E.M.E MOLECULAR MOTION DEMONSTRATOR

STUDY GUIDE

by

A. Mason Turner

Science Department

Orangeburg (South Carolina) High School

PHYSICS LECTURE STOCK

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BACKGROUND

All matter can be conveniently classified into one of three groups: gases, liquids or solids. An understanding of these three groups of matter (usually called "states" of matter) is basic to an understanding of the physical world. A fourth group, or state, is known as "plasma" but does not concern us here.

Of all the ideas suggested to explain the similarities and differences in the properties of gases, liquids and solids, the Kinetic Theory has proven the most useful. This theory assumes that all matter is composed of invisibly small particles that are always in motion. Gases are thought to consist of a collection of molecules moving and colliding at high speed, similar to a collection of rapidly moving marbles. The physical behavior of gases is then explained by applying to the invisible, rapidly moving molecules the demonstrated theories about motion and collision which apply to larger, visible objects. A nearly quantitative explanation of many of the properties of gases can then be given by using such a particle model for matter.

In order to extend the Kinetic Theory to explain the observed behavior of liquids and solids, it is necessary to add the key idea that all neutral molecules have an attraction for each other. These attractive forces are called van der Waals forces. When the motion of gas molecules slows sufficiently, as the temperature is lowered, van der Waals forces cause the gas molecules to clump together and become a liquid. Further cooling results in a more rigid arrangement of molecules known as a solid.

The Kinetic Theory has not been as successful in giving an adequate explanation of the properties of liquids and solids as it has for gases. This theory does, however, help to clarify fundamental concepts and provide a qualitative picture of the physical properties of liquids and solids. A more precise study of liquids and solids requires the application of concepts developed in the Quantum Mechanics Theory not covered in this unit.

As previously noted, the movement and interaction of molecules is believed to be closely similar to that of small balls or marbles. Applying this principle, the E.M.E MOLECULAR MOTION DEMONSTRATOR is a very real aid in clearly presenting some of the basic ideas of the Kinetic Theory. This model, when projected on a screen with an overhead projector, provides an animated and significant presentation of the abstract concepts of the Kinetic Theory visible to the entire class.

In several experiments this Study Guide provides a two-level approach, elementary and advanced. This enhances the teaching value of the E.M.E MOLECULAR MOTION DEMONSTRATOR in elementary science and general physical science courses as well as in chemistry and physics programs.

OPERATION OF THE E.M.E MOLECULAR MOTION DEMONSTRATOR

The E.M.E MOLECULAR MOTION DEMONSTRATOR is essentially a four-sided frame or enclosure mounted over a glass plate. A battery-operated motor vibrates the frame over a range of speeds controlled by the knob. The apparatus is positioned on an overhead projector and the specified number of plastic or steel balls for a given experiment placed within the frame. The motor control knob is then turned on and the speed adjusted until the desired degree of agitation of the balls (molecules) is achieved. The overhead projector is then turned on and focused. Do not use more balls than the optimum suggested for each experiment. Overloading results in friction effects which tend to cause the balls to "run down" in the center of the frame.

Before operating the MOLECULAR MOTION DEMONSTRATOR in a classroom situation note the following points:

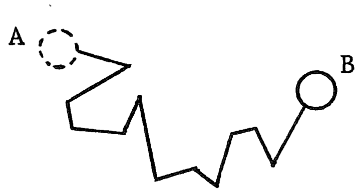
1. Make sure the stage of the overhead projector and the glass surface of the MOLECULAR MOTION DEMONSTRATOR are clean.
2. Check battery strength. If an experiment calls for high speed it is well to turn the DEMONSTRATOR on briefly ahead of class to assure that sufficient power is left in the batteries. The unit is designed to operate on three D-size batteries. These are regular flashlight dry cell batteries and easily obtainable in local stores. The long-life type is recommended.

* * *

Experiment No. 1   BROWNIAN MOVEMENT

Brownian movement, named after the English botanist Robert Brown who first observed the phenomenon, is the continuous zigzag movement of microscopic particles suspended in a liquid or gas.

If students have not viewed the Brownian movement of smoke particles under a microscope they should, if at all possible, have this important scientific experience. While viewing Brownian movement, have students draw a diagram of the movements of one smoke particle. If it is not feasible to view Brownian movement directly, the diagram below illustrates the zigzag path of a smoke particle moving from A to B, a seen under the microscope.



After viewing Brownian movement the students are asked to explain it. Some may state that they have seen molecules moving. This is discounted by explaining that molecules are too small to be seen even with the powerful optical microscope they are using. Explain that the smoke particles seen under the microscope are composed of billions of molecules joined together. After the students have tried to explain the jiggling zigzag motion, place the Brownian movement accessory (the red disc) in the frame. Add 9 large steel balls and 4 small steel balls. Run the apparatus at a speed sufficient to produce slight and erratic movements of the disc. The disc is identified as the smoke particle and the steel balls represent invisible gas molecules. Students will readily see that the movement of the "smoke particle" is caused by collisions with the much smaller "molecules". The disc zigzags around due to the uneven bombardment of its sides. Have students draw a diagram of the disc's movements and compare it to the diagram drawn while viewing Brownian movement under the microscope. The diagrams will not be duplicates but a similar zigzag pattern with long and short spurts will be noted. It should be emphasized that molecules cannot be seen under the microscope but the only reasonable explanation for the motion of the smoke particles is that they are being hit and moved by invisible fast-moving gas molecules.

Experiment No. 2 RANDOM MOTION OF MOLECULES IN GASES

Brownian movement provides one of the most important evidences of the Kinetic Theory. The theory assumes that the invisible molecules of gas that cause the irregular motion of the smoke particle are themselves moving in a completely irregular, haphazard way. Experiment No. 2 explores more deeply the nature of molecular movement in a gas known as random motion.

Elementary Presentation

Place 12 blue balls in the frame and turn the MOLECULAR MOTION DEMONSTRATOR on at medium speed. Let the students view the "molecular motion" as projected on the screen and have them describe in detail all that is happening.

Observations should include:

1. Some molecules are moving faster than others.
2. Molecules collide with each other and the container walls.
3. Generally there is a relatively large amount of space between molecules.
4. There is no regularity of motion but rather a helter-skelter (random) type motion.

To illustrate this randomness of molecular motion have each student draw a diagram of the movement of one particular ball. Then ask them to compare diagrams. If students have difficulty following one ball, place one of the large green balls in with the 12 blue balls and have them draw a diagram of its movement over a different time period. Then diagrams can be compared.

Advanced Presentation

With the concept of gas molecules moving very rapidly in a random manner established, students should be encouraged to sharpen their observations of the activity they are watching and to draw tentative conclusions based on their observations.

The following points may be developed from student observations depending on their sophistication or may be approached by structured questions from the teacher.

1. In relation to their size, gas molecules are very far apart in this demonstration. How can we test for this in a real gas? An experiment may be performed on the compressibility of gases such as air, burner gas, hydrogen and oxygen by using a hand pump or plastic hypodermic syringe without needle. Fill the syringe or pump with gas and hold a finger over the inlet to seal it. Press the plunger down. Compressibility is readily shown by the fact that the plunger moves down and rebounds

after pressure has been released. Thus, the compressibility of a gas supports the Kinetic Theory assumption that the individual molecules of a gas are relatively far apart.

2. Since gas molecules are in rapid, continual motion, a gas is free to take the size and shape of its container.

3. Gas molecules move in a straight line or up, down and sideways until they collide with one of the walls or each other. When they hit a wall of their container they exert a force on it. Discussion of this force leads to the concept of pressure taken up in the next experiment.

Experiment No. 3 GAS PRESSURE

Every time a gas molecule hits a wall it exerts a small push or force on the wall. The total average force over a given area is called pressure. In a sealed container a gas exerts pressure equally in all directions.

Elementary Presentation

Put 6 blue balls in the frame and turn on the MOLECULAR MOTION DEMONSTRATOR at medium speed. Let students view the "random motion of molecules in a gas" briefly. Then students are asked to explain how a balloon remains inflated in terms of moving particles. Generally, students will recognize that the "pushes" of the particles hitting the inside surface of the balloon keep it from collapsing. The sum of these "pushes" on a given area is called pressure.

Advanced Presentation

With the MOLECULAR MOTION DEMONSTRATOR on the overhead projector, raise the end of the DEMONSTRATOR farthest from the screen and place the ½ inch wood block underneath thus tilting the glass surface of the DEMONSTRATOR toward the screen. Place 12 blue balls inside the frame and allow them to roll down to the lower side. Next, place the piston accessory (black bar) as close to the lower side of the enclosure as the balls will allow. Turn on the projector and gradually increase the speed of the DEMONSTRATOR until the piston moves upward as the balls hit it. The collective pushes of the balls (molecules) against the piston is referred to as pressure. As the speed is gradually reduced (pressure lowered) the piston will slide back down. (Note: As will be seen, the practical purpose of raising the DEMONSTRATOR at one end with the small wooden block is to permit gravity to act on the "piston" bar, sliding it down to the bottom of the frame as the speed of the balls is reduced. Brief experimentation to achieve proper angle of tilt may be desirable before turning on the overhead projector light.)

Pressure is defined as the ratio of force to area ($P=\frac{F}{A}$). Although the collisions against the walls of a container of any single molecule of gas are intermittent, there are so many molecules involved in a container of gas that the tremendous number of collisions average out to a steady pressure. If the scale is reduced to the microscopic level this is not necessarily the case--as with Brownian movement.

Experiment No. 4 TEMPERATURE OF A GAS

The temperature of a gas is a measure of the average kinetic or motion energy of its molecules.

Elementary Presentation

The MOLECULAR MOTION DEMONSTRATOR is turned on at slow speed with 12 blue balls in it. After a moment, the students are asked what change should be made to represent a higher temperature. The students may recognize that speeding up the motion of the balls corresponds to increasing the temperature of a collection of gas molecules, and slowing down (but not stopping) their motion represents a decrease in temperature.

Advanced Presentation

After completing the elementary presentation, the students are asked to decide if all of the balls are moving at the same speed at the same time. It will be evident to them that there is a distribution of speeds from slow to fast. The question then asked is: How can temperature be defined in terms of speed of the molecules, since all the molecules in a given gas are evidently not traveling at the same speed? Someone will probably suggest relating the temperature of a gas to the average speed of its molecules.

The question is then raised whether two different gases at the same temperature would have the same average speeds for their molecules. If this is not true, then knowing only the average speed of a collection of molecules is not sufficient in order to know their temperature. In an intimate mixture of two gases, the gases would naturally have to be at the same temperature.

To represent a mixture of two different gases at the same temperature, place 6 green and 6 blue balls (representing two different kinds of molecules) into the enclosure. Turn the unit on at low speed and have students observe and compare the motion of the different size molecules. They will readily see that even though the mixture is at one temperature, the average speed of the smaller balls is much greater than the average speed of the larger balls. The above observation is sufficient to convince students that specifying only the average speed of a collection of gas molecules is not sufficient to determine its temperature. The size (mass) of the molecules is also a factor. A concept exists called kinetic energy, however, which is related to both mass and speed. It states that the kinetic energy of a body having mass "m" moving at a speed "v" is equal to one-half the mass times the speed squared ($KE = \frac{1}{2}mv^2$). From this it can be seen that a small molecule moving at a high speed may have as much or more kinetic energy as a large molecule moving at a low speed. It is reasonable, then, to relate the temperature of a gas to the average kinetic energy of the molecules of that gas. The mixture-of-gases demonstration relates the temperature of a gas to both the mass and the average speed of its molecules.

Experiment No. 5   DIFFUSION

Elementary Presentation

One of the most important physical properties of a gas is its ability to fill uniformly the space in which it is confined. If a container of gas with a particularly strong odor (sulfur dioxide) is opened in one corner of a room, the odor is soon detected throughout the room. This is an example of diffusion--the mixing of one gas (sulfur dioxide) with another (air) due to the constant, rapid motion of gas molecules.

Place the MOLECULAR MOTION DEMONSTRATOR on the overhead projector. It is important to make sure the projector is level for the experiment. Place the diffusion barrier (aluminum piece with cutout at bottom) into the slots found in the middle of two opposite frame walls. Place 6 green balls on one side and 6 blue balls on the other side. Turn on at medium speed and project the motion on the screen. As expected the two different size molecules will mix, representing the diffusion of two gases into each other.

Students will observe that the population in the two halves of the divided enclosure varies from time to time. This fluctuation can be discussed, and the following questions considered: Would this fluctuation be greater as more molecules are added? (No. The tendency would be for less fluctuation to occur since there are more molecules available to "average out" the situation.) When there are fewer molecules? (Yes.) What about real gases and this fluctuation? (Fluctuation would be negligible since billions of molecules are involved.)

Advanced Presentation

Graham's Law of Diffusion states that the rate of diffusion of a gas is inversely proportional to the square root of its molecular weight.

An interesting experiment can be performed to illustrate this with the MOLECULAR MOTION DEMONSTRATOR. Divide the class into two groups. Let each member of one of the groups count the number of large balls passing through the barrier in either direction, and let the other group similarly count the number of small balls passing through the opening in either direction over the same time period. Counting should continue until the number of large balls counted exceeds fifty. It is not easy for the students to get an accurate count, but this can be made easier and more accurate by being careful about the following points:

1. Make sure the apparatus is level.
2. Mark the size of the opening clearly on the glass with a marking pencil.
3. Operate the unit as slowly as possible without stopping the balls.
4. Practice counting briefly before actually beginning.
5. Count by the tally method; that is, a mark on paper for every ball passing through the hole.
6. Take an average for each group.

To compare the rates of diffusion of two different gases use the formula:

$\frac{r_1}{r_2} = \sqrt{\frac{m_2}{m_1}}$. After finding an average count, weigh six green balls and six blue balls on a balance. Finally, the ratio of the number of small balls (r_1) passing through compared to large balls (r_2) passing through is calculated $\frac{r_1}{r_2}$ and this quotient is compared to the square root of the inverse ratio of the masses of the balls $\frac{m_2}{m_1}$ where m_2 is the mass (for this purpose, the weight) of six large balls and m_1 is the mass (weight) of six small balls. Careful attention to the listed details should produce a ratio of rates respectably close to the square root of the inverse ratio of the masses.

Experiment No. 6 AVOGADRO'S HYPOTHESIS

Avogadro's Hypothesis states that equal volumes of gases measured under identical temperature and pressure contain the same number of molecules. The following table supports the hypothesis by showing that one mole (6.02×10^{23} molecules) of eleven different gases occupies approximately the same volume. These volumes were derived experimentally at the same temperature and pressure.

Table 1. Volumes of Various Gases at $0^{o}C$. and 760mm Pressure

1 mole	oxygen	occupies	22.393	liters
"	sulfur dioxide	"	21.888	"
"	hydrogen	"	22.430	"
"	helium	"	22.426	"
"	chlorine	"	22.063	"
"	nitrogen	"	22.403	"
"	ammonia	"	22.094	"
"	hydrogen chloride	"	22.248	"
"	carbon monoxide	"	22.402	"
"	carbon dioxide	"	22.262	"
"	methane	"	22.360	"

At first glance, it seems quite surprising that Avogadro's Hypothesis should be even close to an accurate statement. For example, why should one mole (6.02×10^{23} molecules) of hydrogen occupy nearly the same volume as one mole of oxygen (also 6.02×10^{23} molecules)? Since oxygen molecules are about 16 times as heavy as hydrogen molecules, it would seem more reasonable for a mole of oxygen molecules to occupy much more volume than a mole of hydrogen molecules at the same temperature and pressure.

After raising this question with the students, place 6 small blue balls and 6 large green balls into the frame of the MOLECULAR MOTION DEMONSTRATOR and run at medium speed without varying it during this experiment. It should be emphasized to the students that the temperature and pressure in the following demonstration remain constant throughout. The students are then asked if they notice anything about the motion of the small balls which might explain how they could occupy just as much volume as an equal number of larger balls at the same temperature and pressure. The students will recognize that the small balls are traveling faster on an average than the large balls. Thus, the smaller balls make up in speed what they lack in size in "carving out" an area. This reasoning can be applied to the volume occupied by lighter gas molecules compared to the identical volume occupied by an equal number of heavier gas molecules at the same temperature and pressure.

The preceding does not constitute a rigorous explanation of Avogadro's Hypothesis. It does, however, give the student a beginning explanation for this unexpected property of gases.

Experiment No. 7   VAN DER WAALS FORCES

The attractive forces between gas molecules are called van der Waals forces. They are thought to be much stronger than gravitational forces but usually weaker than chemical bonding forces. They occur primarily between molecules whose atoms have filled their outer (valence) electron orbital, giving them an inert gas configuration. Examples are the molecules of hydrogen, oxygen, nitrogen and neon. Although the total electrical charge of the gas molecule is neutral, the positively charged nucleus of its atoms is not completely shielded by negatively charged electrons. At short distances the nucleus of one atom is attracted by the negatively charged electron orbitals of another atom. It is these forces that cause gas molecules to come together and condense to a liquid when the speeds of the gas molecules are slowed enough to allow the attractive forces to operate. In general, the magnitude of van der Waals forces increases with an increase in the number of electrons per atom, with an increase in size of the molecule and with a higher degree of symmetry of the molecules.

Level the overhead projector. With the MOLECULAR MOTION DEMONSTRATOR on it, place 12 blue balls in the frame and operate at medium speed. With the background established that this demonstration represents our model of a gas, students are asked what should be done to change the gas to a liquid. The natural suggestion is made to decrease the agitation (corresponding to lowering the temperature). When the agitation is decreased to the point where the molecules are barely moving, the model still represents a gas. The students are next asked how low a temperature would be necessary for a real gas to keep the agitation from separating its molecules. A reasonable answer would be that the temperature should be lowered to absolute zero in order for the molecules to stop, clump together, and represent a liquid. Since most gases liquefy far above absolute zero, it appears that our model system is inadequate to represent a liquid or a solid. Students realize that some other factor must be added to our Kinetic Theory of gases before it will begin to explain how gas molecules join together to form liquids and solids.

To introduce this new factor remove all the blue balls from the frame and replace them with the 14 small steel balls stored on the magnet. Run the apparatus briefly at high speed to illustrate a gas. Then reduce the speed (lower the temperature) until the steel balls begin to clump together. As the speed is reduced further most or all of the steel balls will eventually gather together in one or more groups. If one or two steel balls remain in motion they may be considered to be the vapor in contact with the liquid. This illustrates how van der Waals forces between molecules are thought to account for the condensation of a gas to a liquid as the kinetic energy of the molecules of the gas is lowered.

Experiment No. 8 BOYLE'S LAW

Boyle's Law gives us a quantitative relationship between the pressure and the volume of a gas. It is usually stated as Pressure times Volume = a Constant, or the pressure of a gas varies inversely with its volume provided the temperature remains unchanged.

An effective visual presentation is possible with the MOLECULAR MOTION DEMONSTRATOR to show what effect a change in volume has on a gas system when the temperature remains constant.

Among the accessories there is a solid piece of aluminum similar to the diffusion barrier but without cutout at bottom. Slip this barrier into the two slots provided on opposite enclosure walls of the DEMONSTRATOR frame, dividing the frame into two equal parts. Then place 12 blue balls all on one side of the barrier. With a felt tip marker or grease pencil mark off two lines 3/4 inch apart along one of the side walls in the area where the balls are. Turn on the apparatus at medium speed. After students have observed the general action for a minute or two, have each one count the number of ball-wall collisions occurring inside the 3/4 inch section during a one-minute time span. A student timekeeper, using a clock or watch with a second hand or a stop watch, can give the signal to start counting and to stop. After this time period the counts taken by the students should be averaged and recorded.

Without changing the rate of agitation quickly pluck out the barrier, thus doubling the area (volume). (Note: This might be practiced before class; if done too slowly the motion of the frame is interrupted.) Again have students count the number of ball-wall collisions as before. When the results of the two countings are compared, students will readily see that the number of collisions per minute of the balls with the walls decreases as the available area (volume) increases. With this observation clear they should be encouraged to predict what effect the reduction of ball-to-wall collisions will have on the pressure of a gas (temperature remaining constant). Most students will realize that the pressure will be reduced. Thus, the generalization can be drawn that as volume increases, pressure decreases when the temperature remains constant.

The above procedure does not constitute a comprehensive proof of Boyle's Law but does clearly illustrate one aspect -- the decrease in pressure when volume is increased -- and the consistency of Boyle's Law with our moving-particle model of a gas.

Experiment No. 9 CHARLES' LAW

Charles' Law states that the volume of a confined gas varies directly with its temperature if the pressure remains constant.

The following procedure illustrates in a qualitative manner the consistency of this temperature-volume relationship stated in Charles' Law with the particle-motion concept (Kinetic Theory) of gases.

Raise the end of the MOLECULAR MOTION DEMONSTRATOR farthest from the screen and set the wood block underneath. Place 12 blue balls inside the frame where they will collect at the lower side. Next, insert the black piston bar into the frame as close to the lower side as the balls will allow. Turn on the projector and gradually increase the speed of the DEMONSTRATOR until the piston moves upward as the balls hit it. As the apparatus is <u>gradually</u> varied in speed (temperature) the piston will move up or down, increasing or decreasing the area (volume). With the rate of speed representing the temperature, this presentation demonstrates that the volume of a confined gas varies directly with its temperature, at a constant pressure. In the MOLECULAR MOTION DEMONSTRATOR, the constant pressure is simulated by the weight of the bar; raising or lowering the temperature is represented respectively by increasing or decreasing the speed. When working with real gases, however, the constant external pressure is usually supplied by the combination of atmospheric pressure and the force of the piston acting against the confined gas.

In a previous experiment students observed that increasing the temperature of a gas caused the molecules to move faster, hitting the walls harder and more often. Here they observe that the volume can be increased or decreased by a corresponding change in temperature when the pressure (weight of the bar) remains constant. This is the relationship stated in Charles' Law.

Experiment No. 10 SOLIDS AND LIQUIDS

Part I SOLIDS

The structure of almost all pure solids is a regular, repeating arrangement of individual particles. This orderly arrangement of particles is called the crystalline structure. The particles may be molecules, atoms or ions.

To illustrate the crystalline structure of a solid with the MOLECULAR MOTION DEMONSTRATOR place the glass dish inside the frame, concave side up. Then pour all of the pink balls into the dish and arrange the balls in one layer. Start the apparatus at low speed and turn on the projector. Students will observe that the "molecules" are close together and have arranged themselves into an orderly pattern representing a crystalline solid. The general form of a six-sided (hexagonal) outline will also be apparent. Since the "molecules" are pulled together by the attractive van der Waals forces (simulated by the gravity effect on the balls in the dish) they arrange themselves as close together as possible consistent with their shape. The "molecules" are moving also but instead of bouncing about freely as in a gas, they are vibrating back and forth over a limited distance.

At this point the MOLECULAR MOTION DEMONSTRATOR may be stopped. Ask students how many adjoining neighbors each molecule has. From the answer (6) it can be developed that this type of arrangement of molecules is called hexagonal closest packing -- typical of many metallic type crystals, such as magnesium and zinc.

Part II LIQUIDS

A liquid is a collection of molecules that are very close together but still have enough kinetic energy to move one over the other, or flow. This "collapsed heap" of molecules lacks the near perfect regular structure of crystalline solids.

With the pink balls in the glass dish as in Part I, slowly increase the speed until the hexagonal outline is no longer as apparent. At this point the balls will be observed to migrate from place to place. This can best be pointed out to students by asking them to notice whether the particles are changing neighbors or not. In a general description of the model at this point, students should observe:

1. The regular arrangement of particles has partially disappeared.
2. The particles are moving much more independently. They move <u>around</u> each other and change neighbors, but still generally tend to cling together.
3. The particles are much closer together than in a gas, but not as close together as the tightly-packed orderly arrangement of a crystalline solid.

When the above points are observed the model represents the liquid state. Such a group of molecules would be able to change its shape but not its volume.

THE E.M.E MOLECULAR MOTION DEMONSTRATOR AS A MODEL SYSTEM

After the performance of some or all of the preceding experiments it is helpful to consider how a model system helps us gain more information about the real system it represents.

Students should be asked: "In what ways do we believe our model is similar to actual solids, liquids and gases, and in what ways do we believe our model is different?" The depth of the answers to these questions will depend in part on the maturity of the students. Students can list the comparisons they develop by themselves, or the teacher can elicit suggestions during a class discussion. Some of these similarities and differences are as follows:

Similarities:

1. Both our model and real gases involve particles in continual, helter-skelter (random) motion. The particles move in straight lines until they hit another particle or a wall and rebound.
2. In both the model and real gases at ordinary temperatures and pressures, the particles themselves occupy only a very small fraction of the total volume (area).
3. In both our model and in real gases, changes in agitation of the particles is associated with the idea of changes in temperature.
4. The rebounding forces of the particles produce a pressure in both instances.
5. Both our model and real crystalline solids assume an orderly arrangement of particles.
6. Both our model and real liquids have a particle structure differing from both gases and solids.

Differences:

1. Size--Our model uses particles approximately ten million times the diameter of the particles that make up real gases.
2. Distance traveled between collisions--The average distance a gas molecule travels without colliding with another molecule (mean free path) is much greater in relation to its size than the distance traveled by the plastic ball in relation to its size.
3. Speed--The speeds of the balls in the model are at most a few miles per hour, but gas molecules travel at speeds of hundreds of miles an hour.
4. Friction effects--We believe that the motion and collisions in real gases take place in a frictionless manner, whereas friction effects are involved in our model. This explains why our model "runs down" unless energy is continually added, whereas a container of gas molecules does not.
5. Dimensions--Our model is flat or two-dimensional, whereas real gases move in three dimensions.
6. Shape--Most gas molecules are not spherical. Exceptions include nearly spherical inert gas molecules and vaporized metal atoms.
7. Spaces between particles--The spaces between the balls in our model are taken up by air, whereas the spaces between gas molecules are thought to consist of empty space.

From the differences listed above, it can be readily seen that our model is not a faithful reproduction of all the aspects of the concepts discussed. It does, however, present the student with a dynamic visual presentation of many significant abstract ideas that are difficult for most students to grasp by discussion or diagrams alone. Further, it is of great assistance in interpreting direct observations such as Brownian movement, change of state and changes in temperature and pressure.

Teachers will be able to innovate or discover other applications for the E.M.E MOLECULAR MOTION DEMONSTRATOR not included in this Study Guide. Additions and suggestions will be welcomed and may be sent to the address below. We will make every effort to pass along significant new ideas to educational institutions already using this apparatus.

Educational Materials and Equipment Company
Post Office Box 63
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E.M.E MOLECULAR MOTION DEMONSTRATOR

1	Basic Demonstrator Unit, 10½" x 10½"
1	vial pink balls
1	vial blue, green and large steel balls
1	vial small steel balls with magnet
1	glass dish
1	red disc (Brownian movement accessory)
1	black bar (piston)
1	aluminum strip (solid barrier)
1	aluminum strip with cutout (diffusion barrier)
1	wood support
1	black battery tube
1	Study Guide
...	set(s) of 3 long-life batteries

Instructions for inserting batteries:

You will note that the batteries are marked positive at one end and negative at the other end. The three batteries, negative end to positive end, are to be inserted into the black battery tube. With the batteries in the tube firmly snap the entire assembly (facing in either direction) into place between the contact points of the metal battery holder on the base of the E.M.E MOLECULAR MOTION DEMONSTRATOR.