Lesson Plan: Particles in Motion

Summary
In this lesson, students learn that particles that make up matter are in constant motion. The concepts that matter is made of invisible particles and that these particles are in constant motion can be difficult for students to comprehend. Although this motion isn’t noticeable on a daily basis, the results of this motion can be observed.

In Part A, students interact with an online simulation to compare the ways that atoms and molecules move in solids, liquids, and gases. In Part B, to further understand one aspect of particle motion, students design an investigation to examine the time it takes to dissolve a sugar cube in water as a function of the temperature of the water. To collect quantitative data for this investigation, students learn about what it means for a substance to dissolve and they witness the process of the term “dissolve.”

Resource Type Lesson plan
Grade Level Elementary school

Objectives
By the end of this lesson, students should be able to:
- Explain that matter is composed of extremely small particles, which are constantly moving.
- Describe the three states of matter.
- Compare how particles move in solids, liquids, and gases.
- Investigate the effect of water temperature on the solubility of a sugar cube in water.
- Measure, record, graph, and analyze quantitative data.
- Communicate investigation findings.

Chemistry Topics
This lesson supports students’ understanding of the following topics in chemistry:
- States of matter
- Solutions
- Quantitative chemistry
- Reaction rate
- Solubility

Time
Teacher Preparation for Explore Part 2: 45 minutes to prepare amounts of water at different temperatures
Lesson: (times are approximate)
- Engage Part A: 45 minutes; optional video: 23 minutes
- Explore Part A: 45 minutes
- Explain Part A: 45 minutes
- Engage Part B: 20 minutes
- Explore Part B: 2 × 45 minutes
- Explain Part B: 45 minutes
Materials

Part A Engage

For each group:

- Small container of water

For each pair of students:

- Aluminum foil (approximately 10 cm × 10 cm)
- Scissors
- Tweezers
- Hand lens

Part A Explore

- Computer with Internet access for each student or pair of students
- Science journal for each student

Part B Explore

For teacher demonstration:

- Small object to weigh (e.g. small pencil, paper clip, crumpled sheet of paper)
- Scale or balance

For each group:

- Sugar cubes
- Plastic cup
- Plastic spoons or stir sticks
- Water of different temperatures
- Thermometer, metric
- Stopwatch or clock
- Measuring cup or graduated cylinder
- Science journal, each student

For the class:

- Refrigerator or ice
- Hot plate
- Containers to hold water, about 2 liters in size
- Cloth towels for water spills
- Bucket or sink for disposal of water

Safety

- Students should not taste any water (unless directed to by the teacher).
- Caution students to be careful if any water spills on the floor and to clean up spills immediately to avoid accidents.
Vocabulary Terms
- dissolve
- gas
- liquid
- solid
- solubility
- solute
- solution
- solvent

Keywords
particle model, dissolve, atom, molecule, state of matter, solution, solubility

Teacher Notes

Science Background
All matter is made up of very tiny particles that are in constant motion, and these particles are attracted to one another. The temperature of a substance is related to the average kinetic energy of its particles; the faster the particles move, the higher the temperature of the substance (in general, an object with a greater speed equates to greater kinetic energy).

One ramification of this behavior of particles is the dissolution of a sugar cube in water. If a sugar cube is submerged in a liquid such as water, the water molecules will come into contact with the sugar molecules. This results in the sugar cube dissolving in the water. The warmer the water, the faster the water molecules move, and the water molecules will strike the sugar molecules more frequently. As a result, more of the sugar cube will dissolve in warm water than in cold water in a given amount of time.

The following websites provide additional information about the concepts discussed.

- [Chemistry Review](https://www.chemsoc.org/education/chemistry-review) (American Chemical Society)
- [Particle Theory](https://www.le.ac.uk/physics/education/courses/undergraduate/particle.html) (University of Leicester)
- [Solubility](https://www.chemistryinformation.co.uk/solubility.html) (Chemistry Information Site)

Design of the Lesson
The lesson is divided into two parts, each of which contains an Engage, Explore, and Explain section. **Part A** deals with the particle model of matter and utilizes an online simulation to model the behavior of particles in a solid, liquid, and gas. **Part B** engages students in a hands-on investigation that lends credence to the particle model. After both parts, the lesson concludes with an Elaborate and Evaluate section. The lesson can be taught over a period of four or five days, with different lengths of class periods if needed.

Design of the Investigation & Tips
It would be best if students are given the freedom to design their own investigation for the Engage Part B section: looking for a relationship between the time to dissolve and the temperature of the water. A design that can work for groups and a whole class would be the following:
1. Prepare three to five samples of water at different temperatures. Use ice, a refrigerator, and a hot plate to help raise or lower room temperature water. Ideally, each group will have three samples of water at different temperatures. You could have students assist with this preparation.

2. You should discuss with students what it means for the sugar cube to dissolve, so every group uses the same technique. See the narrative below in Explore Part B on developing an “operational definition.” You might find you can use this concept in other activities and curricula.

3. Think about how you want to organize and distribute the different temperatures of water. You might want to consider using picnic or foam coolers to keep the water from changing temperature quickly once you’ve prepared it. Have a towel or two available for any spills.

4. Have a sink or bucket ready for disposal of the sugar-water solutions.

5. Reasons for why the investigation may not have work as planned: There may be some uncertainty of when the sugar cube “dissolves” or there might not be much difference in temperatures among samples by the time groups receive their water so students may not measure significant time differences for dissolving times. One way to handle this is to collect the time and temperature data from each group (assuming each group had all the different water temperatures), organize the data on the board, and find the average time for each water temperature. Students could then use the average time-to-dissolve vs. temperature as the data to graph and analyze.

6. The online simulation States of Matter: Basics has an accompanying tip for teachers. Both the simulation and teacher tips provide more advanced content than you will probably want to use with your students. Use the parts that you feel are most appropriate for your students.

Lesson

Part A - Engage

Students access prior knowledge of the differences between solids, liquids, and gases.

Give each small group of students a bottle or similar container of water to observe. Ask them to share their observations within the group. They should record their observations in their science journals. Gather students back together as a class and discuss each group’s observations.

Continue the discussion about water by asking: What is this liquid water made of? Can you describe what makes it up? If you could imagine or even see this water up close at a very tiny scale, how would it behave? How would it act? Probe students’ ideas about the particulate nature of matter, but don’t tell them the accepted scientific view.

Don’t dwell on this for long, but continue the discussion by asking: What will happen to this water if you put it in a freezer for several hours? What properties would this substance have? What will happen to this water if you put it in a pan and boil it for several minutes? What properties would this substance have then? Continue the discussion about the different states of matter by asking students: Do the particles (or whatever term the class uses to talk about the makeup of water) that make up liquid water change at all when water freezes or boils? If they do change, how do they change? Can students tell you what size these particles are? What they
might look like? How many are they?

To involve students in a physical activity, pair them with a partner to cut a piece of aluminum foil in half. Take one of the pieces, cut it in half again and continue this process. Offer each pair some tweezers and a magnifying glass as a way of hinting that these pieces are going to get very very small. At some point, ask: *Can you keep going like this forever? How small would the pieces be? Will they still be made of aluminum when you get them invisibly small?*

Ask students to imagine being shrunk to the size of a particle. *What would water particles and aluminum particles look like?* Encourage students to use their science journals to describe and sketch both types of particles. *Would both types of particles look the same? If not, how would they differ? How would a group of particles of ice look compared to a group of particles of liquid water; compared to a group of particles of water as a gas? What would particles of aluminum look like?* Provide time for students to work on this task, and then allow them to share their ideas with the class.

An option at this point is to show students the video *Bill Nye the Science Guy – Atoms and Molecules*, about 23 minutes long. Using a very entertaining style, this video reinforces the concepts of:

- the composition of matter (all matter is made of atoms)
- the structure of atoms and molecules
- the small size of fundamental particles

(It also includes concepts that are not addressed in this lesson but may be important for your class: the variety of atoms that make up different substances; the components of the nucleus; the idea that all living organisms are based on the carbon atom.)

Tell students they are going to have a number of opportunities in this lesson to explore and learn more about what water is like as a solid, liquid, and gas, and how the particles that make them behave on a very small scale (too small to see under a typical microscope).

**Part A - Explore**

*Students use an online simulation States of Matter: Basics to explore how particles move in solids, liquids, and gases.*

Students at this age will probably get the most out of the first tab of the simulation: “Solid, Liquid, Gas.” (The second tab, Phase Changes, can be used in the Elaborate section.) Note that one option (variable) that students can control is the addition of “heat” or “cold” to the container holding the particles. This concept ties back to some of the probing questions you posed in the Engage section and is an important aspect of the particle theory of matter.

Introduce students to the online simulation *States of Matter: Basics* and invite them to freely explore the different options it offers.

- You might choose to have students work with a partner if you feel the peer interaction would be beneficial.
- If computer resources or time are limited, consider running the simulation as a class demonstration, allowing for as much student input and interaction as possible.
- Encourage students to take notes in their science journals as they investigate the behavior of the atoms and molecules in the simulation.
• If you have not brought up the concepts of atoms and molecules yet or have shown the optional video Bill Nye the Science Guy – Atoms and Molecules, you might want to do that before students see the simulation.

Part A - Explain
Students use what they learned in the simulation to describe the difference between how particles move in solids, liquids, and gases.

For students to demonstrate their conceptual understanding of the particle nature of matter and the difference between states of matter, choose from these possible activities. Offer support and access to materials and resources as students undertake this essential component of the lesson.

• Have students make a drawing in their science journals that shows the difference between a solid, liquid, and gas at the particle or atomic level of detail.
• Have students write a creative piece that follows a molecule of water in a beaker of water that is slowly heated until the molecules are in the gaseous state.
• Have students create a multiple choice quiz to give to a classmate that addresses the particle nature of matter, the difference between the three states of matter, and the effect of temperature on the microscopic behavior of particles.

Once students have completed the task, facilitate a means for them to share their understandings with others in the class, or even with parents at home. This could take the form of a gallery walk, formal time in front of the class, a blog on a dedicated webpage, or another method of your choosing. Use this as an opportunity to interact with students to clarify possible misconceptions and assess their current level of understanding of the main concepts. In this part of the lesson, you want students to broaden and deepen their understanding of the particle nature of matter and related concepts. This is an opportunity to discuss the role and value of models in developing and communicating an understanding of matter (e.g. atoms and molecules) and phenomena (e.g. change of state and temperature change).

Part B - Engage
Students review what they know about sugar solutions and how sugar dissolves in water.

Ask if any students have ever had the task of preparing food for hummingbirds. Perhaps someone has helped a parent or relative make a sugar solution for a feeder. Probe the students to see if they are aware that when sugar is dissolved in water it is no longer visible in the water. Find out if any student has had experience dissolving sugar in water for any other reason.

Optional: Write the following terms on the board: solvent, solute, solution, and solubility. Can students use these terms correctly when talking about preparing sugar water for hummingbirds? (The water base is the solvent, the sugar is the solute, the resulting sugary syrup is the solution, and solubility refers to how much sugar can be dissolved in a given amount of water. Try to use these terms as you work with students throughout the rest of the lesson.)

Part B - Explore
Students design and conduct a simple investigation to examine the effect of water temperature on the rate that sugar dissolves in water.
1. Explain to students that they will work in small groups to design and conduct an investigation to see what effect the temperature of water has on the time it takes to dissolve some sugar in the form of a sugar cube.

2. Show students the materials you have available for their use for this investigation.

3. Allow the groups to begin their design and then work on the investigation; facilitate as necessary.
   - Encourage students to keep all variables other than water temperature the same. These include the amount of water, the size of the sugar cube, the type of cup used, and the starting time.
   - Encourage students to use their science journals to record their observations and data.
   - Ensure that students create an appropriate data table to organize their measurements. For example:

<table>
<thead>
<tr>
<th>Cup #</th>
<th>Water Temperature</th>
<th>Amount of Water</th>
<th>Amount of Sugar</th>
<th>Starting Time</th>
<th>Ending Time</th>
<th>Amount of time to dissolve</th>
<th>Other Observations</th>
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3. Encourage students to
   - make accurate labeled diagrams of their equipment and allow time for groups to analyze their data.
   - graphically display their results (a bar graph of temperature on the x-axis and time to dissolve on the y-axis would be most appropriate).
   - examine their investigative design and compare designs with those from other groups.
   - consider ways their design could have been improved.

This investigation, regardless of how students choose to design it, provides an opportunity to introduce the concept of operational definition. One of the challenges when observing a sugar cube dissolve in water is to decide just when the cube is dissolved. The cube will slowly get smaller and change shape as it dissolves. Eventually, and over a period of time, the amount of sugar that is visible will become so small that it will be not easy to see as a distinct blob of sugar. The challenge is to decide just when the sugar cube has been dissolved. Mention this fact to students and suggest that they should consider the cube to be dissolved when they can no longer see any remains of the cube. (At that point, they would stop their timer or note the time on a clock.)

See the Teacher Notes section for a design that will provide enough evidence such that students will be able to observe a relationship between water temperature and the time it takes to dissolve a sugar cube.

**Part B - Explain**

_Students explain the results of their investigation in terms of the particle model of matter._
Review with students the major concepts they explored related to the particle model of matter:

- All matter is composed of extremely tiny particles called atoms or molecules.
- Each pure substance is composed of its own unique kind of particle.
- The particles are in constant motion and attract each other.
- The particles on average move faster when they are heated.

Ask students to gather as a group to use the results from their investigations, review and consider the concepts they’ve explored earlier in the lesson, and then develop a scientific explanation of their results. In other words, do their results make sense when they consider the particle model of matter? Be explicit when you use the term “model,” and expect that students should be able to refer to the explanation they develop as a model.

For example, students likely observed that the sugar cubes dissolved more quickly in hot water than in cold water.

**Claim:** Sugar dissolves more quickly in hot water than in cold water.

**Evidence and Reasoning:** I conducted an investigation. I placed one sugar cube in 4 ounces of hot water and one sugar cube in 4 ounces of cold water. The sugar cube in the hot water dissolved in 3 minutes, 15 seconds. The sugar cube in the cold water never dissolved completely. I also placed a sugar cube in warm water. It dissolved in 8 minutes, 50 seconds. Every other group got almost the same results.

**How my results relate to the particle model of matter:** The particle model says that particles of hot water move faster than particles of cold water. I think that the particles of hot water bumped into the sugar harder and more often than the particles of cold water. So the hot water was able to break apart and dissolve the sugar cube more quickly than the cold water.

To allow students to demonstrate their conceptual understanding of the mechanism (model) underlying the dissolving of a sugar cube in water, choose from the following possible activities. Offer support and access to materials and resources as students undertake this task. Students can:

- create a drawing in their science journals showing, at microscopic scale, the interaction of water molecules with sugar molecules;
- write an entry in a blog dealing with the particle model about how temperature affects the time it takes to dissolve a sugar cube;
- write a recipe for making chocolate milk from a powder mix and include instructions for how to speed up the process; the recipe should include a brief description behind the science of their instructions;
- write an article for the school newspaper explaining why the temperature of the water affects the time needed to dissolve a sugar cube;
- develop an argument explaining why using the gaseous phase of water would not produce the same results for dissolving a sugar cube as did the liquid, or water, phase.
Elaborate

Students apply what they have learned or extend the investigation to answer additional questions.

1. Challenge students to think of ways to apply what they have learned. For example,
   - What is the best method for making sweetened iced tea?
   - What can you do if not all of the sugar will dissolve when you are making hummingbird food?
   - Why is it easier to dissolve salt in hot water than in cold water?
   - Is the mass or weight of the sugar solution greater, less than, or the same as the mass or weight of the sugar and water added together, before the sugar is dissolved?

2. One way students can extend this lesson is to have them conduct additional investigations to answer related questions. Suggestions include:
   - Does the amount of water affect the rate at which a sugar cube dissolves?
   - How does stirring affect the rate at which the sugar cube dissolves? Why?
   - Does the surface area of the water affect the rate at which a sugar cube dissolves?
   - Which dissolves faster, sugar or salt?

3. Students can also use the Internet to explore further:
   - Return to the States of Matter: Basics simulation and explore the “Phase Changes” tab. After students have explored this simulation, they will likely have questions that could lead to additional inquiry.
   - View the 2 minute YouTube video Compare the solubility of salt, sugar and chalk – Solutions – Chemistry.
   - Explore the simulations of solids, liquids, and gasses on this Web site: Particle Model.
   - Research on the Web to identify substances that are not soluble in water.
   - Explore this interactive description of the particle model on the Web.
   - After researching on the Web, have students describe, using words or illustrations, the range of sizes of matter from the visible (sugar cube) to the invisible (molecules of sugar).

Evaluate

Assess the quality of the student’s response to tasks you assigned in both Explain sections. Further assessment can be made using any of the following items.

Discussion Questions

1. How would you describe the motion of water molecules in the simulation you explored? How does heating or cooling the substance change the motion of the molecules? [Students should have observed that when a substance is heated, the particles that make it up move faster. When it is cooled, they slow down.]

2. Energy is often associated with motion. How does heat energy relate to the energy of motion? [the faster the particles in a substance are moving, the hotter it is; the faster the particles are moving, the more energy each particle has; NOTE: students should not assume that something that anything that is hot has more heat energy in total than]
anything that is cool – the total amount of heat energy depends on the amount of substance as well as the temperature (a boiling cup of water has less energy than an ocean of cool water)

3. David’s group measured the time it took a sugar cube to dissolve in 30 °C water; they did not stir the water. John’s group also measured the time it took to dissolve a sugar cube, but their water was 40 °C; they did stir their water. Explain why it would not be fair to compare the two groups’ results. [Students should understand that to compare the effect of temperature, only temperature can be varied. To compare the effect of stirring to not stirring, the temperatures would need to be the same.]

Multiple Choice Items

1. Barry leaves some juice out in the sun and it heats up. What happens to the motion of the particles that make up the juice?
   a. they slow down
   b. they speed up *
   c. there is no change in motion
   d. half speed up and half slow down

2. Aisha has a cube of ice, a cup of water, and some water vapor (gas). Each is sitting in a container on a table.
   a. Water vapor only
   b. Liquid water and water vapor only
   c. None of them
   d. All three of them *

3. In which are the particles most free to move throughout the container?
   a. Cube of ice
   b. Liquid water
   c. Water vapor
   d. none of the states

4. Kayla conducts an experiment to determine the effect of water temperature on how long it takes a sugar cube to dissolve. Each cube is the same size and shape. Her data are shown in the table below.

<table>
<thead>
<tr>
<th>Water Temperature</th>
<th>Time for a Sugar Cube to Dissolve</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 °C</td>
<td>12 minutes</td>
</tr>
<tr>
<td>20 °C</td>
<td>6 minutes</td>
</tr>
<tr>
<td>40 °C</td>
<td>?</td>
</tr>
</tbody>
</table>

How much time will it most likely take for the cube to dissolve in water that is 40 °C?
   a. 2 minutes *
b. 6 minutes  
c. 9 minutes  
d. 18 minutes

5. When someone dissolves a sugar cube in a cup of water, what is the water called?  
   a. the solution  
   b. the solvent*  
   c. the solute  
   d. the suspension

Open-Ended Questions

1. Why is a computer simulation like the one you explored early in the lesson so helpful when learning about how very tiny particles behave?  
   [These particles are so small that I can’t easily see them, even with a pretty powerful microscope. If I can make a model of something very big like the solar system or very small like a molecule, it makes it easier to imagine what the real thing might be like.]

2. When you study the origin of the word “dissolve” you see that the word comes from two Latin words: “dis” for “apart” and “solvere” for “loosen.” When you consider that you dissolved a sugar cube in water, why does the origin of the word “dissolve” seem logical?  
   [When I put a sugar cube in water, it slowly disappeared and since there was nowhere for the sugar to go except into the water, that’s where the sugar must have ended up. I did not taste the water to check this. So the cube of sugar broke or “loosened” apart as it dissolved.]

3. Another way to model the motion of particles at the microscopic scale is to compare it to popcorn being popped in a pan with a lid on a hot burner. Explain why this would be a good model for particle motion and why it might not be such a good model.  
   [It is a good model because as the popcorn heats up, it starts to move in the pan. When it gets really hot, it pops. The pieces move around in the pan, like molecules do when they heat up. It is not a good model because once the popcorn has popped, it stops moving (unless another piece moves it). Molecules would move faster and faster as they heat up.]

Cross-Disciplinary Extensions

Connect to Math

- Have students examine their time-to-dissolve vs. temperature data to see if they can find a pattern in the values that can be expressed mathematically.
- Using either group or class data of the time-to-dissolve vs. temperature, have students extrapolate the data to infer the time-to-dissolve for a temperature higher (or lower) than what they actually observed, or interpolate to estimate times for temperatures between those measured.

Connect to Writing

- Have students write a creative writing piece detailing what they might see on a microscopic scale if they could observe the behavior of water molecules evaporating from a puddle on the ground in the sun.
Next Generation Science Standards
This lesson supports the following:

Practices of Science and Engineering
- Asking questions
- Developing and using models
- Planning and carrying out investigations
- Analyzing and interpreting data
- Constructing explanations
- Engaging in argument from evidence
- Obtaining, evaluating, and communicating information

Crosscutting Concepts
- Cause and Effect: Mechanism and Explanation
- Scale, Proportion, and Quantity
- Systems and System Models
- Energy and Matter: Flows, Cycles, and Conservation

Disciplinary Core Ideas, Grades 3-5

Physical science
- Matter of any type can be subdivided into particles that are too small to see, but even then the matter still exists and can be detected by other means. A model shows that gases are made from matter particles that are too small to see and are moving freely around in space can explain many observations, including the inflation and shape of a balloon; the effects of air on larger particles or objects. (5-PS1-1)

- The faster a given object is moving, the more energy it possesses. (4-PS3-1)

- Energy is present whenever there are moving objects, sound, light, or heat. When objects collide, energy can be transferred from one object to another, thereby changing their motion. In such collisions, some energy is typically also transferred to the surrounding air; as a result, the air gets heated and sound is produced. (4-PS3-2),(4-PS3-3)

Engineering Design
- At whatever stage, communicating with peers about proposed solutions is an important part of the design process, and shared ideas can lead to improved designs. (3-5-ETS1-2)