Kinetic Molecular Theory and Gas Laws

I. **Handout**: Unit Notes
II. Modeling at the Atomic Scale

  I. 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".
  II. 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 buy 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.

Click on the image to see a dynamic model of traffic congestion in action:

Model created at the MIT Media lab. Copyright 1997 by Uri Wilensky. All rights reserved. See http://ccl.northwestern.edu/netlogo/models/TrafficBasic for terms of use.

  III. 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.
  IV. 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.

i. **Demo**: Bouncing various balls
ii. **Kinesthetic Lab**: Kinesthetic Modeling of a Superball. List all the rules we need to model a ball rolling around on a table full of objects.
iii. Superballs are Like Atoms
    I. List every kind of energy that you can think of.

    II. The energy of motion is called kinetic energy.
    III. 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].
    IV. Which has more kinetic energy, a bowling ball or a baseball moving at the same velocity?

    V. How can we make the baseball have the same kinetic energy as the bowling ball?

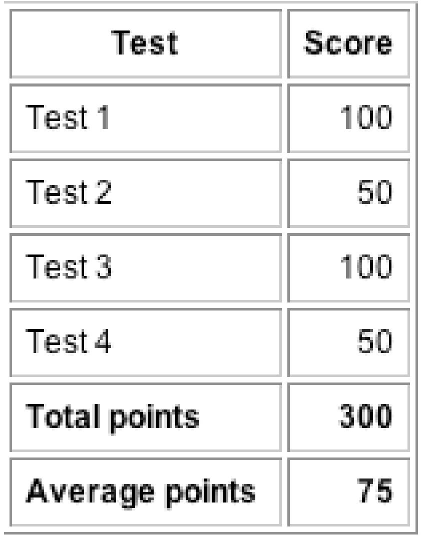
    VI. **Demo**: Bouncing Superball
    VII. Why does the superball stop bouncing?

  - VIII. 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.
  - IX. 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.
- iv. **Computer Lab**: Modeling of a Superball(How to run this?)
- v. **Demo**: Two Atoms in a Box(How to run this?)
- vi. **Homework**: Modeling Questions
- III. Spatial Equilibrium (or Nature Abhors a Vacuum)
  - I. 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.
  - II. 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.
  - III. The random motion of atoms as they jostled around by other atoms is called "Brownian Motion".
  - IV. After the model is allowed to run for some time the gas molecules will reach a dynamic equilibrium.
  - V. 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.
  - VI. **Spatial equilibrium occurs when the average number of molecules of a particular kind found in a specific volume is unchanging.**
  - VII. 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.
- i. **Lab**: View Brownian motion in microscope.
- ii. **Demo**: Computer model of Brownian motion(How to run this?)
- iii. **Demo**: Mint Smell

iv. **Computer Lab**: Spatial Equilibrium(How to run this?)
v. **Computer Lab**: Diffusion and Osmosis(How to run this?)
vi. **Homework**: Equilibrium/Diffusion Questions
IV. Heat vs. Temperature

Heat and temperature are not the same thing.

II. **Heat energy** is the **total kinetic energy** of the atoms of a substance.
III. **Temperature** is the **average kinetic energy** of the atoms of a substance.
IV. Test score analogy with points being like heat:



Test	Score
Test 1	100
Test 2	50
Test 3	100
Test 4	50
Total points	**300**
Average points	**75**

Heat is like the total number of points and temperature is like the average score.

V. 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.

VI. 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.

VII. 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.

VIII. The higher the temperature the faster the atoms move.

IX. 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).

X. 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).

XI. 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).

XII. In summary:
    i. **For an atom** Kinetic Energy = Heat Energy
    ii. **For a substance** Heat Energy = Total of all the Kinetic Energies of its atoms
    iii. **For a substance** Temperature = Average Kinetic energy of its atoms

i. **Demo**: Heat vs. Temperature(How to run this?)

ii. **Computer Lab**: Heat vs. Temperature(How to run this?)

iii. Heat Transfer and Thermal Equilibrium

I. 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.

II. 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.

III. If there are two substances each inside their own container, then heat energy can be transferred between the two substances through the following process:

  i. The atoms of each substance collide with the atoms of their respective containers.

  ii. 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.

  iii. 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].

IV. During the process of exchanging kinetic energy through collisions, substances are 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 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.

V. 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.

I. **Demo**: Heat Transfer(How to run this?)

II. **Homework**: Heat Questions

III. Kinetic Molecular Theory

I. Matter is made of tiny particles (atoms and molecules)

II. These particles are always in motion.

III. The kinetic energy of the particles remains constant if the temperature and pressure of the substance remains constant.

i. Kinetic energy = 1/2mv^2 (m=mass and v=velocity)

ii. Temperature is a measure of the average kinetic energy of the atoms of a substance. Higher average kinetic energy = faster moving molecules or atoms = higher temperature.

iii. Pressure is related to the impacts of molecules. Higher average molecular kinetic energy = Increased number of impacts and increased speed of impacts = higher pressure.

iv. See the Flash plugin below to see demonstration of Kinetic Molecular Theory:

i. **Demo**: Balloon on bottle

IV. Force vs. Pressure

  I. Force is the total impact of one object or gas on another

  II.

  Pressure is the ratio of force to area over which it is applied.

    i. $$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{or} \quad P = \frac{F}{A}$$

    ii. The force I exert on the floor when standing on both feet is equal to the force I exert on the floor when standing on one foot. However, when standing on one foot I put twice the pressure on the floor as if I were standing on two feet. Calculate your own pressure when standing on two and then one foot.

  III. Units for pressure

$$\text{standard pressure} = 14.69\,\frac{\text{lbs}}{\text{in}^2} = 14.69\text{ psi} = 1.000\text{ atm} = 760.0\text{ mmHg} = 760.0\text{ torr}$$
$$= 101{,}325\text{ Pa} = 101.325\text{ kPa}$$

i. **Lab**: Measure the mass of a car with just a ruler.

V. Gas Pressure

  I. Gasses exert pressure through the impacts of their molecules on the walls of their containers.

  II. 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*.

  III. 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.

  IV. 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.

        - i. There are several ways that gas pressure can be increased due to **increased frequency of impacts**.
            - a. **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.
            - b. **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.
            - c. **Raise the temperature.** If you make the atoms move faster then they will hit the walls more frequently, increasing the pressure on the walls.
        - ii. 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:
            - a. **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.
    - V. There is an intimate relationship between gas pressure, temperature, volume of the container, and the number of molecules inside the container.
- i. **Computer Lab**: Gas Laws(How to run this?)
- ii. **Demo**: Hydrogen Spout
- iii. **Homework**: Gas Pressure Questions
- VI. Air pressure
    - I. We live at the bottom of an ocean of air.
    - II. Gravity pulls down on our atmosphere just as it pulls on all nearby matter.
    - III. We are under constant bombardment by an uncountable number of gas molecules every second over every part of our body. The impacts of these molecules are collectively felt as a pressure. We don't normally recognize this pressure because we are used to it.
    - IV. The higher we go in the atmosphere the fewer molecules there are on top of us. Since gravity pulls on these molecules they are less compressed by having fewer molecules on top of them, so the gas pressure drops the higher you go in the atmosphere.
    - V. Notice the mountain climber's body is being hit by fewer gas molecules per second. Pressure is lower on top of the mountain and the air is "thinner" making it hard to get enough oxygen molecules into your lungs.

i. **Demo**: Tube with holes filled with water.
ii. **Demo**: upside down test tube and bottle.
iii. **Demo**: Hg barometer
iv. Normal air pressure can support a column of mercury 760.0 mm tall or water 32 ft tall
v. **Homework**: Describe in detail at the molecular level how a straw works.

VII. You Can't Vacuum the Moon

  I. *There is no such thing as the pulling force of suction!!!!*
  II. 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.)
  III. 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.

i. **Demo**: Plates
ii. **Demos**: Multiple "suction" demos and explanations that don't involve the pulling forces of suction
iii. **Homework**: No Such Thing As Suction Questions

XIII. **Handout**: Review Sheet