# Penn State RET in Interdisciplinary Materials
## Teacher's Preparatory Guide

## *Under Pressure*

**Purpose** These series of chemical demonstrations are designed to help students understand the effects of high amounts of pressure on phase changes.

**Objectives** To show the effects of high pressure through the use of chemical demonstrations.

**Time required** 30-60 minutes depending on how much time is spent on content.

**Level** Middle School or High School – Any level of science in which pressure is being discussed.

**National Science Education Standards Grades 9-12**

A. Science as Inquiry

- Identify questions and concepts that guide scientific investigations (form a hypothesis).
- Design and conduct scientific investigations based on knowledge of major concepts, equipment, and safety precautions.
- Recognize and analyze alternative explanations and models by reviewing current scientific understanding, weighing evidence, and examining the logic.
- Scientists usually inquire about how physical, living, or designed systems function and are guided by conceptual principles and knowledge.
- Scientists conduct investigations for a wide variety of reasons. For example, they may wish to discover new aspects about the natural world, explain recently observed phenomena, or the testing of prior conclusions.
- Scientific explanations should be logical, based on evidence, open to questions and possible modification, and be based on historical and current scientific knowledge.

B. Physical Sciences

- The physical properties of compounds reflect the nature of the interactions among its molecules.
- Solids, liquids, and gases differ in the distances and angles between molecules or atoms and, therefore, the energy that binds them together.

**Pennsylvania Science Education Standards**

3.2 – Physical Sciences

7.A – Grade 7 Chemistry

A3 – Explain how energy transfer can affect the chemical and physical properties of matter.

10.A – Grade 10 Chemistry

A3 – Describe phases of matter according to the kinetic molecular theory

A6


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- Know that both direct and indirect observations are used by scientists to study the natural world and universe.
- Identify questions and concepts that guide scientific investigations.
- Recognize and analyze alternative explanations and models.

12.A – Grade 12 Chemistry

A6

- Evaluate experimental information for relevance and adherence to science processes.
- Judge that conclusions are consistent and logical with experimental conditions.
- Interpret results of experimental research to predict new information, propose additional investigable questions, or advance solution.

10.B – Grade 10 Physics

B6 – Explain how the behavior of matter and energy follow predictable patterns that are defined by laws.

12.B – Grade 12 Physics

B3 – Describe the relationship between the average kinetic molecular energy, temperature, and phase changes.

## Teacher Background

This activity could be used to discuss phase changes and/or pressure. In discussing phase changes, make sure students know the terms of the various phase changes. Have the students complete questions 1-3 in the student activity worksheet.

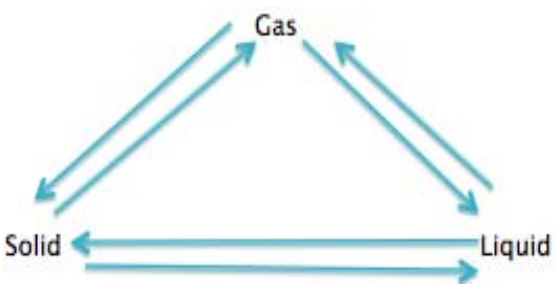


**Figure 1 – Phase Changes**

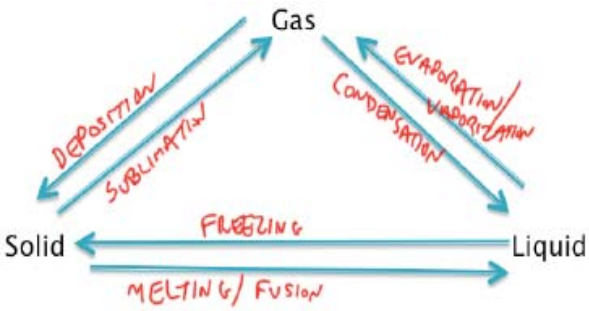


**Figure 2 – Terms of Phase Changes**

Go over student answers, to those questions to make sure students all have the same background information.

When students give their answers to question 3, transition the discussion into how pressure would affect freezing and boiling points. To introduce this topic, you can show the YouTube clip of water boiling at room temperature. https://youtu.be/XoOQNwcrDWE


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You can the show Figure 3 to explain a phase diagram.

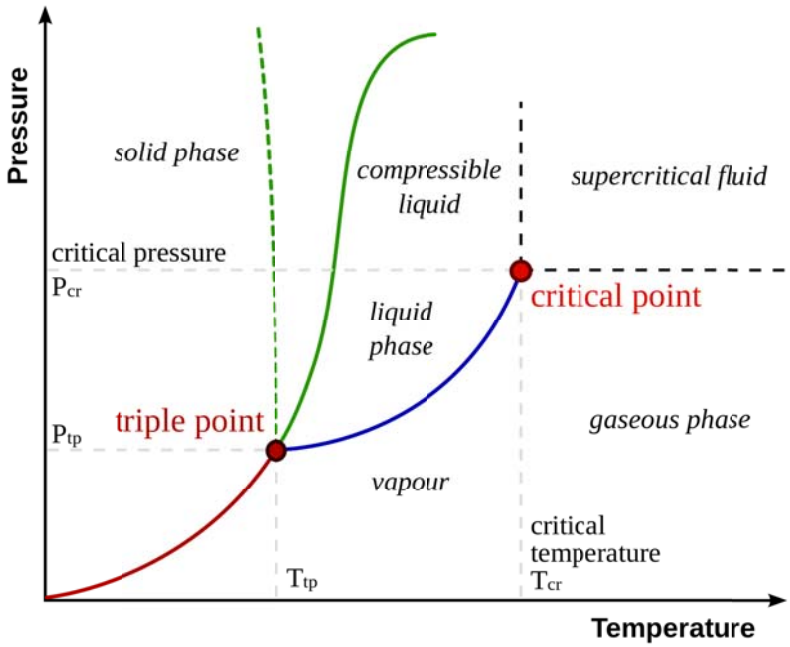


**Figure 3 – A phase diagram** (https://en.wikipedia.org/wiki/Phase_diagram)

While discussing a phase diagram, be sure to discuss the following terminology:

Triple point – the temperature and pressure conditions at which the solid, liquid, and gaseous phases of a substance coexist at equilibrium
Critical point – the temperature and pressure at which the gas and liquid states of a substance become identical and form one phase
Critical pressure – the pressure associated with the critical point
Critical temperature – the temperature associated with the critical point
Supercritical fluid – the state at which the liquid and vapor phases are indistinguishable

After discussing a phase change diagram, you could show the students a phase change diagram for carbon dioxide, as seen in Figure 4.


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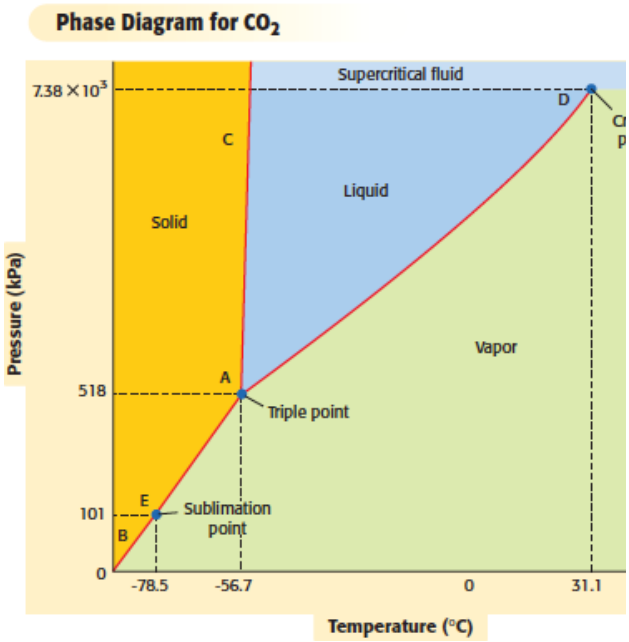


**Figure 4 – Phase Diagram for $CO_2$**

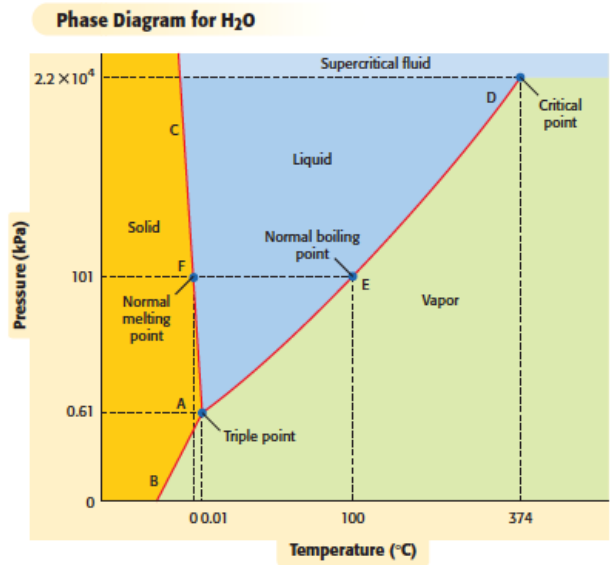


**Figure 5 – Phase Diagram for $H_2O$**

Have students note the similarities and differences between the phase diagram for $CO_2$ and $H_2O$ (Figure 5).

At this point go through the two demonstrations. Have students answer questions 4-8 while completing the demonstrations.

After completing the demonstrations, have students complete the Enhancing Understanding questions in the activity worksheet.

**Materials**

$CO_2$ Demonstrations:

- Supercritical fluid apparatus
- Hair dryer or other heat source
- Dry ice sublimation apparatus
- Small block of dry ice
- Warm water

**Advance Preparation**

The only chemical needed is a block of dry ice. Locations to purchase dry ice will vary depending on location.

**Safety Information** When handling dry ice, avoid skin contact. Use either tongs or cryogenic gloves when handling dry ice. When disposing of dry ice, be sure the area is well ventilated. When heating the supercritical liquid/gas $CO_2$ tube, use caution. Overheating can cause an increase in pressure in the tube, causing it to burst.


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**Teaching Strategies:** The following strategies could be used to introduce pressure.

Bell Ringer – As students walk in the classroom, have them answer the questions, "What is pressure? How would you explain it to an elementary school aged student?" As class begins give students a few minutes to come up with a response.

KWL Chart – Ask students to fill in the following KWL chart prior to (the first two columns) and after (the last column) introducing pressure and the chemical demonstrations.

| K<br>What I **Know**<br>(about pressure) | W<br>What I **Want** to Know<br>(about pressure) | L<br>What I **Learned**<br>(about pressure) |
|---|---|---|
| | | |
| | | |

**Resources:**

Dr. John Badding from Penn State University has excellent videos on supercritical liquid and high-pressure systems. They can be viewed here: http://bg.chem.psu.edu/demos.html

Other helpful websites on supercritical fluids including:

- Wikipedia - https://en.wikipedia.org/wiki/Supercritical_fluid
- UC Davis - http://chemwiki.ucdavis.edu/Physical_Chemistry/Physical_Properties_of_Matter/Phases_of_Matter/Supercritical_Fluids
- Video of supercritical $CO_2$ fluid - https://youtu.be/GEr3NxsPTOA

**Directions for the activities**

- 5 minutes – Opening bell ringer
- 5-10 minutes – Discussing phase changes and having students complete questions #1-3 on the activity worksheet
- 5 minutes – Going over questions 1-3
- 10 minutes – Explaining phase diagrams
- 5-10 minutes – Supercritical fluid demonstration and explanation
- 5-10 minutes – Dry ice deposition demonstration and explanation
- Remaining class time – Have students complete Enhancing Understanding questions and clean up


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## Procedure

The demonstrations can be done either before or after delivering the content on phase changes. See the teacher background above for assistance with the content.

**The Supercritical Fluid Demo**

Building the Apparatus

Obtain the following parts. Many of these parts were ordered from McMaster-Carr at http://www.mcmaster.com/. Item number, description, and price as of July 2015 are included.

- 2 - 1079K18 - High-Pressure Nickel-Plated Steel Glass Sight, without Reflector, ¼" NPT Male, 5/8" Hex Size - $6.97 each
- 45525K552 - High-Pressure 304 Stainless Steel Threaded Pipe Fitting, ¼" Pipe Size, Cross - $26.47
- 32255K7 - Welding & Compressed Gas Gauge, Brass Case, 2" Dial, ¼" NPT Male Bottom, 0-2000 PSI - $21.05
- 7833K84 - Medium-Pressure Needle Valve, Zinc Nickel-Plated Steel, ¼" NPT Male X Female - $26.17
- Teflon tape

Once you have the supplies put the supplies together so that it looks like the picture below.


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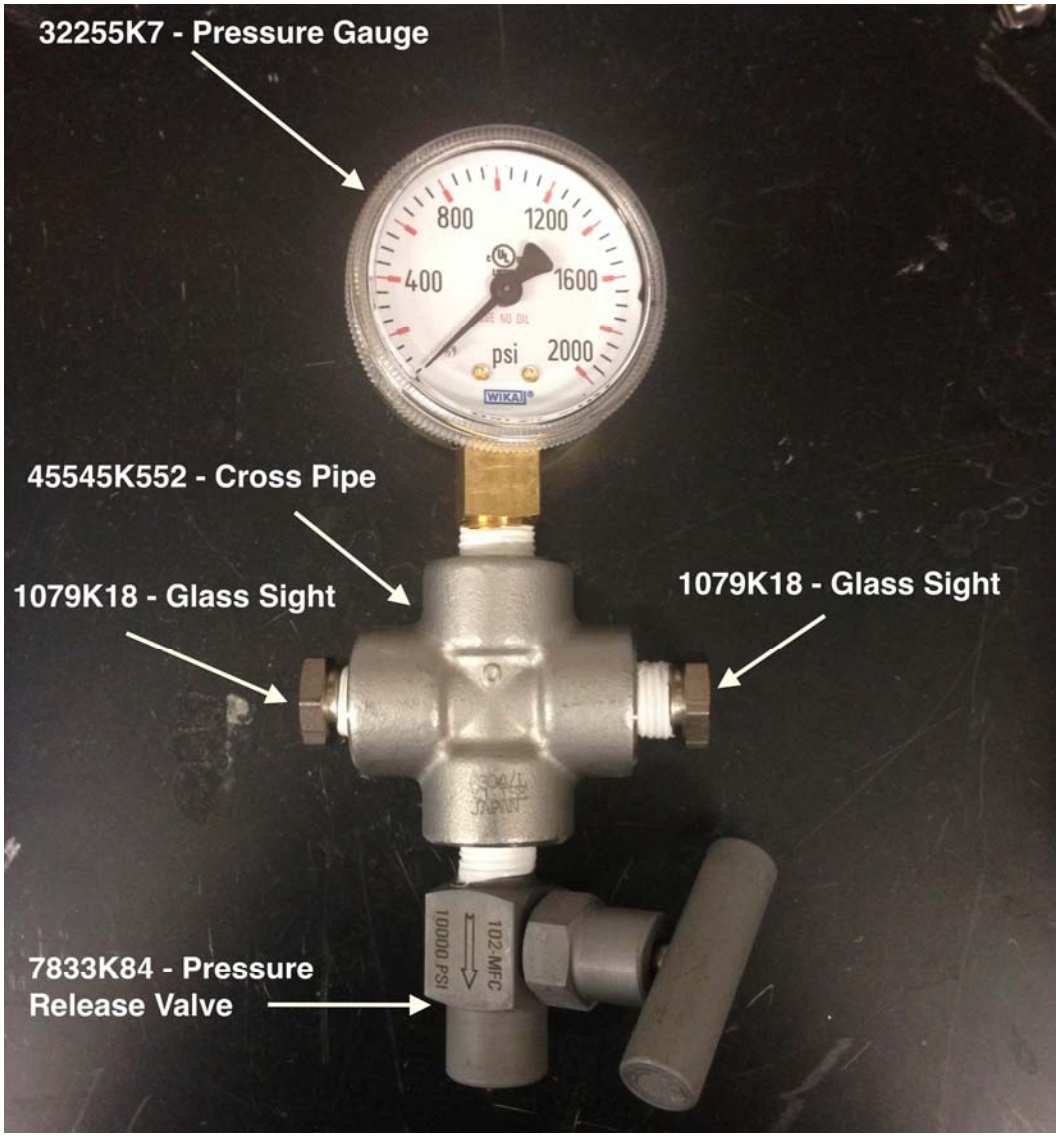


When building the apparatus use Teflon tape when attaching to the cross pipe. All attachments should be tightened with wrenches.

Explaining the Lesson

- Explain what a supercritical fluid is to the students. Use the phase diagram of $CO_2$ to help students visualize it.
- Have students complete question #4.
- Using a heat source, like a hair dryer, begin lightly heating the apparatus. Have students make observations about what is taking place in question #5. To aid students in viewing, you may want to utilize some type of digital camera with projection capability.


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## The Dry Ice Demo

Building the Apparatus

Obtain the following parts. Many of these parts were ordered from McMaster-Carr at http://www.mcmaster.com/. Item number, description, and price as of July 2015 are included.

- 44705K256 - Low-Pressure Aluminum Threaded Pipe Fitting, ¼" Pipe Size, Cross - $9.07
- 49315K71 - Clean/Bag Cryogenic Brass Relief Valve, ¼" NPT Male Inlet, 150 PSI Set Pressure - $36.88
- 47865K41 - Brass Ball Valve, ¼" NPT Connection, Female X Male - $9.29
- 3846K6 - Multipurpose Gauge, Steel Case, 2" Dial, ¼" NPT Bottom, 0 - 200 PSI - $9.84
- ¼" Metal tubing
- Swag lock connecting to NPT
- EpoHeat 2 Epoxy Resin 20-3420-064
- EpoHeat 2 Epoxy Hardener 20-3422-016
- Teflon tape
- Plastic soda bottle with lid. Be sure to use a plastic soda bottle so that it can withstand the pressure build up. Do NOT use a water bottle as those bottles tend to use thinner plastic.

Once you have the supplies put the supplies together so that it looks like the picture below.


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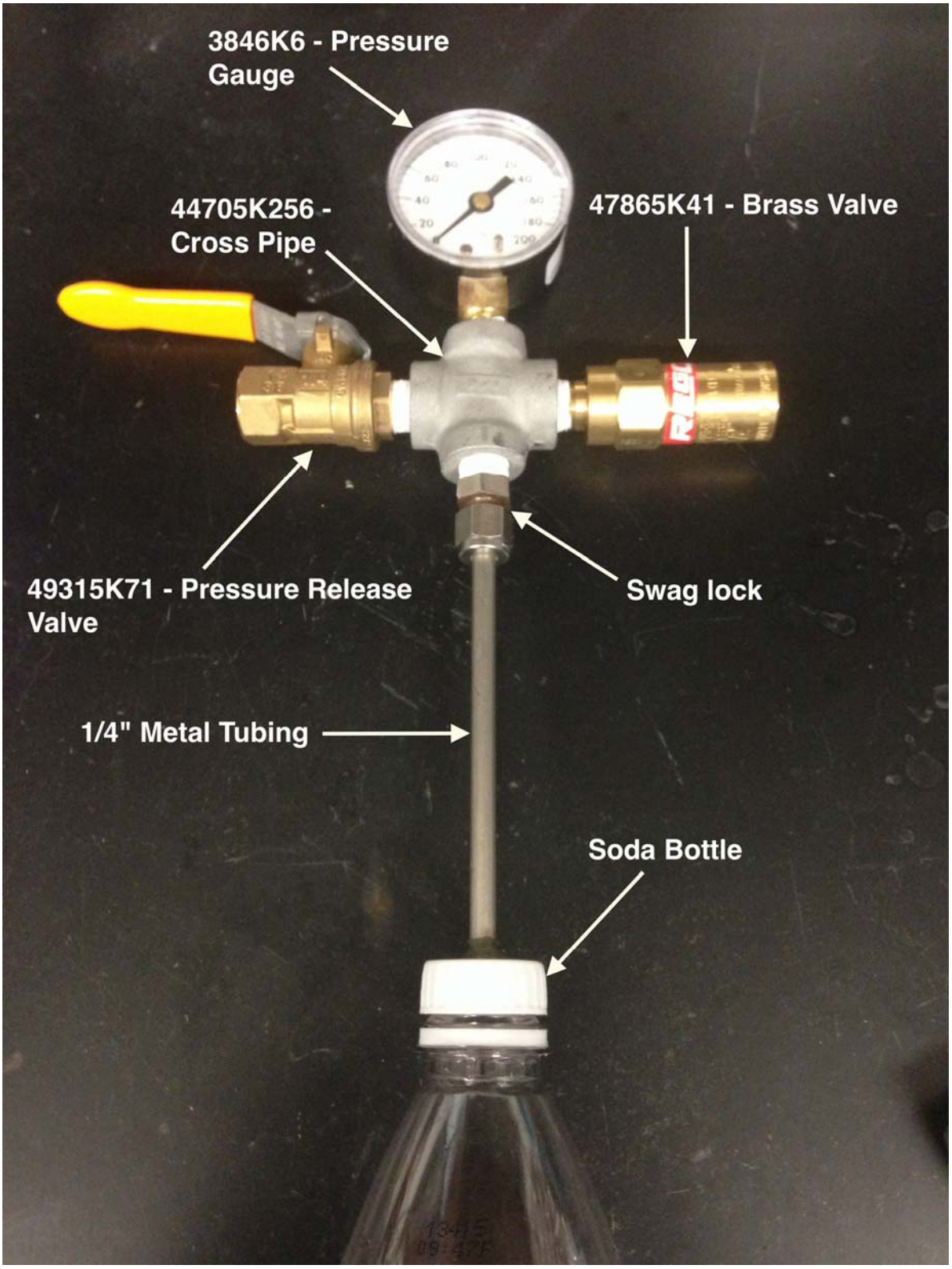


When building the apparatus use Teflon tape when attaching to the cross pipe. All attachments should be tightened with wrenches.


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To attach the metal tubing to the bottle cap, use a ¼" drill bit to drill a hole in the plastic lid. Once the metal tubing is through the lid, use the epoxy resin and hardener, in a 4:1 ratio, to create a seal between the metal tubing and the plastic lid. Put the epoxy on the underside of the lid and be sure the epoxy does not cover the opening of the metal tubing.

- Show the students the block of dry ice. Have students make a prediction in question #6.
- Place the dry ice in the soda bottle. This may involve having to hammer the dry ice into smaller pieces so that it can fit in the mouth of the bottle. You should have enough dry ice to fill the bottle at least ¼ of the way full.
- To speed up the sublimation process, place the soda bottle in warm water. As the pressure builds up have students make predictions in question #7.
- Once the dry ice has completely sublimed, manually release the pressure. Have students make observations in question #8.

**Cleanup**

For the supercritical fluid, be sure to release the pressure by using the pressure release valve. If the supercritical fluid stays in the apparatus for long periods of time, the fluid could damage the parts.

The soda bottle with dry ice can be left out to allow the solid to fully sublimate and diffuse into the air. Make sure there is plenty of ventilation in your area.


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# Student Worksheet or Guide

## *Under Pressure*

### Introduction

Phase changes are something that commonly occur in high school chemistry labs. The temperature of these phase changes for many common chemicals, especially water, is known. But did you know that by changing the pressure of a system, you can alter the temperatures at which phase changes can occur? In the following teacher-led activities, you will observe the effects of pressure on phase changes.

**Materials**

- Supercritical $CO_2$ liquid
- Heat source
- Dry Ice Apparatus
- Dry Ice
- Warm $H_2O$

**Make a Prediction**

Predicitions will be made throughout the activity.

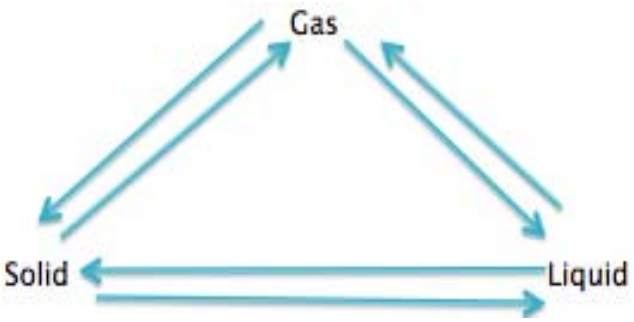
**Procedure**

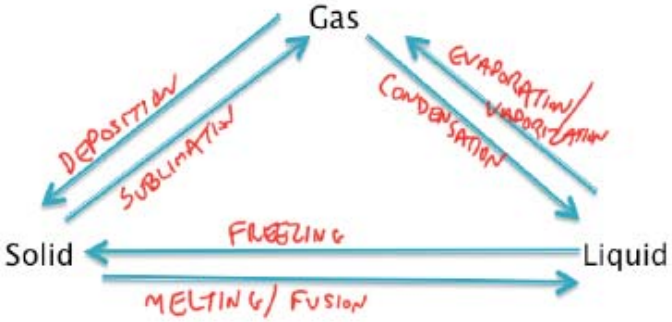
Follow along with the teacher. Make predictions and observations below.

**Observations/Analysis**

Pre-Activity Questions:

1. Terminology – determine the names of the six phase changes using the chart below.





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2a. What is the freezing point of water?

0°C

2b. What is the boiling point of water?

100°C

3. Do you think changing the pressure would affect the temperature at which phase changes would occur? If so, would the temperatures increase or decrease? Explain with your own reasoning.

Answers will vary.

**During the Demonstration Analysis/Observations:**

4. What do you expect to happen during the heating of the supercritical liquid $CO_2$?

Answers will vary.

5. What actually happened during the heating of the supercritical liquid $CO_2$? Why did this happen? Make some observations and analyze why it happened.

The barrier between the liquid and gaseous layer is indistinguishable.

6. What happened when the dry ice was placed in the warm water?

The dry ice went through sublimation and created gaseous $CO_2$.

7. When the pressure is manually released, what do you expect to happen?

Answers will vary.

8. What actually happened when the pressure was released? Why do you think this happened? Make some observations.

Solid dry ice was recreated.


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**Enhancing Understanding**

1. What is a supercritical fluid?

A supercritical fluid is a substance that is just above its critical temperature and pressure.

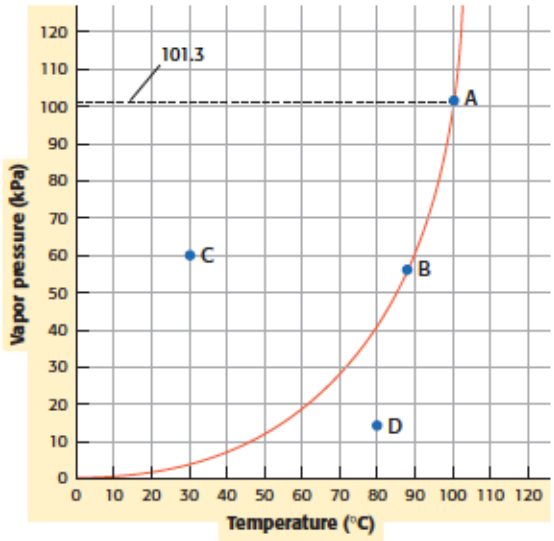
2. What are the differences in heating a supercritical fluid and a normal liquid?

When heating a normal liquid, the liquid would heat up to and then go through a phase change once the boiling point was reached. This could be at any pressure. A supercritical fluid is at a pressure above the critical point when the phases between liquid and vapor are indistinguishable.

3. In the dry ice demonstration, explain what happened to the gaseous dry ice when the pressure was released.

The gaseous $CO_2$ went through a gas to solid transition known as deposition.

4. Use the phase diagram for water to the right to answer the following questions.




a. At what point(s) does water boil at standard atmospheric pressure?

Point A

b. At what point(s) is water in the gaseous phase?

Point D

c. At what point(s) is water only in the liquid phase?

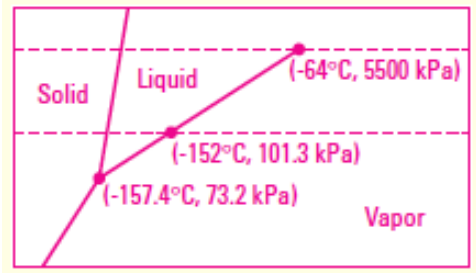
Point C

d. At what point(s) is liquid water in the equilibrium phase?

Point A and B

5. On a piece of graph paper, graph a phase diagram for Krypton based on the following information:

- The critical point is at -64°C and 5500 kPa
- The triple point is at -157.4°C and 73.2 kPa
- At -172°C the vapor pressure is 13 kPa
- The normal boiling point is -152°C





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**Going Further**

1. Explain how a pressure cooker works by relating it to the pressure demonstrations.
At the higher pressure in the cooker, the boiling point of water is higher. Whatever you are cooking will cook faster.

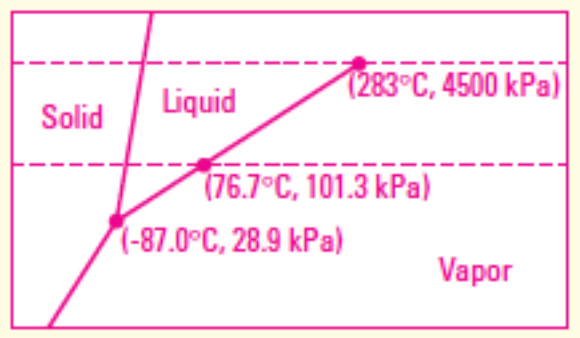
2. Why is the triple point near the normal freezing point of a substance?
Small changes in pressure have little effect on the freezing point.

## Assessment and rubrics:

Students should be able to answer all of the questions and make all of the observations in the above handout. Upon entering class the next day, the students should be able to complete the following bell ringer.

Sketch the phase diagram for carbon tetrachloride based on the following information:

- The critical point is 283°C and 4500 kPa
- The triple point is -87.0°C and 28.9 kPa
- The normal boiling point is 76.7°C





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