

7.2: Activities

Equipment

- laptop

The General Idea

Typically in labs we explore the real-world applications of physical principles, but the topic of kinetic theory presents us with a problem on that count. We can (and will) explore the *results* that come from kinetic theory, namely the relationships between macroscopically-measurable quantities like pressure, temperature, and volume, but the theory itself involves linking a microscopic model to the macroscopic world, and given this involves a number of particles on the order of 10^{23} , this cannot be directly observed. So instead we'll explore this theory by cutting down the number of particles to a manageable level, and use [computer simulation](#) to model what we want to examine. [You can click on the link now to run the simulator in a separate window. If you are reading this on your own device and wish to use the laptop in the lab room for this purpose, you need to log into eduroam, run the browser, then look under "simulators" for "kinetic theory."]

What we will be doing with the simulator comes in two parts. The first is rather unusual, inasmuch as it tests/demonstrates the limitations of the particular simulator we are using to reflect correct physical behavior. Namely, the behavior of the particles in the animation implies that the gas should behave like a van der Waal gas, and we will test whether this is happening. The second part ignores its limitations and moves on to examine the system it is intended to simulate – a volume of an ideal gas.

Things to Think About




Part 1 - Critiquing the Simulator

Normally when we use a simulator, we take the numbers it provides as gospel, but this simulator is a bit different. It exhibits observable behavior of particles in an accurate manner, and it provides numbers that are correct under the certain assumptions, *but the observable behavior does not match these assumptions!* The behavior of the particles on the screen model one physical system, and the thermodynamic quantities displayed numerically model a different physical system. Normally a flaw like this would preclude our using the simulator at all, but it turns out that rooting out these problems is highly instructive, so for the first part of this lab we will do exactly this.

Open the "Energy" panel of the simulator and configure it as follows:

- **Open the "Particles" and "Injection Temperature" drop-downs (the "Average Speed" and "Speed" drop-downs should already be open, but if they are not, then open them as well).**
- **Select the units for the Pressure gauge to be kilopascals (kPa).**
- **Uncheck the "Collisions" box in the "Particles" drop-down.**

A few useful features of the simulator to know about:

- All the particles injected into the chamber come in with the same kinetic energy (which is proportional to their "temperature"). The injection temperature can be selected, or the default injection temperature is the same as the current temperature of the gas in the chamber.
- You can inject 50 particles at a time of a single variety with the  button (fully extending the pump does the same, if you are into the animation). Using the  button injects one particle at a time. The similar buttons whose arrows point to the left remove particles in the same number. [These removal buttons are of little use, as they choose particles at random to remove, and may select more "hot" particles than "cold" ones, meaning that while we can add particles without changing the gas temperature, we cannot remove them without changing the gas temperature.]
- You can remove all of the particles from the chamber at once with the  button.

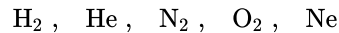
The first thing we will look at is the effect of allowing particle collisions. **Inject a few hundred of the "light" particles into the chamber by clicking the 50-particle button several times.** With the collisions box unchecked, you'll note that the particles follow very predictable, "non-random" paths. They are not interacting with each other, which is a critical element of being an ideal gas, but they fail to exhibit the "randomly-distributed motion" element also required of an ideal gas.

Before we introduce some randomness, make a note of the number in the "Average Speed" dropdown for future reference. Also, have a look at the histogram in the "Speed" dropdown, which indicates that every particle has the same speed (which is apparently

equal to the average speed). If every particle has the same speed, then it's easy to show that the rms speed equals this same speed.

Empty the chamber and repeat this process for the "heavy" particles, then solve the puzzle that follows.

1. Assume that the particles are occupying a three-dimensional volume (not withstanding the two-dimensional screen where they are displayed). The "light" and "heavy" particles are modeled after specific gases. Of the five gases listed below, one is represented by the light particles, and one by the heavy particles. Your task is to determine which is which. You are of course free to look up properties of these atoms and molecules to help you make this determination.



Okay, so let's use the simulator's means for randomizing the velocities. **Check the "Collisions" box in the "Particles" dropdown and observe the behavior of the particles.** Also note that the histogram of particle speeds has diversified from the single spike to a wide spectrum of speeds, and that this histogram fluctuates with time.

2. Discuss what happens when the change to "collisions" mode is made.
 - How does this change affect the distribution of the speeds of the particles?
 - How does this change affect the average and rms speeds of the particles?
 - Does turning off collisions return the gas to its previous state?
 - Which of the three states (before turning on collisions / having collisions turned on / after turning collisions off) most closely represents what we have been using as a model for an ideal gas? Explain.
3. **(simulator flaw)** After watching the action for a short time, it's clear that the particles in "collisions" mode never go past each other without deflecting, which means that these particles are in fact confined to two dimensions, not three. If we follow this strictly, we find that the particles don't represent any of the gases in part (1). Why is this? [You may want to look back at the text reference where kinetic theory is discussed to help you answer this.]

From the [Background Material](#), we know that collisions between particles in the gas leads to a state equation that differs from the ideal gas law. We should be able to measure this change with the simulator. To do this, configure the simulator as follows:

- **Empty the chamber.**
- **Select the "Set to:" radio button in the "Injection Temperature" dropdown.**
- **Set the injection temperature to 100K.**
- **Make sure that the "Collisions" box is checked.**
- **Inject 1000 heavy particles (this is the maximum number) into the chamber.**
- **Wait until the particles fill the chamber and the gas appears to be in equilibrium.**

4. **(simulator flaw)** Now to test the simulator.

- If we turn off collisions, what variable in the "modified van der Waals equation" given in the [Background Material](#), changes? What does it change to? [Hint: What happens to the space available to a given particle when the collisions are turned off?]
- When we turn off collisions, the volume and particle number are not affected, so the relationship between the pressure and temperature must change if the equation of state changes. Do we observe this?
- Is it possible that the constant β in the modified van der Waals equation is just negligibly small for this simulation, accounting for what we see? Explain.

Part 2 - Ideal Gases

Okay, so the simulator has a few flaws with regard to how the displayed particle motions fit with the measured thermodynamic quantities. Let's move past this and assume from now on that the simulator does represent a 3-dimensional ideal gas (i.e. ignore that collisions are occurring). **Change the pane of simulator to "Ideal."** Configure it as follows:

- **Select the units for the Pressure gauge to be kilopascals (kPa).**
- **Check the "Width" box.**
- **Leave the "Nothing" radio button selected in the "Hold Constant" list.**
- **Open the "Particles" dropdown.**

[Note: Unlike the previous simulator, this one allows for an adjustment of the volume by dragging the handle on the left wall of the container, and you can heat or cool the gas to a new temperature using the bucket below the container.]

The volume of this container can only vary along one dimension (left-to-right on the screen), and we can only measure length along this direction, so we will assume that whatever the dimensions of container are, they remain constant. Calling the measurable width x and the cross-sectional area resulting from the other two dimensions A . Then the ideal gas law is:

$$PV = P \cdot (Ax) = Nk_B T \quad (7.2.1)$$

We are going to confirm and then use this equation, but to do this, we need to take measurements of the pressure, and the value jumps around in the gauge. So we will do this by randomly sampling:

- **To take a pressure measurement, freeze the simulation and read off the number.**
 - **Repeat this several times, giving you several measurements (at least 4, but more is better).**
1. Compute the average value and the statistical uncertainty (standard deviation). For a refresher on how to compute standard deviation, review [this](#) from your very first 9A lab.
 2. Using different values for P , N , T , and x for two different states, determine whether the simulator confirms the ideal gas law within the uncertainty. For a refresher on how to compare two uncertain numbers, review [this](#) from 9A Lab #4. [Note: The only variable that comes with uncertainty here is the pressure, so its percentage uncertainty equals the percentage uncertainty for any product or quotient of these values.]
 3. Using one of your two sets of data from above, compute the value of A , the cross-sectional area of the chamber (don't worry about the uncertainty).

Lab Report

While this is not a traditional lab, you still need to put together a lab report with your group. In it, you need to document your work address the questions indicated. As always, every member of the group must upload a separate digital copy of the report to their lab assignment in Canvas *prior to leaving the lab classroom*. These reports are not to be written outside the lab setting.

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