Atomic Motion and Interactions

1. Handout: Unit Notes
2. Have You Seen an Atom Lately?
   1. Lab: Oil Spreading on Water
   2. Demo: Computer animation of spreading oil
   3. Lab: Mixing Alcohol and Water
   4. Demo: Is the glass full yet?

1. List some things that are considered "matter" and some that are non-matter. How do you know something is matter?

2. There are only two possibilities for the underlying structure of matter: either there is a smallest piece of something (the particle theory of matter), or you can divide a thing in half forever, never reaching a smallest piece that can't be divided (the continuous theory of matter).

3. After many years and experiments there is good evidence that all matter consists of atoms and molecules [tightly bonded groups of atoms]. The smallest part of an element is a single atom and the smallest part of a compound [more than one kind of element bonded together] is a molecule.

4. In the past several experiments have been done to suggest that atoms and molecules exist. However, it has only been recently that we created instruments which can "see" atoms - scanning tunneling microscopes. (The word "see" is in quotes because atoms are about 3 powers of ten smaller than the wavelength of visible light. If atoms are smaller than light waves then we can't use light waves to image atoms.) The scanning tunneling microscope "sees" atoms by dragging a needle that is so sharp that its tip is only one
atom wide, across a substance. While it is moving across the substance the instrument monitors an electric current. When the atom of the needle is close to the atom of the substance there is greater current flow. Computers can turn these current flow observations into a picture which maps the location of atoms on the substance. Go to: http://www.howstuffworks.com/atom9.htm for a more detailed picture.

5. Try going to the links below to see some pictures of atoms made with scanning tunneling microscopes:


5. **Homework:** Have you Seen an Atom Questions

3. Superballs are Like Atoms
   1. Lab: Superball Lab Questions
      1. List every kind of energy that you can think of.

      2. The energy of motion is called kinetic energy.

      3. The amount of kinetic energy something has depends on both its mass and velocity [speed]. An object with more mass and/or higher velocity [speed] will have more kinetic energy [energy of motion].

      4. For example, if a bowling ball and a tennis ball are moving at the same velocity [speed], then the bowling ball has more kinetic energy because it has more mass. If the bowling
ball and tennis ball are to have the same kinetic energy [energy of motion], then the
tennis ball would have to be moving much faster than the bowling ball. A rough estimate
of the comparative kinetic energy [energy of motion] possessed by an object, can be
gauged by how hard it would be to stop that object from moving.

5. Demo: Bouncing Superball
6. Why does the superball stop bouncing?

7. When most objects bounce off something, they convert some of their kinetic energy [energy
   of motion] into heat or sound energy. That is why, when you drop a superball straight
down, it bounces to lower and lower heights each time. Its kinetic energy [energy of
motion] is changing to heat and sound energy.

8. Atoms (which we can't directly handle) behave very much like superballs (which we can
handle). We will spend some time understanding the behavior of superballs, so that we
can better understand the less accessible world of atoms.

2. Homework: Superball Questions

4. Modeling Microworlds
   1. Kinesthetic Lab: Kinesthetic Modeling of a Superball
   2. Computer Lab: Modeling of a Superball (How to run this?)
      1. In another unit you learned about the history of the atom and the different models people
         had of what the atom was like. This kind of model was an idea or "concept model".
      2. The term model can also apply to something that acts on rules described by a concept
         model. This is called a "dynamic model". For example:

         A concept model of highway congestion: Traffic congestion is due to people driving fast
         enough that they catch up to the person in front of them, causing them to slow down more
         than necessary resulting in congestion.
A dynamic model of highway congestion: A computer could simulate this behavior by having shapes on the screen move according to the rule of accelerating until meeting another shape. This second type of model is a dynamic model which can be used to see if the congestion does actually result from this type of driving behavior. The person setting up the model can now change various parameters like, how many cars, how fast they drive, how many lanes there are, etc.

3. Dynamic modeling is used every day in many different fields. People predict the weather, the stock market, the affect of waves on beaches, the results of high energy physics experiments, the ultimate fate of the universe, the mechanism of how drugs work, etc.

4. We will use dynamic modeling to understand how superballs and ultimately atoms behave so that we can make predictions about matter and properties that are made of atoms that we can't even see.

3. **Homework:** On a separate sheet of paper list all of the rules you need to describe a model of how atoms behave. You will be adding to this later in the unit, so make sure this rule list gets into your binder.

4. **Homework:** Modeling Questions

5. It Takes Two to Tango: Modeling Two Atoms in a Box

   1. Computer Lab: Two Atoms in a Box (How to run this?)
      1. Energy cannot be created or destroyed. It can be transferred from one object to another or it can be converted into other forms of energy.
      2. Collisions between atoms are 100% elastic, which means that none of their energy is converted to other forms when colliding.
      3. This means that the total kinetic energy of the two atoms will be the same before and after the collision. Each atom may have a different kinetic energy than before the collision, but if one atom gained energy, the other lost energy, leaving the total unchanged.

6. **Homework:** Two Atoms Questions

1. Kinesthetic Lab: Modeling a Gas
2. Computer Lab: Modeling a Gas (How to run this?)

1. When atoms collide with each other, the total amount of kinetic energy [energy of motion] they have is conserved [remains constant]. Typically, when one atom collides with another of the same mass, the faster atom, the one with more energy, will slow down and consequently now have less kinetic energy. The other atom with which it collided will speed up and consequently now have more kinetic energy. The total energy of the atoms before and after the collision will be the same.

2. As the number of atoms being modeled increases, patterns and certain statistical behaviors emerge that are not easily observed in simpler models. Using a computer model with many atoms, we begin to approach the modeling of macro scale phenomena (e.g., the behavior of gasses). With many atoms, we can now study the statistical behavior of atoms in a gas.

3. After the model is allowed to run for some time the gas molecules will reach a dynamic equilibrium.

4. A state of dynamic equilibrium occurs when measurements on a system are constant even though individual parts of the system are rapidly changing. For example, imagine two sets of people on opposite sides of a bridge. They begin to walk across in such a way that for every person who crosses from side A to side B, one crosses from side B to A. If you were to measure how many people are on either side of the bridge you would always get the same number. However, the specific people are always changing. This is a state of dynamic equilibrium.

5. There are two kinds of equilibrium related to the gas atoms:

   1. Spatial Equilibrium: A state reached when the atoms of a gas are spread out evenly in a container. This doesn't mean that the atoms have exactly equal spacing between them - it means the average distance between atoms will be the same.
2. Thermal Equilibrium: A state reached when the kinetic energy is "spread out evenly" between the atoms. This doesn't mean the atoms all have the same energy - it means they will have the same average kinetic energy over time (or same running average of kinetic energy).

3. Homework: Modeling a Gas/Equilibrium Questions

7. Diffusion - A Molecular Race

1. Demo: How did that smell get over here?
2. Demo: Ammonia and HCl diffusion
3. Computer Model: Gas Diffusion (How to run this?)

1. Gas molecules are in continual motion. They move in a straight line until they collide with another molecule or with the walls of their container (also made of atoms and molecules). When molecules collide, they rebound with 100% elasticity [bounciness].
2. Air is made of colliding gas molecules and odors are also made of gas molecules. If some odor is released from a container then the molecules will mix with molecules in the air. The multiple random collisions will cause the odor molecules to diffuse [spread randomly in all directions] into the surroundings.
3. The random motion of atoms as they jostled around by other atoms is called "Brownian Motion".
4. For simplicity all gasses will be modeled as if they are made from single atoms. While true of some gasses (the ones in the Noble gas column of the periodic table), this is not true of other gasses at room temperature.
5. When molecules are mixed together, the kinetic energy of the the molecules will be transferred via collisions until they all have the same average kinetic energy
6. If you mix two different gasses together, then the mixture contains molecules with two different masses. The kinetic energy each molecule has is affected by both its mass and velocity.
7. Because two different molecules end up with the same average kinetic energy but have different masses, they must necessarily have different velocities. For example, molecules with less mass must move faster than molecules with more mass in order for them to both have the same kinetic energy. If two different gasses are mixed together, then the lighter molecules will have higher average velocities.

4. **Homework:** Diffusion Questions

8. Heat vs. Temperature

   1. Computer Lab: Heat vs. Temperature (How to run this?)
   1. Heat and temperature are not the same thing.
   2. Heat energy is the total kinetic energy of the atoms of a substance.
   3. Temperature is the average kinetic energy of the atoms of a substance.
   4. Each atom has a certain amount of kinetic energy. This energy fluctuates due to the many collisions with other atoms. However, when two atoms collide transferring kinetic energy from one to the other, no kinetic energy is lost. If the amount of kinetic energy for each atom is added up then you would have a value representing the heat energy of that collection of atoms. It follows that the more atoms which are counted, the greater the heat energy will be.
   5. Temperature is a measure of the average kinetic energy of those atoms. The result of this difference between heat and temperature causes the number of atoms measured to play a major role in understanding how much heat energy an object has at a particular temperature.
   6. For example, if two glasses of water are left out on the table, one completely full and the other exactly half full, they will eventually both come to room temperature, about 21°C. They may have the same temperature, but the full glass has twice the heat energy of the half full glass. Because the full glass has twice as many molecules each carrying some heat energy (or kinetic energy) the full glass has more heat at the same temperature.
   7. The higher the temperature the faster the atoms move.
8. Large objects can have a kinetic energy and temperature which are distinctly separate things. For example, a baseball sitting still has no kinetic energy, but its atoms are moving, so they have kinetic energy. Because the temperature of a substance is due to the average kinetic energy of its atoms, the ball does have a temperature. Depending on how many atoms it takes to make up the ball, it has a certain amount of heat energy (the total energy of the atoms comprising the ball).

9. Because temperature is a function of the average kinetic energy of the atoms, the lowest possible temperature would be when the atoms stop moving, therefore having no kinetic energy. Because there is a lowest possible temperature, it would make sense to use a temperature scale that starts at zero. This temperature scale is called the Kelvin temperature scale and zero Kelvin is a special temperature called absolute zero (when all atomic motion is stopped).

10. An atom, however, can't separate kinetic energy from heat energy. For atoms they are one and the same thing. A bunch of atoms sitting still have no kinetic energy, no heat energy, and would have zero temperature (on the Kelvin temperature scale).

11. In summary:

* For an atom Kinetic Energy = Heat Energy
* For a substance Heat Energy = Total of all the Kinetic Energies of its atoms
* For a substance Temperature = Average Kinetic energy of its atoms

2. Homework: Heat vs. Temperature Questions

9. Heat Transfer

   1. Kinesthetic Lab: Heat Transfer
   2. Computer Lab: Heat Transfer (How to run this?)

   1. Heat energy can be transferred between two containers by putting them in direct physical contact, and this heat energy will always flow from the hotter container to the cooler container.
2. The temperature of a substance is dependent on the kinetic energy of its atoms or molecules. Because atoms or molecules can transfer some of their kinetic energy by colliding with other atoms, heat energy can be transferred through atomic collisions.

3. If there are two substances each inside their own container, then heat energy can be transferred between the two substances through the following process:
   * The atoms of each substance collide with the atoms of their respective containers.
   * If the containers are touching each other, the atoms of one container can collide with the atoms of the other container which can then collide with the atoms of the substance within the container.
   * Eventually, the two substances and their containers come to thermal equilibrium [a state in which all atoms in the system have the same average kinetic energy].

4. During the process of reaching thermal equilibrium you might wonder how atoms know which way to transfer their kinetic energy. In fact, heat is flowing from the hot container to the cold AND from the cold to the hot. However, because the hotter container has a greater portion of atoms with higher kinetic energies, the rate of kinetic energy transfer from the hotter container to the cooler container is faster than the rate of energy transfer back from the cooler container to the hotter container. The result is a decrease in the temperature of the hotter container and an increase in the temperature of the cooler container.

5. Eventually, when the temperatures become equal, the rate of energy exchange is equal and it appears that nothing is happening. However, energy is still being exchanged from one container to another. It’s just that the rate of exchange is equal. This state is known as thermal equilibrium.

3. Homework: Heat Transfer Questions
10. Gas Pressure
   1. Lab: Heating and cooling a gas
   2. Computer Lab: Gas Laws (How to run this?)

   1. Gasses exert pressure through the impacts of their molecules on the walls of their containers.
   2. Although we can’t see any physical evidence of how a gas can exert a pressure, we certainly can feel that pressure. To understand how a gas exerts pressure we need to recall the underlying atomic model: a gas is a bunch of atoms bouncing around like superballs.
   3. When an atom bounces off the walls of its container, the container feels the impact in the same way you would feel an impact from a ball bouncing off of a tennis racquet. However, the impact felt by the wall of the container is extremely small. The bouncing of one atom off of the wall of a container would be virtually insignificant. It takes millions upon millions of impacts between atoms and the walls of their containers concentrated on a vary small area to register a measurable pressure.
   4. There are two primary factors which explain the magnitude of the pressure exerted by atoms: the frequency of impacts and the force of those impacts.

1. There are several ways that gas pressure can be increased due to increased frequency of impacts.
   * Put more gas in the container. If you have more gaseous atoms in a container then there will be more frequent impacts against the walls of the container causing a greater pressure on its walls.
   * Make the container smaller. If you have the same number of atoms crammed into a smaller space, then they will hit the walls more frequently with more atoms hitting the same area repeatedly, increasing the pressure on the walls.
   * Raise the temperature. If you make the atoms move faster then they will hit the walls more frequently, increasing the pressure on the walls.
2. We can also increase gas pressure if each atom hits the wall of its container with greater force. There is one primary way to make this happen:

* Raise the temperature. By raising the temperature you add kinetic energy [energy of motion] to the atoms, therefore, increasing their velocity. If they are moving faster when they hit the wall of the container, then the impact against the wall will be greater, increasing the pressure on the walls.

5. There is an intimate relationship between gas pressure, temperature, volume of the container, and the number of molecules inside the container.

6. **Boyle's Law: Pressure vs. Volume**

1. If you make the volume of a container smaller the molecules will hit off the walls more frequently. This means that the pressure will increase.
2. If you make the volume of a container larger the molecules will spread out and hit the walls of the container less frequently, so exerting a lower pressure on the container.

7. **Charles' Law: Pressure vs. Temperature**

1. If you raise the temperature of the gas molecules then they will move around faster hitting the walls of the container more often AND harder. This will increase the pressure felt by the container.
2. If you lower the temperature of the gas molecules then they will slow down and the opposite will happen.
8. **Avagadro's Law: Pressure vs. Number of Molecules**

   1. If you add more molecules to the same size container then there will be more impacts on the walls of the container causing a greater pressure.
   2. If you remove molecules from the container then the pressure will decrease.

3. **Homework:** Gas Pressure Questions

11. You Can't Vacuum the Moon
   1. Demo: Plates
   2. Demos: Multiple "suction" demos and explanations that don't involve the pulling forces of suction
   3. Demo: Hydrogen Spout

   1. **There is no such thing as the pulling force of suction!!!**
   2. Gases exert a pressure through the collective impacts of their atoms on the surface of an object or container. Because of this, pressure is always a positive value. In other words, gasses can only push on things, never pull on things. The lowest pressure achievable occurs when there are no atoms around, such as in outer space. (Actually, there are some atoms in outer space, but they are so few and far between that the pressure is almost zero there.)

   3. Any time something seems to be pulled by suction, the actual cause must be explained by using pushing forces of gasses. Suction is better defined as a net pushing force in a particular direction due to the differences in two gas pressures.

4. **Homework:** No Such Thing As Suction Questions

12. Density
   1. Demo: Density of Various Gasses
   2. Computer Lab: Determining Density

   1. To calculate density, one needs an object, or if measuring the general density of a substance, a sample of that substance. Calculating density involves knowing the mass and volume of that object or sample.
2. Conceptually, density is a description of the concentration of mass, or the ratio of mass to volume. If a lot of mass is crammed into a small space, then a high density is measured. If the mass is spread out over a large volume, then the density is low.

3. When comparing two substances, imagine that you have a sugar cube sized piece of each substance. The one which is more dense will weigh more because it has more mass crammed into the same volume (both sugar cube sized pieces are the same size).

4. Because gravity will pull harder on the piece that has more mass, less dense things or substances tend to float on more dense substances.

5. Balloons that float do so by having an overall density that is less than the air surrounding them. This can occur in two ways:

   * Fill the balloon with a gas that is less dense than air. Helium gas is typically used in blimps and balloons associated with parties.
   * Heat the air inside the balloon so that the atoms move faster, bumping into each other harder, and causing them to spread apart more. If the same mass (all the bumping gas atoms) takes up more space, then the density will be lowered.

**3. Homework:** Explain in as much detail as possible how a hot air balloon works and the environment the balloonist experiences as they ascend to the clouds. Describe on an atomic level what is happening, starting with the balloon on the ground not yet fully inflated and ending with the balloon inside a cloud. What happens when the burner turns on? What happens as the balloon begins to fly? Explain everything on an atomic level. Be sure to include descriptions of atomic motion, thermal equilibrium, density, and pressure changes in your answer.

13. Handout: Review Sheet