Name: ______________________________________ Date: ________________________

Student Exploration: Temperature and Particle Motion

Vocabulary: absolute zero, Kelvin scale, kinetic energy, Maxwell-Boltzmann distribution, molar mass, molecule, temperature, universal gas constant

Prior Knowledge Questions (Do these BEFORE using the Gizmo.)

1. Why is hot air hot? ____

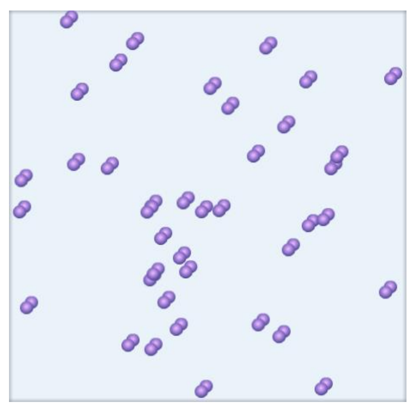
____

2. Why is cold air cold? ____

____

3. Air consists of tiny particles called **molecules**. How do you think the molecules move in hot and in cold air? ____

____



Gizmo Warm-up

The *Temperature and Particle Motion* Gizmo™ illustrates how the molecules of gas move at different temperatures. In this Gizmo, temperature is measured on the **Kelvin scale**, which measures temperature from **absolute zero**, the coldest possible temperature (-273.15 °C). Each unit on the Kelvin scale is equivalent to 1 °C: 273.15 K = 0 °C, and 373.15 K = 100 °C.

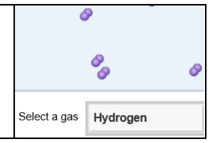
Check that the selected gas is **Hydrogen** and the **Temperature** is 300 K.

1. Describe the motion of the hydrogen molecules: ___________________________________

____

____

2. Are all of the molecules moving at the same speed? ______________________________

Activity A: **Molecular motions**	Get the Gizmo ready: • Check that the selected gas is **Hydrogen** and the **Temperature** is set to 300 K.	

Question: How is the temperature of a gas related to the motion of gas molecules?

1. Observe: Move the **Temperature** slider back and forth. Focus on the particle motion at left.

   What do you notice? ____

   ____

2. Analyze: The **temperature** of a substance is a measure of the average **kinetic energy** of its particles (kinetic energy is the energy of motion). The kinetic energy (KE) of a particle is equal to its mass times the square of its velocity, divided by two:

$$KE = mv^2 / 2$$

   A. Based on the formula for kinetic energy, how will the temperature change if you increase the average velocity of the molecules in a gas? _______________________

   ____

   B. How will the temperature change if you increase the mass of the gas molecules?

   ____

3. Predict: Oxygen molecules are sixteen times as massive as hydrogen molecules. At the same temperature, which type of molecule would you expect to move faster? Explain.

   ____

   ____

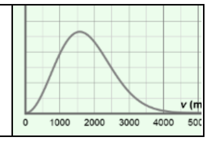
4. Check: Test your prediction by choosing **Oxygen** from the **Select a gas** menu.

   What do you see? ____

5. Explain: Based on the definition of temperature given above, explain why oxygen molecules move more slowly than hydrogen molecules at the same temperature. _________________

   ____

   ____

Activity B: Average particle velocity	Get the Gizmo ready: • Select **Hydrogen** gas. • Set the **Temperature** to 300 K.	

Introduction: The graph on the right side of the Gizmo represents the **Maxwell-Boltzmann distribution** of particle velocities. The curve represents the probability of a particle moving at the velocity shown on the *x*-axis of the graph. The higher the curve, the greater the probability of finding a particle moving at that velocity will be.

Question: How are particle velocities distributed?

1. Observe: Move the **Temperature** slider back and forth. This time focus on the graph at right.

   What do you notice about the shape of the graph? ___________________________________

   ____

   ____

   ____

2. Analyze: Look at the left side of the graph as you raise the temperature from 50 to 1,000 K.

   A. Even at the highest temperatures, are there still a few slow particles? ____________

   B. At what temperature do you see the widest variety of particle velocities? __________

   C. In general, is the Maxwell-Boltzmann curve a symmetrical or an asymmetrical curve?

   ____

3. Estimate: Because particles have a range of velocities at any given temperature, it is useful to calculate the average velocity. Physicists express the average velocity in three ways: *most probable velocity* (v_p), *mean velocity* ($\bar{v}$), and *root mean square velocity* (v_{rms}).

   Set the temperature to 200 K (the selected gas should still be **Hydrogen**).

   A. Estimate the most probable velocity by looking at the peak of the curve. What is your estimate? ______________

   B. Turn on **Show most probable velocity**. What is the actual value? ______________

   C. Base on the shape of the curve, do you think most of the particles are moving faster or slower than the most probable velocity? ______________

(Activity B continued on next page)

Activity B (continued from previous page)

4. Predict: The mean velocity is the average velocity of all of the particles. Based on the shape of the curve and your answer to the previous question, do you expect the mean velocity to be greater than or less than the most probable velocity? Explain your reasoning.

____

____

5. Check: Turn on **Show mean velocity**. What is the mean velocity? ____________________

   Was your prediction correct? ____________________

6. Experiment: Try a variety of other gases and temperatures. Is the mean velocity always

   greater than the most probable velocity? ____

   Explain why this is so: ____

   ____

   ____

7. Calculate: Turn off **Show most probable velocity** and **Show mean velocity**. Select **Hydrogen** and set the **Temperature** to 100 K. You can calculate the most probable velocity (v_p), mean velocity ($\bar{v}$), and root mean square velocity (v_{rms}) using the following formulas:

$$v_p = \sqrt{\frac{2RT}{M}} \qquad \bar{v} = \sqrt{\frac{8RT}{\pi M}} \qquad v_{rms} = \sqrt{\frac{3RT}{M}}$$

   In each formula, R stands for the **universal gas constant**, or 8.3144 J / K mol, T stands for Kelvin temperature, and M stands for the **molar mass**, in kg / mol. Hydrogen gas (H_2) has a molar mass of 0.002016 kg / mol.

   A. Calculate the most probable velocity (v_p): ____________________

   B. Check by turning on **Show most probable velocity**. Were you correct? __________

   C. Calculate the mean velocity ($\bar{v}$): ____________________

   D. Check by turning on **Show mean velocity**. Were you correct? __________

   E. Calculate the root mean squared velocity (v_{rms}): ____________________

   F. Check by turning on **Show root mean square velocity**. Were you correct? _______