Lesson Plan: Phase Diagrams and Phase Equilibria

Teacher-submitted lesson plan, contributed by Dr. Upasana Issar, Assistant Professor, Kirori Mal College and Dr. Richa Arora, Assistant Professor, Shivaji College, (University of Delhi), India.

As an **undergraduate Chemistry, Physics, or Earth Sciences** teacher, you can use this set of computer-based tools to teach **phase diagrams** and **phase equilibria**.

Phase diagrams can be used to understand the stability of different phases of matter (solid, liquid, and gas) under changing temperature and pressure. This lesson plan will help students learn about phase equilibria through the example of the phase diagram of water. Students will learn about the phases of water on Earth, Mars, and Venus and will discuss the role of the water cycle in making the climate of planet Earth habitable.

Thus, the use of this lesson plan allows you to integrate the teaching of a climate science topic with a core topic in Chemistry, Physics, or Earth Sciences.

Use this lesson plan to help your students find answers to:

- What is a phase diagram? Explain the degrees of freedom.
- Define and explain the triple point and critical point in a phase diagram.
- What are supercritical fluids? How are they useful?
- Discuss the water vapor feedback mechanism in the Earth's atmosphere by using the phase diagram of water.
- Using phase diagrams, explain why the climate of Earth is habitable while the climate of Mars and Venus is not.
- Why did Venus experience a runaway greenhouse effect, resulting in a very high surface temperature (462°C)? Discuss why Earth has not yet experienced this effect.

About the Lesson Plan

Grade Level: Undergraduate

Discipline: Chemistry, Physics, Earth Sciences

Topic(s) in Discipline: Phase Equilibria, Phase Diagrams of Water, Triple and Critical Points in a Phase Diagram, Degrees of Freedom, Feedback Mechanisms, Vapor Pressure, Runaway Greenhouse Effect

Climate Topic: Climate and the Atmosphere, The Greenhouse Effect

Location: Global

Access: Online

Language(s): English

Approximate Time Required: 45-60min

1 Contents

A video that introduces phase diagrams and explains how they can be interpreted (using the phase diagram of water as an example).

https://www.khanacademy.org/science/chemistry/states-of-matter-and-intermolecular-forces/states-of-matter/v/phase-diagrams

2. Reading (10 min)

A reading that describes a typical phase diagram and its components, discusses the phase diagrams of water and carbon dioxide, and provides examples and exercises based on these phase diagrams.

https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_General_Chemistry_(Petrucci_et_al.)/12%3A_Intermolecular_Forces%3A_Liquids_And_Solids/12.4%3A_Phase_Diagrams

3. Video micro-lecture (~7 min) and associated reading (15 min)

A video micro-lecture and an associated reading that describe the phase diagrams of water on Earth, Mars, and Venus. They also discuss the water vapor feedback mechanism in the atmospheres of these planets and the role of this mechanism in the greenhouse effect. Further, these resources explain why the climate of Earth is habitable while that of Mars and Venus is not.

Video micro-lecture:
http://www.kaltura.com/index.php/extwidget/preview/partner_id/1090132/uiconf_id/20652192/entry_id/1_v3d6yfus/embed/auto

Reading:

https://geosci.uchicago.edu/~archer/Forecast_2ed/text_2ed.all.pdf (pg. 127-131, 144)

4. Suggested questions/assignments for learning evaluation

- What is a phase diagram? Explain the degrees of freedom.
- Define the triple point and critical point in a phase diagram.
- What are supercritical fluids? How are they useful?
- Discuss the water vapor feedback mechanism in the Earth's atmosphere by using the phase diagram of water.
- Using phase diagrams, explain why the climate of Earth is habitable while the climate of Mars and Venus is not.
- Why did Venus experience a runaway greenhouse effect, resulting in a very high surface temperature (462°C)? Discuss why Earth has not yet experienced this effect.

2 Step-by-step User Guide

Here is a step-by-step guide to using this lesson plan in the classroom/laboratory. We have suggested these steps as a possible plan of action. You may customize the lesson plan according to your preferences and requirements.

1. Introduce the topic by playing a micro-lecture

Play the video micro-lecture "Phase Diagrams" by Khan Academy, available at https://www.khanacademy.org/science/chemistry/states-of-matter-and-intermolecular-forces/states-of-matter/v/phase-diagrams, to

- introduce the topic of phase diagrams
- explain what phase diagrams depict by describing their different regions and degrees of freedom
- understand how to interpret phase diagrams under varying conditions of temperature and pressure

Use the tool to first describe the phase diagram of water, and phase transformations of water at melting and boiling points, at various atmospheric pressures. Then, use the video to describe the phase diagram for carbon dioxide. Further, use the tool to explain the triple and critical points in a phase diagram and discuss the phase transitions at these points. Finally, introduce the term "supercritical fluid" and briefly describe its properties.

2. Use a reading to discuss the topic further

With the help of the reading in the chapter "12.4. Phase Diagrams" (by LibreTexts™), available at https://chem.libretexts.org/Bookshelves/General_Chemistry/Map%3A_General_Chemistry_(Petrucci_et_al.)/12%3A_Intermolecular_Forces%3A_Liquids_And_Solids/12.4%3A_Phase_Diagrams, describe a typical phase diagram. Describe the different regions of a phase diagram where the various phases of a single substance exist in a stable state and the points at which phase transitions take place. Discuss the triple and critical points in a phase diagram and the stability of phases at these points. Further, examine the phase diagrams of water and carbon dioxide, and discuss specific temperature and pressure conditions at which the different phases of these substances are stable/unstable. Use example 12.4.1 and exercise 12.4.2 included in the text to discuss phase transitions of water. Use this reading to also describe supercritical fluids, their properties and their commercial applications as solvents.

3. Use a video micro-lecture and an associated reading to explain the reasons for the Earth's climate being habitable (applying the understanding of phase diagrams)

Play the video micro-lecture "Water Vapor Feedback" by Prof. David Archer, the University of Chicago, available at http://www.kaltura.com/index.php/extwidget/preview/partner_id/1090132/uiconf_id/20652192/entry_id/1_v3d6yfus/embed/auto to explain the stable phases of water at various temperatures on Earth. Introduce the concept of water vapor feedback and explain the greenhouse effect of water vapor on Earth's atmosphere by using the phase diagram of water. Further, compare the effect of water vapor feedback on the atmospheres of Earth, Mars, and Venus. Discuss how the water cycle ensures that Earth has a climate that is more suitable to support life. Explain the runaway greenhouse effect of water vapor on Venus that makes it uninhabitable.

Use the associated reading material "Chapter 7: Feedbacks" from Prof. David Archer's book, 'Global warming- Understanding the Forecast', available at https://geosci.uchicago.edu/~archer/Forecast_2ed/text_2ed.all.pdf to discuss feedback mechanisms, water vapor feedback, and the runaway greenhouse effect on Venus in greater detail (pg. 127-131). The phase diagram of water (Figure 7.2) is on pg. 144 of this reading.

Questions/Assignments

Use the tools and the concepts learned so far to discuss and determine answers to the following questions:

- What is a phase diagram? Explain the degrees of freedom.
- Define the triple point and critical point in a phase diagram.
- What are supercritical fluids? How are they useful?
- Discuss the water vapor feedback mechanism in the Earth's atmosphere by using the phase diagram of water.
- Using phase diagrams, explain why the climate of Earth is habitable while the climate of Mars and Venus is not.
- Why did Venus experience a runaway greenhouse effect, resulting in a very high surface temperature (462°C)? Discuss why Earth has not yet experienced this effect.

3 Learning Outcomes

The tools in this lesson plan will enable students to:

- describe a one-component phase diagram
- explain various regions and points (such as the triple point, the critical point) in a phase diagram
- define a supercritical fluid
- compare the climates of Earth, Venus, and Mars with the help of the phase diagram of water
- use the phase diagram to explain the water vapor feedback mechanism in the Earth's atmosphere and its role in making the planet habitable

4 Additional Resources

If you or your students would like to explore the topic further, these additional resources will be useful.

1. Classroom/Laboratory Activity (15 min)

An interactive simulation from PhET, University of Colorado, to explore the phase transformations of water under changing temperature and pressure conditions.

https://phet.colorado.edu/sims/html/states-of-matter-basics/latest/states-of-matter-basics_en.html

2. Video (~18 min)

A video micro-lecture from Coursera that describes the current and past climatic conditions on Mars.

https://www.coursera.org/lecture/solar-system/lecture-1-15-was-early-mars-warmer-and-wetter-kNENP

5 Credits/Copyrights

All the teaching tools in our collated list are owned by the corresponding creators/authors/organizations as listed on their websites. Please view the individual copyright and ownership details for each tool by following the individual links provided. We have selected and analyzed the tools that align with the overall objective of our project and have provided the corresponding links. We do not claim ownership of or responsibility/liability for any of the listed tools.

1. **Video micro-lecture,** "Phase Diagrams"

   Presented by Sal Khan for Khan Academy.

2. **Reading,** "12.4. Phase Diagrams"

   Chapter provided by LibreTexts™.

3. a. **Video micro-lecture,** "Water Vapor Feedbacks"

   b. **Reading,** Chapter 7, "Feedbacks", pg. 129-131, pg. 144 from the book "Global Warming- Understanding the Forecast", 2nd Ed.

   David Archer, the University of Chicago.

4. **Additional Resources**

   a. Simulation, "States of Matter: Basics" PhET simulation by University of Colorado, Boulder.

   b. Video lecture, "1.15: Was early Mars warmer and wetter?" by Coursera.