**Models of Matter** [**Roberta@Tevlin.ca**](mailto:Roberta@Tevlin.ca)

As students go through the high school curriculum they learn about many different models of matter: particle, atomic, Thompson, Bohr-Rutherford and wave-particle duality. These models are powerful tools that help scientists understand what is going on at the sub-microscopic levels which we can’t experience directly. Unfortunately, for many students, these abstract models are not aids to understanding; they are just another thing that they need to memorize. The activities that follow are designed to have students explore these models using concrete models, diagrams, tableaux and computer simulations.

1. **Grade 9: The Particle Model of Matter**
2. The particle model uses space and speed to explain the difference between solids, liquids and gases. Show the positions of five particles and add arrows whose lengths represent their speeds.

**Solid Liquid Gas**

The solid and liquid should also show speed arrows only very small. Solid particles can stack as crystals or randomly, liquid particles all flow to the bottom and gas particles fill the container.

1. Make a set of three tableaux that clearly show the differences between a solid, liquid and gas.

Planning the tableau is where the thinking and learning occurs. There should be five to eight students in each group. They cannot use words, so they need to come up with a way of showing speed without moving. Should you do the tableaux before the diagrams above - for a group exploration - or should you do it afterward as reinforcement?

1. Explore the three provided materials as physical models of the particle model. Which has the highest ‘melting point’? Which one best demonstrates the formation of crystals, viscosity or ductility? Explain your answers.

Provide clear plastic containers with lids and the three materials.

Glass marbles – If placed in a clear plastic container with a lid you can demonstrate 2-D crystalline solids (tilt and jiggle gently), melting (shake harder) and boiling quite easily.

Magnetic marbles – These have attractions between the particles and can show 3-D crystalline solids and the formation of wires (ductility) well. They have more viscosity and a higher melting point than the glass marbles.

Lego – These have very strong and very directional bonds and show 3-D crystalline solids very well. They have the highest melting and boiling points. Shaking will not ‘melt’ the solid.

1. Explore <https://phet.colorado.edu/en/simulation/states-of-matter-basics>
2. **Grade** **9 or 10: The Lego (Atomic) Model of Matter**

The **particle model** is able to explain physical properties and changes. However, it doesn’t explain what happens in a **chemical** reaction. The Lego model can explain three laws of chemical reactions.

Each group will receive a bag of Lego molecules, which can be broken into two different elements.

If you are using a scale that only goes to 1g, you should make sure that each sample has more than a dozen ‘molecules’ so that the results are not muddied by the measurement error. Avoid 8-bump bricks paired with 4-bump bricks because their mass ratio is 1.9, which can be mistaken for 2.0. It makes extra patterns because of this.

1. **The Law of Conservation of Mass**: Weigh your Lego particles. Separate them into large and small pieces and weigh the two piles. How does the mass of the reactant compare to the mass of the products?

The values before and after will be the same and this will not be surprising. What is surprising is that in the midst of all of the explosions, color changes, evolution of gasses and precipitates of a chemical reaction, the reactants and products do the same thing. They behave like Lego molecules. The sum could be off by 1 gram if the scale can’t read partial grams. For example 10.4 g and 10.3 g will read 10 g and 10 g, but together they will read 21 g.

1. **The Law of Constant Proportions**: Divide the mass of the large pieces by the mass of the small pieces. Which groups have the same molecules? How are compounds different from mixtures?

Groups with the same ratio of big divided by little mass, probably have the same molecules. (A, E and J are all around 2.8 while D and I are both around 0.61.) Mixtures can have a range of ratios. You can have a little bit of sugar dissolved in your tea or a lot. However, pure substances always show the same ratios. They behave like Lego molecules.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sample | big + little | big pieces | little pieces | big/little | A vs.\_\_ | C vs.\_\_ | compound |
| A | 46 | 34 | 12 | **2.83** | **1.00 ~ 1** | 2.32 | **15 (8B + 2B)** |
| B | 56 | 27 | 29 | 0.931 | **3.04 ~3** | 2.50 | **12(8B + 3x2B)** |
| C | 40 | 22 | 18 | 1.22 | 2.32 | 1.00 ~ 1 | 10 (8B + 6B) |
| D | 71 | 27 | 44 | **0.614** | 4.63 | **1.99 ~ 2** | **12 (8B + 2x6B)** |
| E | 91 | 45 | 16 | **2.81** | **1.01 ~ 1** | 2.30 | **20 (8B + 2B)** |
| F | 91 | 38 | 53 | 0.717 | **3.95 ~ 4** | 3.24 | **16(8B + 4x2B)** |
| G | 68 | 20 | 48 | 0.417 | 6.79 | **2.93 ~ 3** | 9 (8B + 3x6B) |
| H | 70 | 41 | 29 | 1.41 | **2.01 ~ 2** | 1.16 | 13 (8B + 2x2B) |
| I | 63 | 24 | 39 | **0.615** | 4.60 | **1.98 ~ 2** | **11 (8B + 2x6B)** |
| J | 41 | 30 | 11 | **2.73** | **1.04 ~ 1** | 2.24 | **13 (8B + 2B)** |

1. **The Law of Multiple Proportions**: Each different Lego compound has a different ratio of big to little mass. Compare compound A to the others by dividing the larger ratio by the smaller one. Repeat for compound C. Which values are very close to a whole number? Explain why.

You get a ratio of two (or three) if you compare samples where one has double (or triple) the number of an element in each molecule. The same thing happens when you compare the different nitrogen-oxygen compounds or carbon-hydrogen compounds. They behave like Lego molecules.

1. **Grade 9 or 12: Rutherford’s gold foil experiment**: Rutherford, shot small positive particles – called alpha particles - at a thin gold foil. Most went through. About 1 in 8,000 came back.
2. Model this experiment by releasing a ball on a track that is at least 30 cm away from the curved base of a wine glass. Try and get the ball to come straight back onto the track. What do you have to do to be successful?

Students will need to prop the metal track on a book to hold it steady. They will need a bit of Plasticine to make a smooth ramp onto the base of the glass. They should provide the ball with enough energy to go up but not hit the stem.

What aspects of the challenge were like Rutherford’s experiment?

The mouse ball represents the alpha particle, which very rarely bounces back. The base represents the repulsion of the nucleus.

What aspects of the challenge were very different from Rutherford’s experiment?

The track allows you to aim, but the experiment didn’t. The track acts like an accelerator, but in the experiment the particles all had the same speed from radioactive decay.

1. Make a set of three tableaux that show the very different behaviours of a set of alpha particles with identical velocities heading toward a gold nucleus. Show the particles when they are very far from the nucleus, at their closest position and a short distance after this.

The tableaux need to show the speeds decreasing as they get closer to the nucleus. The kinetic energy is going into electric potential energy - which is radial. Only particles going directly toward the nucleus will bounce straight back and only these will ever have a speed of zero. The further ones will deflect less than the closer. Should you do the tableaux before the diagram – for a group exploration or should you do it afterward as reinforcement?

1. Sketch the very different paths of the three alpha particles below. Include arrows to indicate their speeds at various points. Make sure that energy is conserved. Go to <http://phet.colorado.edu/en/simulation/rutherford-scattering>to check your diagram**.**

1. **Grade 9 Molecular Bonds:**
2. The non-metal elements just need a few extra electrons to become stable. One way that they do this is by ‘sharing’ electrons. Imagine that you and your fellow students are hydrogen atoms. You each have a pen in your right hand to represent your one electron. Each student wants one more electron so it will be like helium. Turn to a neighbour and grab their ‘electron’ with your left hand without letting go of your own electron. What happens? Draw it in the space on the left as a Bohr-Rutherford diagram and a ball and stick model.
3. How would you have to change things to act out and draw what happens with F and Cl?

This will be the same as hydrogen, except that there will also be three pairs of valence electrons that are not involved with the bonding. They are shown in Bohr-Rutherford diagram, but not in the ball and stick and don’t need to be dramatized with the rulers.

1. How can you act out and draw what happens with O? Draw this in the middle space.

Each student needs a ruler in each hand. The diagrams show this better than the dramatization. Perhaps the double bond could be done by having each atom represented by two students.

1. How can you act out what happens with N? Draw the result in the space above right.

The diagrams are an easy extension. The dramatization with just two students is hard because you need a third hand.

1. Molecular bonds are very strong but molecules have very low boiling points. Explain why by silently acting out what happens when these compounds boil.

Boiling breaks the weak bonds between molecules and leaves the strong bonds within the molecule intact. The pairs of students should move faster and further apart from the other pairs.

1. **Grade 9 Ionic Bonds:** You are going to model the formation of sodium chloride. Each student will be randomly assigned to be either sodium or chlorine. Sodiums have an electron card that they want to get rid of and chlorines want to get one of these. Find someone to react with and transfer the electron. Now the sodium students are positive and want to surround themselves with four chlorine students. The chlorine students are negative and want to surround themselves with four sodium students. What happens?

This can easily become mayhem. You might want to have them discuss and draw diagrams first and then let them act it out.

1. Draw the 2-D arrangement of Na and Cl ions in a solid. How will the 3-D version be different?

Each sodium will have six chlorine ions near it.

1. Ionic compounds form crystals with flat faces and sharp edges. Why?

This configuration results from having opposite charges as close as possible.

1. Ionic compounds will not conduct electricity unless they are melted or dissolved in water. Why?

The ions are not free to move unless the solid is melted or dissolved.

1. Ionic compounds have much higher melting points than molecular compounds. Why?

Melting requires breaking the strong ionic bond.

1. Ionic compounds are very brittle. Why?

If you slide one row slightly, you will end up placing like charges next to each other and these repel. This could be drawn or acted out.

1. **Grade 12 Quantum Physics**
2. Wave-Particle Duality: The Challenge of Quantum Reality (PI Resource) <https://resources.perimeterinstitute.ca/products/the-challenge-of-quantum-reality?variant=17148646726>
3. The Quark Model: Taming the Particle Zoo (PI Resource) <https://resources.perimeterinstitute.ca/products/taming-the-particle-zoo?variant=36262299334>
4. **Randomness of Radioactivity**
5. Suppose you have 100 computers (students, radioactive atoms) and you graph how many are still working each following year. What will the graph look like?

A) B) C) D)

Suppose you have 100 students?

Suppose you have 100 radioactive atoms?

The pattern of radioactive decay is very different because the decay is not a result of the atoms wearing down in some way. Instead, the process is completely random. Computers and people will decay something like B. Most of them last a standard length of time and then towards the end they start failing at ever increasing rates as various parts wear out. Radioactive decay is very different. The rate of decay depends on the sample size and is fastest at the beginning. This is the trademark of a random process.

1. You will simulate radioactive decay with 100 dice. When the dice are rolled, a ‘one’ means that it has decayed and is removed. Fill in your predictions of how many undecayed dice you will have after each round.

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Round | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| Predicted |  |  |  |  |  |  |  |  |  |
| Actual |  |  |  |  |  |  |  |  |  |

1. The half-life is the time it takes for half of the atoms to decay and it is characteristic for a given nucleus. Predict the half-life for the dice.
2. Roll the dice and fill in the actual values. Explain any differences with the predictions..

The sample is small. The larger the sample, the closer it will be.

1. How is this randomness different from the randomness of radioactive decay?

The results of rolling a die are only pseudo random. If you had a high-speed camera you could predict how it will land. However, there is no hidden information in a quantum process like radioactive decay; it is intrinsically random.

1. How is this like the double slit experiment?

You can’t predict where an individual object will land, but you can predict the probabilities

1. Explore the randomness and quantum tunneling of alpha decay. <http://phet.colorado.edu/en/simulation/alpha-decay>