over the following bulls-eye patterns:



Cold Water



Hot Water

The following step should be performed simultaneously by two people – one with the cold water and the other with the hot water.

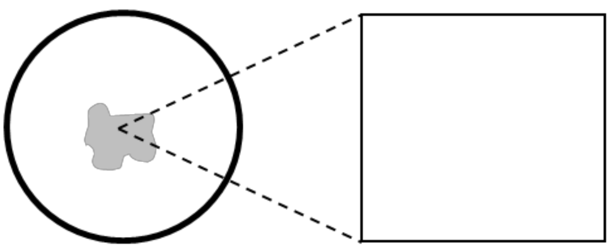
2. Fill a pipet with food coloring. Squeeze the pipet so that the food coloring is right at the tip. Then, gently place the tip under the water, almost to the bottom of the Petri dish, at the center of the target. Squeeze carefully to allow one drop to come out. At the time the food coloring is dropped into the water, start a stopwatch.

3. Measure the times needed for the outermost edge of the drop in each dish to reach circle 1 and circle 2. Record your data in the table below. *You may move on while you are waiting, as long as you have a good idea of the difference between the behavior of the drop in both cases. Make sure you check in periodically so you don't miss any time points.*

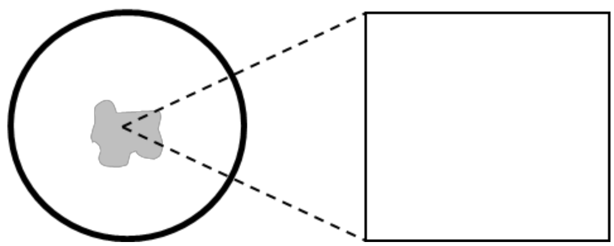
Water temperature	Time to reach circle 1	Time to reach circle 2
Hot		
Cold		

Constructing explanations

1. Below, draw small particle models of the hot and cold food coloring/water mixtures looking at the top of the mixtures, just after the drop of food coloring was added. You may represent the small particles of water and food coloring as spheres. Represent the motion of the small particles with arrows, where longer arrows represent faster motion.



HOT



COLD

2. On p. 3, the fat vesicles were being pushed around by water molecules and smoke particles were being pushed around by air molecules. Their movement is evidence for movement of the water and air molecules. In the food coloring scenario, what is pushing around the food coloring molecules?
3. What does temperature measure? Explain on a small particle level using evidence and reasoning.

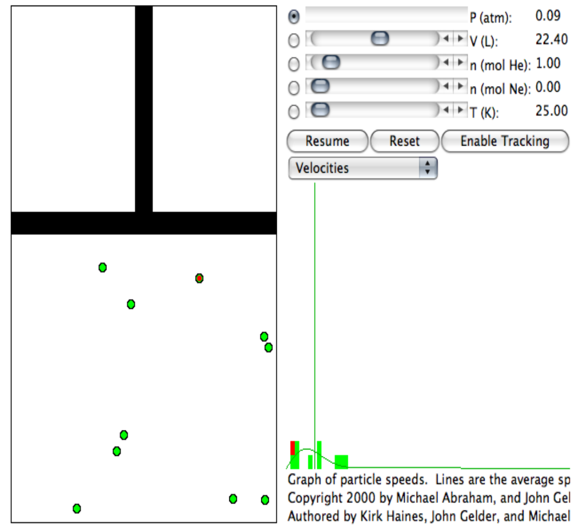
Investigation 2: Heat conduction

In this investigation, you will investigate what creates changes in temperature on a submicroscopic scale.

You will need:

- Computer with internet access

Go to the following website:



http://intro.chem.okstate.edu/1314F00/Laboratory/GLP.htm. This simulation will show the motion of gas particles in the box to the left, and the distribution of speeds of the particles in the bar graph to the right. To the right is a screen shot of the simulator as well as a description of all the variables that can be explored.

For this investigation, ignore the different variables in the upper right portion of the screen, except T (K), temperature in Kelvin. We will be focusing on the speed of the individual particles. Many of the questions below will ask you to think about a type of energy called kinetic energy:

Kinetic energy is the type of energy something has if it is moving. The faster it moves, the more kinetic energy it has. As applied to this simulation, a fast-moving particle will have more kinetic energy than a slow-moving particle. A stopped particle has no kinetic energy.

1. Click “reset” then “enable tracking” on the simulator. Lower the temperature enough to allow you to track the kinetic energy changes in the red particle for a while.

2. Using both the red particle and the histogram, try to determine which of the following actions result in changes to the kinetic energy (measured by speed) of the red particle. Check each action that results in a change.

   ☐ Collisions between the red particle and the container wall

   ☐ Collisions between the red particle and another particle

   ☐ No collisions are necessary – the red particle slows down or speeds up on its own.

3. Specifically, what has to happen to the red particle for it to slow down? What has to be true about the particle it is colliding with?

4. Specifically, what has to happen to the red particle for it to speed up? What has to be true about the particle it is colliding with?

5. When you observe the red particle slowing down due to a collision with a green particle, what happens to the speed of the green particle?

   Increases / decreases / stays the same

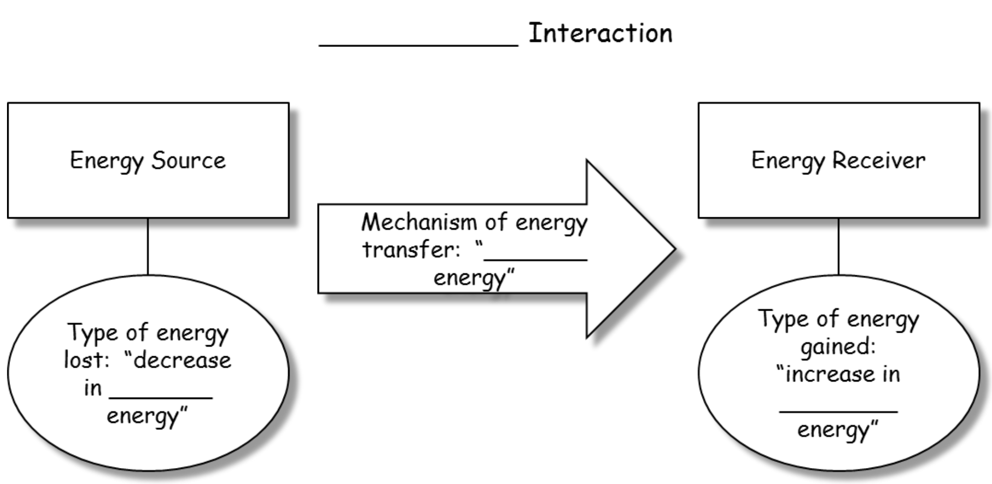
6. What does that mean about its kinetic energy? Kinetic energy of the green particle:

   Increases / decreases / stays the same

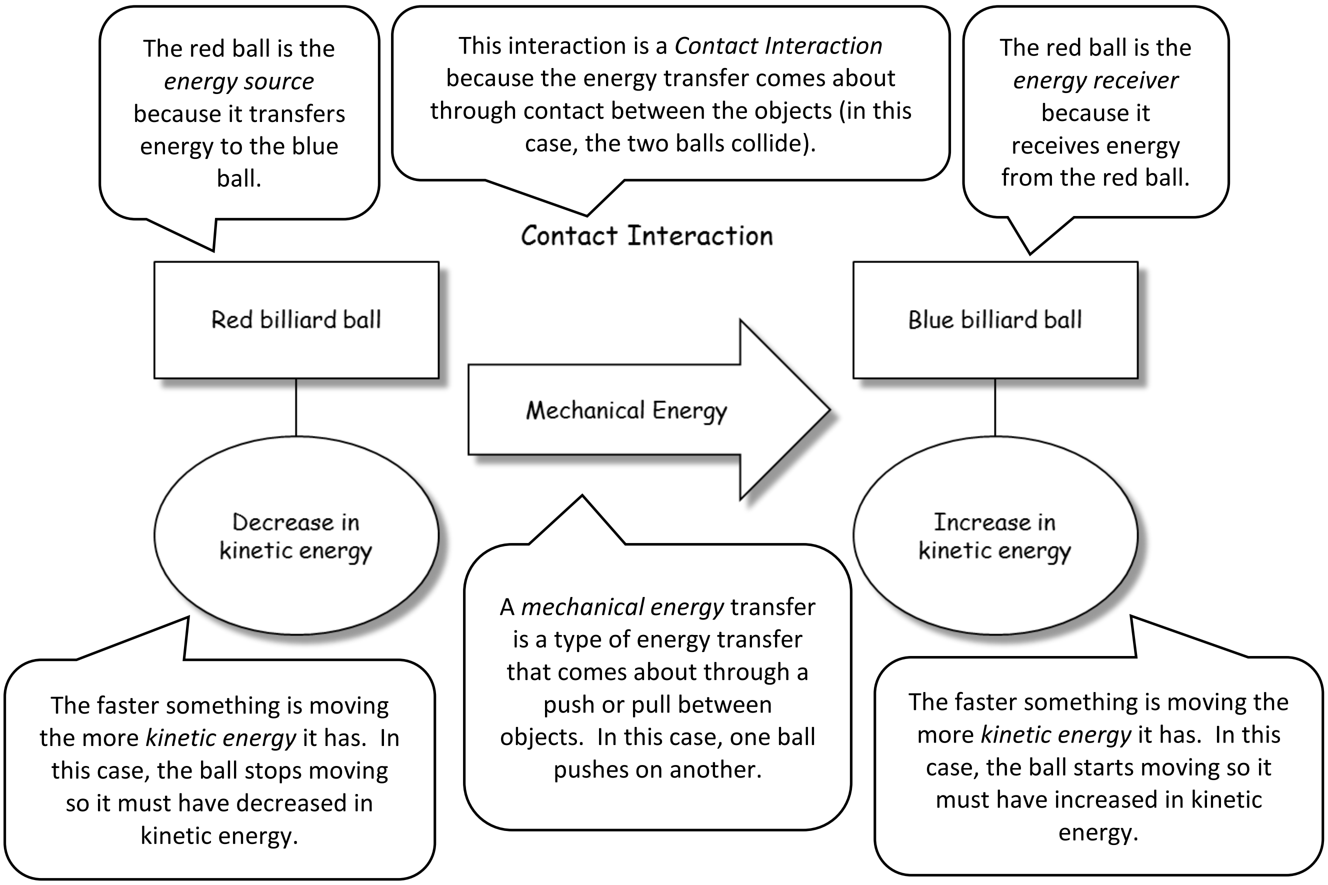
Constructing explanations

When two particles at different speeds collide, one is said to transfer energy to the other. In this case, the type of energy that is being transferred is kinetic energy. We can observe that transfer through changes in speed. To describe the energy changes between two systems (in this case the systems are the red particle and the green particle) we will use **energy diagrams.**

An energy diagram is a way to keep track of energy movement between two objects or substances. At the top of the diagram, the type of interaction is listed. This defines the way in which the two objects are relating to each other, that results in the energy transfer. The two boxes represent the energy source (left) and receiver (right). The type(s) of energy being lost are shown in the left oval and the type(s) of energy being gained are shown in the right oval. Each type of energy transfer also comes with its own mechanism for transferring energy. This mechanism is shown in the arrow. Even though the word "energy" is used in the arrow, it is sometimes more useful to think of this part of the diagram as describing the way energy is transferred, rather than a type of energy being transferred.



Consider a red billiard ball moving directly toward a stopped blue billiard ball. The two collide, after which the red ball stops and the blue one moves at the same speed as the red ball was originally. An energy diagram for this interaction is shown below. Carefully read the annotations to gain an understanding of each term. We will add types of interactions, energy, and energy transfers as we progress through this curriculum.



Energy diagrams are often accompanied by narratives, which describe the interaction in more detail and connect the physics terms used in the energy diagram to the physical situation. An example of a narrative to accompany the diagram above is below.

As the two balls collide, a contact interaction takes place. Energy is transferred from the red billiard ball (the energy source) and the blue billiard ball (the energy receiver). Because energy is transferred through contact of the two objects, this is a mechanical energy transfer. As a result of the transfer, the red billiard ball decreases in kinetic energy: it slows down and stops. After the collision, the blue ball begins to move and speed up, thus increasing in kinetic energy.

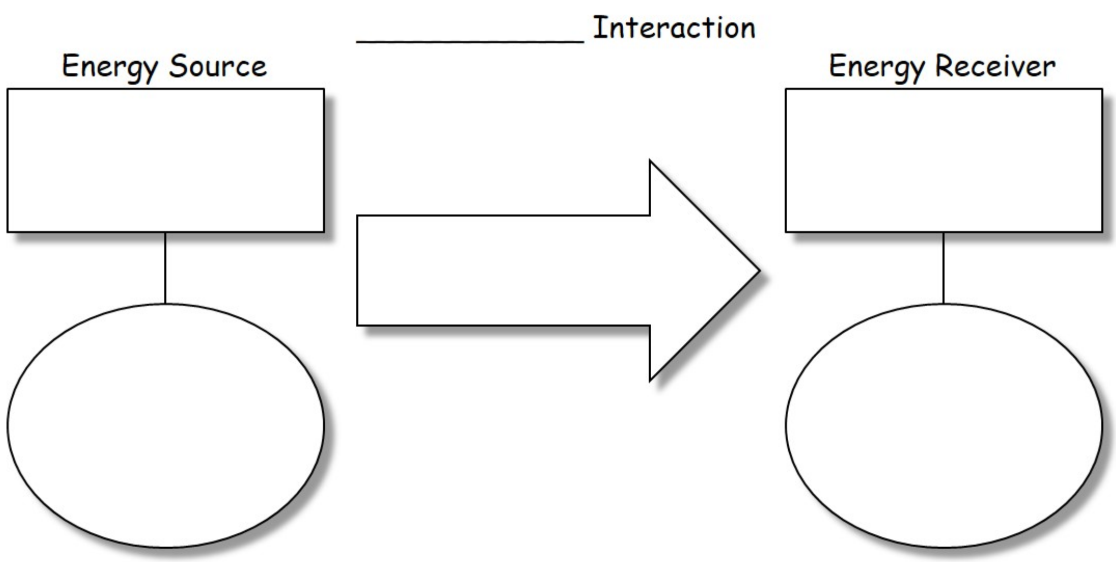
The narrative should meet three criteria:

1. **Logical clarity:** The narrative flows in a logical order and connects the energy change (transformation of potential into kinetic energy) into “real-world” physical observations, by describing the decreased distance between the marbles and increased speed of the moving marble.

2. **Completeness:** The narrative references every part of the energy diagram (type of interaction and transfer, source/receiver, types of energy decreasing and increasing)
3. **Accuracy:** The narrative references important scientific ideas that are relevant to the situation (how potential energy relates to distance, no change in total energy) and uses them in scientifically consistent ways.

These criteria should be applied to every narrative you write.

1. Now try your hand at creating an energy diagram for the red and green particle system you investigated in investigation 2. Specifically, consider the scenario in which the red particle is initially moving more slowly than a green particle, and they collide. Use the energy diagram below to answer the question, **Why does the red particle speed up and the green particle slow down after they collide?**



2. Try writing a narrative to accompany your energy diagram.

3. Share your energy diagram and narrative with the rest of your group. As a group, create a consensus energy diagram and narrative, and prepare to share it with the rest of the class.

Investigation 3

You will be working with two types of particles in this part – He (green) and Ne (blue) particles. The Ne particles are about 5 times more massive than the He particles.

You will need:

- Computer with internet access

Procedure

1. Working with the simulator:

    - Click "Reset."
    - Select the bubble next to pressure.
    - Set the Volume to 22.4 L.
    - Set temperature to about 100 K (record precisely the value, but it need not be exactly 100 K.)
    - Set n (mol He) and n (mol Ne) to about 1.0 each, keeping them as close to equal as you can (you may not be able to get them exactly equal).

2. Compare the two narrow vertical lines – the green line indicates average speed of He particles and the blue line indicates average speed of the Ne particles. What do you observe about the relative average speeds of the He and Ne particles?

    The average speed of Ne (blue) particles is *less than / more than / the same as* the average speed of He (green) particles.

Earlier you saw that kinetic energy is the type of energy something has if it is moving. The faster it moves, the more kinetic energy it has. However, kinetic energy is not just a function of speed but is also depends on the mass of the object moving. The following equation is a mathematical model for kinetic energy (E_k):

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

Where m is mass and v is speed. In the table below are values for the speed (in meters per second), of each type of particle at 100 K as well as the mass of each particle in atomic mass units (AMU).

3. In the final column, use the equation above to calculate kinetic energy for gas. Leave out units for now – the important thing is to compare the average kinetic energy of the particles of each gas.

Gas	Temp. (K)	Mass (AMU)	Average velocity of particles (m/s)	Average E_k
He	100	4.00	1000.00	
Ne	100	20.00	447.21	

4. What is the only submicroscopic property (mass, velocity, kinetic energy) that is the same at a given temperature? ____________________

5. Revise your definition of temperature again. What are you actually measuring when you measure the temperature of a substance?

   Temperature measures. . .

6. Share your responses with your group. Try to reach a consensus before moving on.

Summarizing Questions

S1: Let's visit again with our fictitious lab group. They are having a conversation about how the motion of the particles of sodium and air compare at room temperature:

> **Victor:** Salt is a solid and air is a gas at room temperature, so the air must be moving faster, since it is in gas form, just like how you have to increase the temperature of water to make it boil and become a gas.
>
> **Devon:** Yeah, I agree, plus particles in a solid are rigid, so they don't really move. Gas goes all over the place, so it is clearly moving faster
>
> **Kate:** But wait, they are both at the same temperature, and didn't we say that temperature measures the speed of particles? So, how could they be moving at different speeds?

Do you agree with any of them? What would you add (evidence or reasoning) to the conversation to help them come to a constructive conclusion?

S2: Below, draw representations showing *how* small particles might move differently in each phase of matter (solid, liquid, gas), at a single temperature. For example, do they move completely randomly, or jiggle inside a set volume? Somewhere in between? Then, discuss how the *type* of motion is different from *speed* of motion.

Solid	Liquid	Gas

Description:

S3: Summarize the difference between speed and kinetic energy. Discuss how two particles can have the: a) same kinetic energy but different speeds, and b) same speeds but different kinetic energy.

S4: A heat conduction interaction is described on the macroscopic scale as a transfer of energy between two objects of different temperature that are touching one another. How would you describe a heat conduction interaction on a submicroscopic scale?

S5: In what direction does a heat conduction interaction always occur? Justify why, on the submicroscopic level.

S6: If the rock and water in the initial ideas section were not made of small particles, would their temperatures change? Why or why not?

Revisiting initial ideas

1. How were your drawings of water at different temperatures in the initial ideas section consistent with or inconsistent with your current definition of temperature? If there were inconsistencies, what prompted a change in your ideas?

2. How were your drawings of sodium, water, and neon at room temperature in the initial ideas section consistent with or inconsistent with your current definition of temperature? If there were inconsistencies, what prompted a change in your ideas?

3. Would you make any changes to your small particle model for how the stone and water reach equal temperatures in the initial ideas section, based on your exploration of the gas particles exchanging energy via collisions? If so, summarize what changes you would make below (again, don't actually make changes in the initial ideas section). If not, discuss why you wouldn't make changes.