

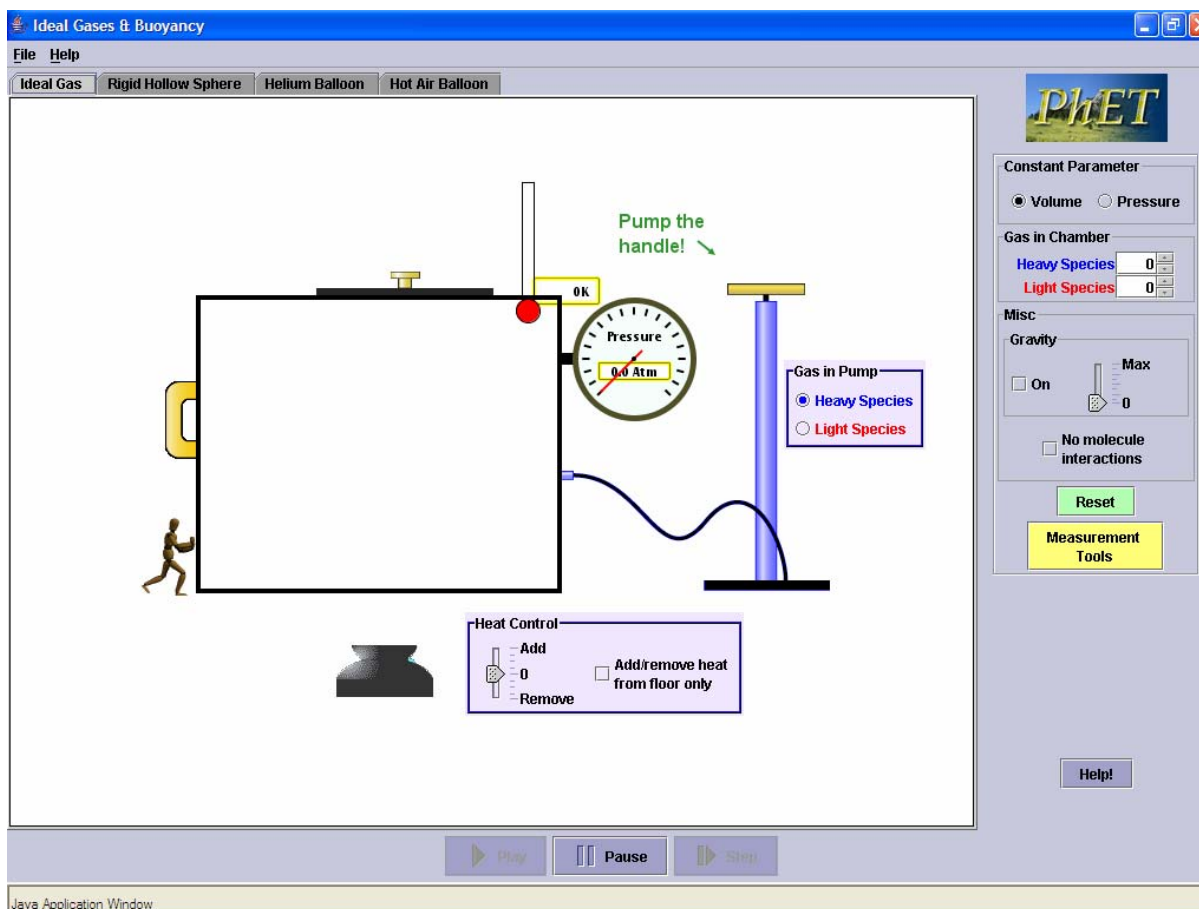
Lab 13: Temperature and Thermodynamics

INTRODUCTION & BACKGROUND:

By now you are probably very familiar with the ideal gas law $PV=nRT$, or the equivalent $PV=Nk_B T$, which define the “ideal” behavior of gases. In today’s lab, you will use the Physics Education Technology (PhET) web-site to observe a model of an ideal gas in action, and perform a number of “virtual” experiments on it.

PART I: QUALITATIVE OBSERVATIONS

Open up the PhET web-site www.colorado.edu/physics/phet and follow the link to “simulations” then “ideal gases and buoyancy”. A Java applet should appear that looks like this:



Spend a few minutes playing with the various controls and getting used to the behavior of the applet.

Using only **heavy species**, and with the constant parameter set to **volume**, use the pump to put some particles into the box. If you add more particles, what happens to the pressure? What happens to the temperature? Is this what you expect?

If you add heat to the system (using the burner at the bottom), what happens to the pressure? What happens to the temperature? Is this what you expect?

PART II: THERMAL EQUILIBRIUM

Hit the **reset** button to clear the chamber. Using the **gas in chamber** control at the right, set the number of **heavy** particles (only) to 200 so that the pressure reads around 1 atm. We know from class that the average kinetic energy associated with each particle is related to the average particle velocity, and is given by:

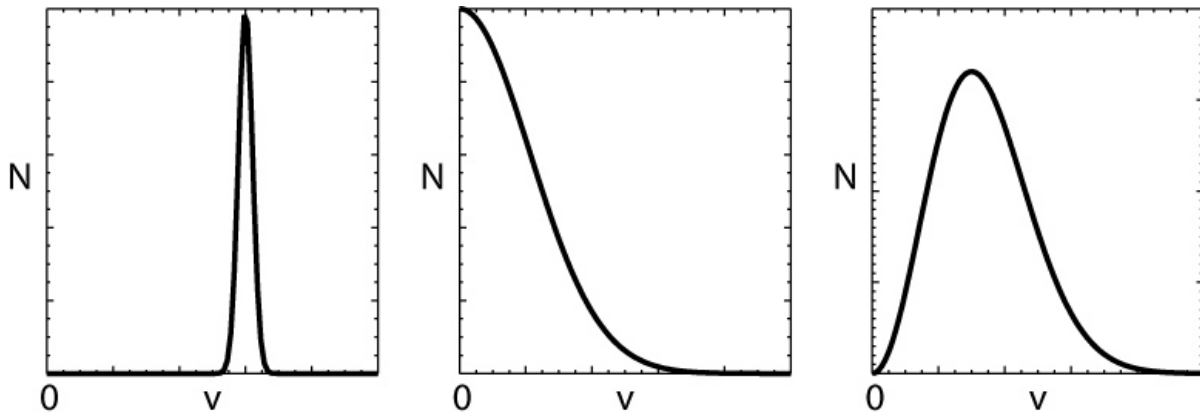
$$KE_{avg} = \frac{1}{2} m v_{avg}^2 = \frac{3}{2} k_B T$$

Notice that **velocity** here is a scalar, not a vector – this is what we have previously referred to as “speed”, but in this lab we will use the term **velocity** to mean “the magnitude of the velocity vector”.

Indicate whether each of the following statements is true or false:

- The gas has one unique temperature, so all of the particles must have the same velocity.
- The particles have lots of different velocities, so each particle has its own temperature.
- The particles have lots of different velocities, but the average velocity determines a single temperature for the whole group of particles.
- The velocity of each particle keeps changing due to collisions, so the temperature is not uniquely defined.
- The velocity of each particle keeps changing due to collisions, but the average velocity stays roughly constant, so the temperature is well defined.

Below are three plots of particle population vs. velocity. Which of the following plots is a good description of the velocity distribution in the chamber? For each of the plots that you didn't choose, explain why.



On the plot that you chose, indicate which velocity (i.e. where on the x axis) is the “average” or “thermal” velocity.

Use the burner to add some heat to the chamber. What happens to the pressure? What happens to the temperature? What happens to the particle velocities?

If the temperature is doubled, what should happen to the average particle velocity? Does it change by a factor of two? More than a factor of two? Less than a factor of two? Explain your reasoning.

Below, plot two velocity distributions: one similar to the plot you chose on the previous page, and one representing the velocity distribution after the temperature is doubled.

Hit the **reset** button to clear the chamber. Using the **gas in chamber** control at the right, set the number of **light** particles to 200 so that the pressure reads around 1 atm. What differences do you observe between this configuration and the initial configuration with the heavy particles?

If the mass of the species is cut in half but the temperature is kept constant, what should happen to the average velocity? Does it change by a factor of two? More than a factor of two? Less than a factor of two? Explain your reasoning (back up your reasoning with formulas).

Record the number of light particles, the temperature, and the pressure of the chamber. Now, using the **gas in chamber** control at the far right, remove **half** of the light particles and replace them with heavy particles. What do you observe?

Recall that pressure is associated with collisions between the particles and the walls. Which particles (heavy or light) impart a higher force with each collision?

Which particles impart more collisions per second?

Below, on a single graph, plot the velocity distribution of the heavy particles and the velocity distribution of the light particles.

Indicate whether each of the following statements is true:

- The light particles are moving faster (on average) than the heavy particles, so the temperature of the light particles is higher.
- Some of the light particles are moving faster than some of the heavy particles, but their average velocities are the same, so the two species have the same temperature.
- The light particles are moving faster (on average) than the heavy particles, but the temperature is related to both the average velocity and the mass, so despite the difference in v_{avg} , the two species have the same temperature.
- The average kinetic energy of the light particles is the same as the average kinetic energy of the heavy particles since they are in thermal equilibrium.

PART III: COMPRESSING THE GAS

Reset the chamber and pull the left wall as far to the left (expanding the chamber) as possible. Use the **gas in chamber** control to put 250 heavy particles in the chamber.

As we know from class, gas pressure is a result of collisions with the gas molecules. Draw a force diagram of the forces acting on the left wall of the chamber.

Now push on the left wall, compressing the chamber by about a factor of two. What happened to the temperature?

What happened to the average kinetic energy of the particles? What happened to the total kinetic energy of all of the particles? What is the source of this energy?

When the chamber was compressed by a factor of two, what happened to the pressure? Did it change by a factor of two? More than a factor of two? Less than a factor of two? What would you expect based on the ideal gas law and the other observable parameters?

Expand the chamber to the size it was before it was compressed. What happened to the temperature? What happened to the energy in the gas? Was energy conserved? Explain.

Reset the chamber, compress the size, and then set the number of heavy species to 5. The starting kinetic energy of the particles is set so that the initial temperature is 300K. Now expand the chamber very quickly **so that no particles bounce off the left wall while it is moving**. (This might take a couple of tries.) What happened to the temperature? What happened to the energy in the gas? Is this situation different than the previous expansion? If so, explain how and why it is different.

PART IV: EVAPORATION

Reset the chamber, expand it to its maximum size, and turn on the **gravity** control to **max**. Use the **gas in chamber** control to put in 1000 heavy particles. Use the **heat control** to remove enough heat so that the temperature is around 1500K (it doesn't have to be exact). As accurately as possible, record the temperature here. Include an error estimate (for example $T = 1492 \pm 200$ K).

If a hole at the top of the chamber were opened to let gas escape, would you expect the **average kinetic energy** of the particles left in the chamber to change? How about the temperature? Explain your reasoning.

Slide the lid open and let gas particles escape until there are about 900 left. What happened to the temperature? What happened to the average kinetic energy of the particles left in the chamber? Does it match your expectations? If not, why not?

Now open the lid and leave it open for several minutes. Does the temperature continue to change? Explain what happens.

While it is not perfect, this behavior is analogous to how water always boils at the same temperature. What would happen if water was heated to a temperature slightly higher than its boiling temperature?

PRELAB QUESTIONS: (to be turned in upon arriving at lab)

1. How is the temperature of a gas related to the average kinetic energy of the gas particles? Be specific.
2. How is the temperature of a gas related to the average velocity of the gas particles? Be specific.
3. If a bowling ball and a ping-pong ball each have the same kinetic energy, how do their velocities compare? Be specific.
4. Answer the four questions attached to the end of this document. Keep them separate from the first three questions, but turn in all the questions to your TA at the beginning of lab.

POTENTIAL EXAM QUESTIONS:

1. Cylinders A and B are identical. 100 g of Ne (atomic weight = 20 g/mol) is introduced into cylinder A and 100 g of He (atomic weight = 4 g/mol) is introduced into cylinder B. Both cylinders are then closed. The temperature of both cylinders is the same. Which one of the following statements is true?
 - a) The pressure in the Ne cylinder is higher than that in the He cylinder.
 - b) The pressure in the Ne cylinder is lower than that in the He cylinder.
 - c) The pressure in the two cylinders is equal.
 - d) The pressures cannot be compared without knowing the temperature.
 - e) None of the above
2. Consider a single bottle of a gas mixture composed of equal numbers of He atoms (atomic weight = 4 g/mol) and Ne atoms (atomic weight = 20 g/mol). Which of the following statements is true?
 - a) The average kinetic energy of the He atoms is less than the average kinetic energy of the Ne atoms.
 - b) The average velocity of the He atoms is higher than the average velocity of the Ne atoms.
 - c) If the bottle is connected to a tube and the gas is used to pump up a car tire, the gas will heat up because work is being done on the gas.
 - d) Both B and C are true.
 - e) A, B, and C are all true.

Physics 2020

Name _____

TA _____

Student # _____

Please turn this in to your TA at the **beginning** of section.

NOTE: While these may *seem* to be identical problems, they are not!

Question 1 - Verbal Format

An electron in a Bohr-model hydrogen atom is in the 'orbit' with the lowest possible energy. How does the radius of the electron orbit change if it moves up to the third energy level?

- A) The radius of the new orbit will be three times the original radius.
- B) The radius of the new orbit will be nine times the original radius.
- C) The radius of the new orbit will be one-third the original radius.
- D) The radius of the new orbit will be one-ninth the original radius.
- E) None of these.

How difficult did you consider this question? (Circle the best number)

Easy 1 2 3 4 5 Hard

Question 2 - Mathematical Format

The Bohr radius for an electron is $r_1=0.529 \times 10^{-10}$ m. Calculate the radius of the $n=4$ energy level.

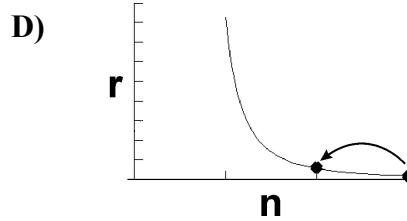
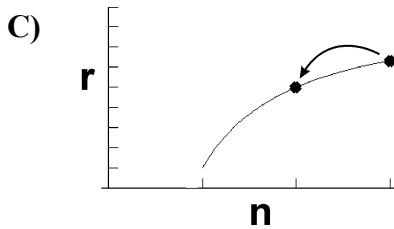
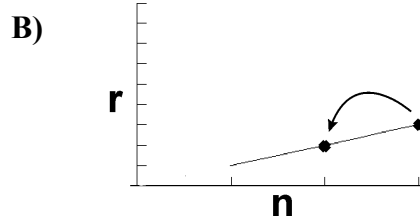
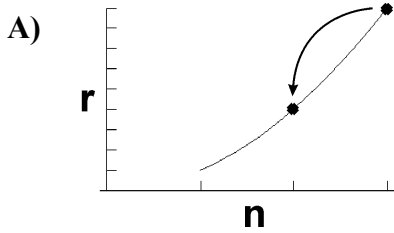
- A) $r_4=0.033 \times 10^{-10}$ m
- B) $r_4=0.132 \times 10^{-10}$ m
- C) $r_4=2.116 \times 10^{-10}$ m
- D) $r_4=8.464 \times 10^{-10}$ m
- E) None of the above.

How difficult did you consider this question? (Circle the best number)

Easy 1 2 3 4 5 Hard

Question 3 – Graphical

An electron in a Bohr hydrogen atom jumps from the $n=3$ orbit to the $n=2$ orbit. The following graphs show the orbit radius r as a function of the orbit number n . Choose the graph that best represents the relative locations of the electron orbits.



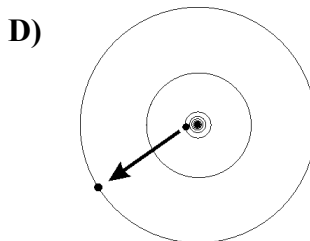
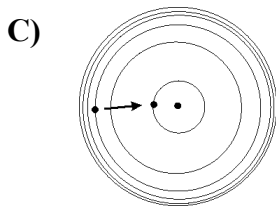
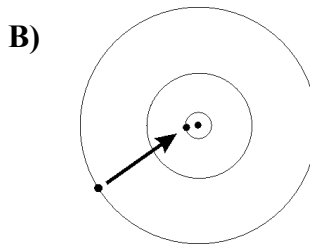
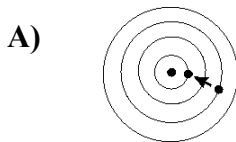
E) None of these.

How difficult did you consider this question? (Circle the best number)

Easy 1 2 3 4 5 Hard

Question 4 – Pictorial

An electron in a Bohr hydrogen atom jumps from the $n=3$ orbit to the $n=1$ orbit. Choose the picture that best represents the relative locations of the electron orbits.



E) None of these.

How difficult did you consider this question? (Circle the best number)

Easy 1 2 3 4 5 Hard