States of Matter
Preparation

Grade Level: Grades 3 – 6	**Time:** 45 – 60 minutes
Group Size: 25 – 30 students	**Presenters:** Minimum of three

Objectives:

The lesson will enable students to:

- Define the three states of matter.
- Describe the characteristics of each state of matter.
- Provide examples of matter moving from one state to another.
- Identify carbon, oxygen, and hydrogen on the periodic table.

Standards:

This lesson aligns with the following **National Content Science Standards:**

- **Physical science, grades K – 8**

Materials:

- States of Matter posters
  - Characteristics of solids, liquids and gases (pdf)
  - Energy level (pdf)
- Periodic chart (pdf)
- Experiment Handouts (used at each activity station) and Answer Keys
  - Experiments (Dry Ice and Water / Dry Ice and Soap / Plastic Tube and Dry Ice) (pdf)
  - Experiment Answer Keys (pdf)
- Newspapers (used to protect table tops)
- Goggles or safety glasses
- Three pairs of leather gloves
- Dry ice (about 3 – 5 lbs.)
- Hammer or rubber mallet
- Dishcloth (for wrapping around dry ice when crushing)

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- Two large balloons (one inflated for the introduction)
- Silly Putty
- Oil
- Six beakers
    - Two – 250 milliliter
    - Four – 1 liter
- Tea candle
- Lighter or matches
- Container of water
- Food coloring
- Liquid soap
- Plastic tubes
- Stopper
- Isopropyl alcohol (rubbing alcohol)
- Large funnel

The lesson is written in narrative form to provide an outline for what might be said by the presenters. This material is not intended to be totally comprehensive, and presenters should plan to add additional dialogue as necessary.

Glossary

Melting: Changing from a solid to a liquid state by application of heat or pressure, or both.
Freezing: Changing from a liquid to a solid state by loss of heat.
Boiling/Vaporization: Changing from a liquid to the gaseous state by the application of heat.
Condensation: Changing from a gas or vapor to the liquid state.
Sublimation: Changing from a solid to the gaseous state without passing through the liquid state.
Deposition: Changing from a gas to the solid state without passing through the liquid state.
CO_2: Carbon dioxide, a gas made up of one carbon atom and two oxygen atoms. Identify these atoms on the periodic table.
H_2O: Water, a liquid made up of two hydrogen and one oxygen atoms. It can be a solid, liquid, or a gas.

Safety Issues with Dry Ice

Handling
Dry ice is extremely cold. It freezes at -109.3°F (-78.5°C) and must always be handled with care. Wear leather gloves or oven mitts whenever you touch it. If touched briefly, it is harmless; but prolonged contact will freeze cells and cause injury similar to a burn.

Burn Treatment
Treat dry ice burns in the same manner as heat burns. See a doctor if the skin blisters or comes off. If the skin only turns red, it will heal in time, like a sunburn or any other first-degree burn. Apply antibiotic ointment to prevent infection and bandage only if the burned skin needs to be protected.

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Storage
It's very important to follow these rules when storing dry ice.

- Store dry ice in an insulated container. The thicker the insulation, the slower the ice will sublimate.
- Do not store dry ice in a completely airtight container. The sublimation of dry ice to carbon dioxide gas will cause any airtight container to expand and possibly explode.
- Make sure the storage area is properly ventilated. Do not store dry ice in unventilated rooms, cellars, autos, or boat holds. The sublimated carbon dioxide gas will sink to low areas and replace oxygenated air. This could cause suffocation if breathed exclusively.
- Do not store dry ice in a refrigerator or freezer. Its extremely cold temperature will cause your thermostat to turn off the freezer. It will keep everything frozen in the freezer, but it will be used up at a faster rate.

Ventilation
Normal air is composed of 78 percent nitrogen, 21 percent oxygen, and only 0.035 percent carbon dioxide. If the concentration of carbon dioxide in the air exceeds 5 percent, it can become toxic. Smaller concentrations can cause quicker breathing but otherwise is not harmful. If dry ice has been in a closed vehicle, room, or walk-in for more than 15 minutes, open the doors and windows to allow adequate ventilation before you enter. If you're in an area that contains dry ice and start to pant or breathe quickly, leave immediately. You have inhaled too much CO_2 and not enough oxygen. Carbon dioxide is heavier than air and will accumulate in low spaces.

Transporting
Dry ice is available at most grocery stores. Obtain it as close to the time you need it as possible. It sublimates at 10 percent, or 5 to 10 pounds every 24 hours, whichever is greater. Carry it in a well-insulated container, such as an ice chest. If you transport it inside a car or van for more than 15 minutes, make sure the vehicle is well ventilated.

Disposal
Unwrap and leave the dry ice at room temperature in a well-ventilated area. It will sublimate from a solid to a gas. Do not leave it on a tiled countertop as the extreme cold could crack the tile.

DO NOT leave dry ice unattended around children.
NOTE: Safety information adapted from http://www.dryiceinfo.com/safe.htm

To break the dry ice into usable pieces:

- Put on safety goggles to protect your eyes and leather gloves or oven mitts to protect your hands.
- Wrap the dry ice in a dishcloth and break it into approximately one-inch squares with a hammer or rubber mallet.

Set up each of the stations with the equipment needed. Ask the teacher to organize the students into three groups at the conclusion of the introduction. Each station needs a facilitator.

Group #1	Dry ice in water
Group #2	Dry ice in soapy water
Group #3	Dry ice in plastic tube with stopper

States of Matter
Introduction

Q: What is a chemist? What is chemistry?
A: A chemist is someone who studies chemistry. Chemistry is the study of matter.

Q: How would you define or describe matter?
A: Matter is anything that has mass (weighs something) and occupies space.

There are two types of change that can occur to matter: chemical and physical. Chemical change occurs when an object's original material changes into a different kind of material, e.g., burning a match or baking a cake. Physical change results in a new form of the same material, e.g., ice melting, water boiling or freezing, steam condensing, and carbon dioxide sublimating. We are going to look at physical changes today.

Q: How many states of matter are there? Who can name them?
A: Matter is found in three different states: solid, liquid, and gas. Each of these states is known as a phase.

Use the Energy Levels poster to support the discussion of energy levels.

Elements and compounds can move from one phase to another phase when physical forces are applied. These physical forces either add or remove energy. Heat is one of these physical forces.

Q: How is heat measured?
A: Heat is measured by temperature.

Q: Is energy added or removed when temperature increases?
A: Energy is added when temperature increases.

Present to the class three different materials. Ask them to identify the state of matter for each material (Silly Putty, oil, and inflated balloon).

Ask students to define the different characteristics of the Silly Putty, oil, and gas in the balloon.

Use the poster Characteristics of Solids, Liquids, and Gases to support the discussion.

Q: What are the characteristics of a solid?
A: The characteristics of a solid are:

- Solids hold their own shapes (definite shape)
- Solids are hard to compress (definite volume)
- Their atoms and molecules are tightly packed

Q: Who can give me an example?
A: Examples of solids: Silly Putty, rocks, chairs, trees, books

Q: What are the characteristics of a liquid?
A: The characteristics of a liquid are:

- Liquids fill the shape of any container (indefinite shape)
- Liquids are hard to compress (definite volume)
- Their atoms and molecules tend to be a little more spread out than a solid, but much more compact than a gas

Q: Who can give me an example?
A: Examples of liquids: oil, water, orange juice, syrup

Q: What are the characteristics of a gas?
A: The characteristics of gas are:

- Gases fill a container of any size or shape (indefinite shape)
- The volume of a gas is defined only by the size of its container (indefinite volume)
- The atoms and molecules are free to move around independently of one another

Q: Who can give me an example?
A: Examples of gas: helium in balloons, air (nitrogen and oxygen)

Q: Think of a material, such as water. In what order does it move from one state to another?
A: Water can move from a solid, to a liquid, and then to a gas. It can also move from a gas to a liquid and then to a solid.

Q: Can you think of any materials that move in a different order?
A: Dry ice

Dry Ice Sublimation Demonstration

Ask students how ice changes states (solid-liquid-gas). Ask students to predict what they think will happen when dry ice is placed on the counter. Have a student put on a pair of leather gloves and remove one piece of dry ice from the ice container and place it on the countertop. Have students explain what is happening. Why isn't there a puddle? What state was skipped?

Q: How is dry ice different than ice? What is dry ice?
A: Ice is frozen water (H_2O). Dry ice is frozen carbon dioxide (CO_2), the gas we exhale as we breathe. Identify carbon and oxygen on the periodic table. It is much denser and colder than ice. The temperature at which CO_2 freezes and forms dry ice is -109.3°F (-78.5°C). Ice melts at 32°F (O°C). Dry ice doesn't melt; it sublimates. Sublimation is the process of going directly from a solid to a gas. Dry ice bypasses the liquid form. That's why we call it "dry" ice.

Q: Observe the gas. What direction does it move? Why do you think it goes down instead of up, like steam?
A: This is due to two things:

1) the temperature difference between the dry ice and the air, and
2) the density of the CO_2 gas.

Place a lighted tea candle in the bottom of a 1-liter beaker.

Candle/Flame Demonstration

Q: Ask the students to predict what they think will happen when the dry ice is placed alongside the candle in the bottom of the beaker. Why?

Using leather gloves, a student places a piece of dry ice in the beaker.

Q: The flame is extinguished. Why? Why can CO_2 be used to extinguish a fire?
A: CO_2 gas is heavier than air. It does not have enough oxygen to support combustion. It is the gas that humans breathe out and trees breathe in. It is the bubbles in our soda pop. CO_2 fire extinguishers are quite common.

A chemist asks a lot of questions: What? How? and Why? Today, you have an opportunity to be a chemist as you participate in three different activities. Ask what, how, and why about each of the activities in which you participate. You will have scientific data sheets to record the results of each of the experiments.

Divide students into three groups and begin rotations.

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Dry Ice in Water

Fill a 250-mL beaker half full with warm or hot water.

Have students make predictions about what they think will happen when the dry ice is placed in the beaker of warm water, and have them share their rationale for their predictions. Record their observations.

Instruct one student in the group to put on a pair of leather gloves and place a chunk of dry ice in the beaker of hot water. Establish with the students that the dry ice is shrinking. Ask the students the following questions.

Q: What is causing the water to bubble?
A: The bubbles are created from the pressure of the CO_2 gas sublimating in the water (H_2O).

Guide the students to the fact that the water is not boiling, even though it is bubbling. Reiterate that the gas coming off the top is not steam, like when a pot of water boils, but CO_2.

Q: Why was the bubbling rapid at first and then slow?
A: The rate of bubbling slows as the water cools. Initially, the dry ice was heating at a rapid rate due to the extreme temperature difference between the dry ice and the water. As the water begins to cool and the temperature difference between the dry ice and water becomes smaller, the bubbling begins to slow.

Q: What happens as the water cools?
A: When the water cools enough, water ice will form a covering on the dry ice. The ice will even encapsulate the chunk of dry ice, then pop, as further sublimation builds up inside the capsule of ice.

To prepare for the next student rotation, dump the contents of the 250-mL beaker into the 1-L beaker and prepare the activity station for the next rotation.

Extension

In the previous activity, students have experimented in an open-ended manner. Now, have them experiment in a systematic manner by measuring the temperature. Give each group of students a thermometer and a beaker of water at room temperature.

- Instruct the students to measure and record the temperature of the water before placing a cube of dry ice in the beaker.
- Assist the students with adding a cube of dry ice in the water.
- Instruct the students to measure the temperature of the water every minute after the dry ice is added.
- Have the group graph the change in temperature over time. (The y-axis is the temperature, and the x-axis is the time).

States of Matter
Dry Ice in Soapy Water

Fill a 250-mL beaker half full with warm or hot water and add some liquid soap.

Have the students make predictions about what they think will happen when the dry ice is placed in the beaker of soapy water. Then have them share their rationale for their predictions. Record their observations.

Instruct one student in the group to put on a pair of leather gloves and place a chunk of dry ice in the beaker of soapy water. Establish with the students that the dry ice is shrinking. Ask the students the following questions.

Q: What causes this physical reaction?
A: The dry ice is heated by the water, causing it to sublime rapidly. The carbon dioxide gas becomes "trapped" in the soap that is dissolved in the water. If you pop the soap bubbles, the CO_2 gas will be released into the air.

Q: Why does the bubble tube move in a downward direction?
A: The bubble tube moves in a downward direction because CO_2 is heavier than the O_2 in the air and because the bubbles are connected to each other.

Q: If we add food coloring to the water, would the CO_2 be trapped in the bubbles or would the bubbles become the color of the food coloring?
A: Have the students make predictions. Neither the CO_2 nor the bubbles took on the color of the food coloring. The food coloring dissolved in the water but not in the dry ice or soap. And since the sublimation of the dry ice is a physical change and not a chemical change, the CO_2 remains unchanged. Likewise, the soap is not changed by the water, so it does not "react" with the food coloring dissolved in the water.

To prepare for the next student rotation, dump the contents of the 250-mL beaker into the 1-L beaker and prepare the activity station for the next rotation.

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Dry Ice in Plastic Tube with Stopper

Fill a plastic tube about 4 – 5 inches high with isopropyl alcohol.

Have students make predictions about what they think will happen when the dry ice is placed in the sealed test tube of isopropyl alcohol (rubbing alcohol), and have them share their rationale for their predictions. Record their observations.

Instruct one student in the group to put on a pair of leather gloves and place a chunk of dry ice in the test tube. Place a stopper on the top opening of the tube and point it away from the students.

Q: What caused the physical reaction?
A: The isopropyl alcohol (rubbing alcohol) acts as a heat source because it is at room temperature (28°C) and dry ice is at -78°C. This heat speeds up the transition from solid to gas. In the tube, the gas builds up pressure and pushes on the sides and ends of the tube. Finally, the gas builds up enough pressure to pop the stopper off.

Q: What would you change to increase the reaction?
A: Warming the isopropyl alcohol so the dry ice would sublime faster would increase the reaction.

Q: If you used water instead of isopropyl alcohol, why would the time for the stopper to pop off increase?
A: The increase in time is due to the water cooling down faster than would Isopropyl alcohol, thus decreasing the heat provided to the dry ice, which slows the rate of sublimation. The slower the sublimation, the slower the evolution of gas, which is the force that pops the stopper.

NOTE: The last and next questions reinforce one another.

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Dry Ice in Plastic Tube with Stopper

Q: What is the effect of isopropyl alcohol compared to water in the plastic tube?
A: Due to differences in freezing points of isopropyl alcohol and water, the water cools down much faster than the isopropyl alcohol. This causes the stopper to take longer to pop off for each consecutive "pop." Eventually, the water would freeze over. Since isopropyl alcohol has a lower freezing point -89.5°C, it does not freeze at the same temperature as dry ice.

To prepare for the next student rotation, dump the contents of the plastic tube into the 1-L beaker and prepare for the activity station for the next rotation.

States of Matter
Conclusion

Concluding activity

Mystery Balloon

Q: From what you have learned, what do you think will happen when dry ice is funneled into the balloon? Why?

Funnel a few pieces of dry ice into the balloon. Have one student hold the opening of the balloon under the funnel and another student scoop dry ice into the funnel (make sure each student wears leather gloves). After a few scoops of dry ice are funneled into the balloon, tie it off.

Q: What is the mystery? How did the balloon self-inflate?
A: Dry ice doesn't melt, it just gets smaller. When the dry ice sublimates, large amounts of gas are generated, causing the balloon to inflate. Eventually the pressure of the gas becomes so great that the balloon will burst (hold the balloon away from your body and the students).

Q: Concluding Questions:

- **How many states of matter are there?**
- **Describe how elements move from one state to the next. (heated, cooled, can skip states)**
- **What are the characteristics of a solid, liquid, and gas?**
- **Give an example of material moving from one state to the next.**

Chemistry is a lot like cooking. You mix chemicals together like you mix the ingredients in a recipe (flour, sugar, butter, milk) and then wait to see what happens.

Dry Ice Trivia

Q: How is dry ice made?
A: The first step in making dry ice is to turn the carbon dioxide gas into a liquid. This is done by compressing the CO_2 and removing any excess heat. The CO_2 will liquefy at a pressure of approximately 870 pounds per square inch. Next, the pressure is reduced by sending the liquid carbon dioxide through an expansion valve. Part of the liquid sublimates, causing the remainder to freeze into snowflakes. The dry ice snow is then compacted together under a large press to form blocks. Dry ice is much heavier than traditional ice, weighing about the same as standard bricks.

Additional Information:

The Fourth State of Matter

Scientists also recognize a fourth state of matter called plasma.

Q: What is plasma?
A: Plasma has properties similar to a gas, except it is composed of charged particles, called ions, which dramatically respond to electric and magnetic forces. Plasma has the highest energy of all the states of matter.

Q: Where can you find plasma?
A: Surprisingly, plasma is probably the most prevalent state of matter in the universe. Materials in the plasma state include flames, the outer portion of the earth's atmosphere, the atmosphere of stars, like the sun, much of the material of nebular space, and part of a comet's tail. The aurora borealis is matter in the plasma state, streaming through a magnetic field. Closer to home, plasmas are found in florescent lights, neon signs, and lightning.

Q: Where can I find more information on plasmas?
A: Since this lesson plan was structured for students in grades 3 – 6, plasma was not included. More information on plasmas can be found by contacting The Division of Plasma Physics of the American Physical Society.

Resources:

- **http://www.plasmacoalition.org/edmaterials.htm**
- **Call toll free 1-877-PLASMAS**
- **E-mail CPS@plasmacoalition.org**