How does a pressure cooker work?

Note:
This task is designed so that it can be solved with the incremental hints.
The hints are available on the media portal for printing, or the students can use them online on a tablet or smartphone via the QR code included on the worksheet.
The worksheet for the students and the hints for printing are available as separate files on the media portal of the Siemens Stiftung. General information on using tasks with incremental hints in the classroom is provided in the “Tasks with incremental hints – An introduction” document, which is also available on the media portal.

1 Topical aspects

The task is related to the states of aggregation of water. More precisely, this task investigates the behavior of water at increased pressure and temperatures of over 100 °C as well as, more generally, the dependence of the boiling point on pressure. From an everyday standpoint, it is related to how a pressure cooker works and to how and why cooking time changes with a pressure cooker.

2 Learning prerequisites and level of difficulty

The students must be familiar with the states of aggregation of water and the transitions between the phases. They must also be acquainted with the representation of the phases on a phase diagram.
It is beneficial if they have prior knowledge about the dependence of the boiling point of water on air pressure and therefore on the altitude of a location where water is to be brought to a boil.
Given these prerequisites, the task has a medium level of difficulty.

3 Background on the task

The pressure cooker that is found in many households today has a long history. Its forerunner, the steam digester, was invented by the French scientist Denis Papin (1647–1712), who also developed the first steam engine. Papin developed the steam digester to study the change in the boiling point of water based on different pressures. The first pressure cookers used in households were named after him, referred to as “Papin pots.” The pressure cooker found its way into many households as a mass-produced item in the 1930s.
The primary benefit of using a pressure cooker is the time saved when food is cooked. Some of the water in the airtight pot turns to steam when it reaches a temperature of approximately 100 °C; because the steam cannot escape, the pressure increases. As can be seen on the phase diagram of water, the boiling point of water also increases. For this reason, temperatures can reach well over 100 °C in a pressure cooker and yet some of the water remains liquid. In commercially available pressure cookers, the increase in pressure and therefore in temperature is limited by a valve through which steam is released when it reaches a certain pressure. The working temperature is normally 115–117 °C.
The acceleration of the cooking process, for example, the cooking of potatoes, can be explained with the rule of thumb that the speed of many chemical reactions depends on factors like temperature. The Q10 (temperature coefficient) rule of thumb states that for an increase in temperature of 10 °C, the reaction rate approximately doubles. Another benefit of working with a pressure cooker is the option to use suitable inserts that hold the food to be cooked above the water level in the pot so that the food comes into contact only with the steam. This prevents the loss of nutrients.

In this task, only the physical aspects of how a pressure cooker works are addressed; the other aspects mentioned here can be addressed in a subsequent lesson as needed.

4 The task

In the simplest form, the task can be formulated as follows:

> Find out how a pressure cooker works.
> Use the phase diagram of water as an aid.

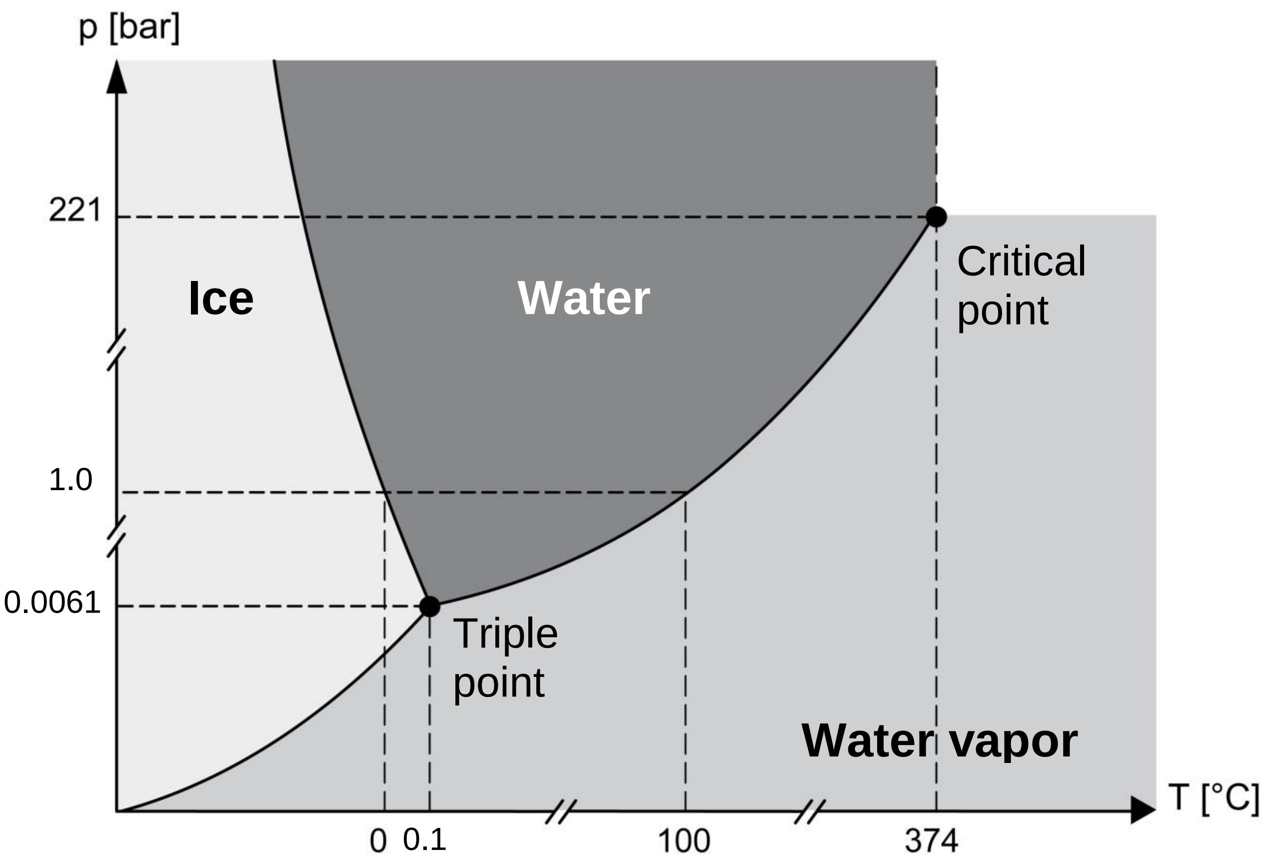
Because the context from which a task is developed fosters learning, depending on the teacher's assessment, a contextual scenario can be developed, such as the following:

> The class trip this year is to an unfurnished alpine hut. The list of items that should be taken along is quite long. However, everything needs to be carried up the mountain on foot. Some students therefore protest when Imke also suggests taking a pressure cooker.
> "Why should we lug that with us?" asks Marco.
> "Well, if you want to spend all your time standing at the stove until the potatoes are cooked, then it can stay here. I could make better use of my time," Imke replies.

Accordingly, the task is as follows:

> Find out why a pressure cooker can be especially advantageous for cooking food, such as potatoes, at higher altitudes. Use the phase diagram of water as an aid.

In addition to the worksheet and the hints, the students are given a copy of the phase diagram of water, where they can enter their thoughts as a path.



Phase diagram of water.

After the task is completed, practical cooking trials should be conducted using a pressure cooker. Information on cooking times can be found in the pressure cooker instructions or in the collection of recipes for the respective pressure cooker. Due to the danger that may result from potential improper use of a pressure cooker, such trials may be conducted only under teacher supervision.

5 Variations

Reading phase diagrams proves to be quite difficult for many students. To facilitate their accessibility, the class can clarify questions as a group before they work on the task, such as:

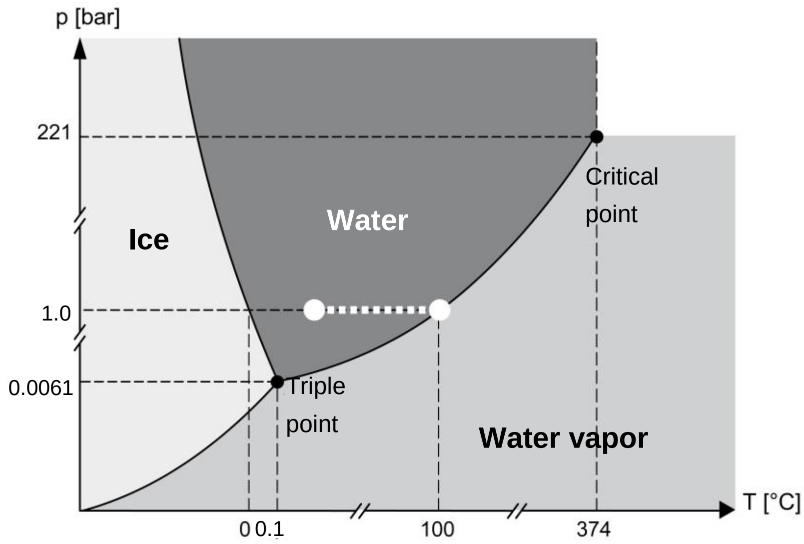
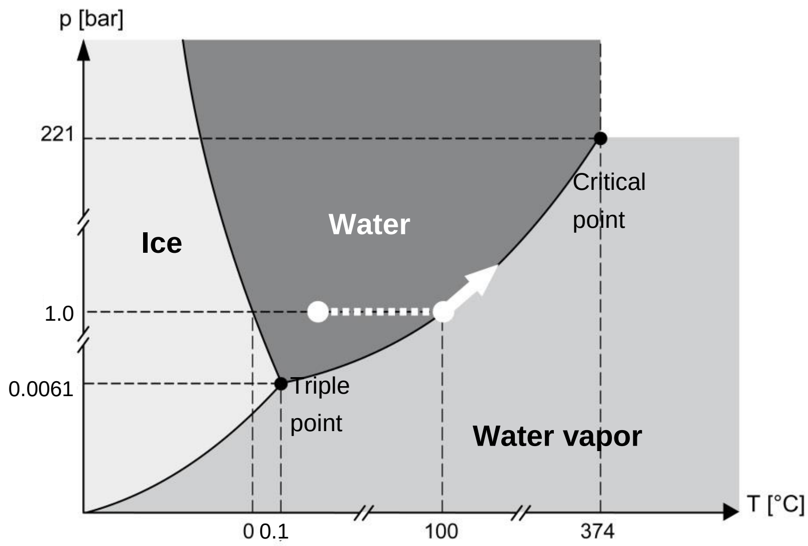
- Our habitat is characterized by temperatures between -20 °C and +40 °C and pressure of approximately 1 bar. Where do you find these conditions on the phase diagram of water?
- Where are you on the phase diagram if you climb Mt. Everest?

It should be noted that practically all representations of the phase diagram of water show non-linear (logarithmically distorted) axes.
At the end of the task, the Q10 temperature coefficient, which is often already familiar from chemistry class, can be studied in more detail.
A related task is the question of how freeze-drying works, although it places somewhat higher requirements on the students. This task is found in the task with incremental hints titled “How does ‘freeze-drying’ work?” available on the media portal of the Siemens Stiftung.

6 Overview of the hints

Note: The hints have been prepared as a separate file for printing or can be used online via the QR codes on the worksheet.

Hint 1 Explain the task to each other again in your own words. State what you understood the task to be and what is still unclear to you.	**Answer 1** We’re supposed to use the phase diagram of water to explain how a pressure cooker works and why it is especially advantageous at higher altitudes.
Hint 2 Write down what you know about how a pressure cooker works.	**Answer 2** A little water is added. Then the cover is sealed and the pot is heated. Overpressure soon builds up in the pot; you can tell by the valve that goes up.

Hint 3 Now refer to the phase diagram of water and draw in what happens until the water starts to boil at 100 °C. Begin at room temperature and normal pressure. What happens after that if even more energy is added?	**Answer 3**  When the water is heated to 100 °C, it begins to boil. If more energy is added, more steam forms and the pressure increases.
Hint 4 Trace the path on the phase diagram for what you think happens next and explain your reasons.	**Answer 4**  When the pressure increases, the temperature must also increase. As long as liquid water and steam are present together, the path must run along the border between the two phases.

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Hint 5

Now you must also find out why a pressure cooker could be useful high up in the mountains.
To do so, look again at the phase diagram.
Where are you on the diagram when you are at an altitude of 2,000 m?

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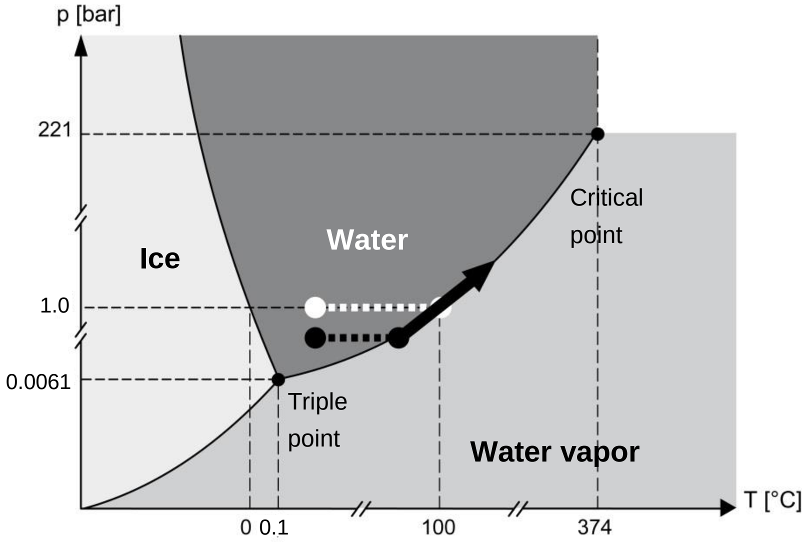
Answer 5



The air pressure is lower at an altitude of 2,000 m than at sea level. That’s why water already begins to boil at a temperature below 100 °C. Cooking potatoes, for example, then takes longer because they are boiling at a lower temperature.
The lower external pressure doesn’t matter in the pressure cooker. The temperature in the pot is above 100°C, and cooking takes less time.

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Hint 6

Now you have all the information you need to answer the question of how a pressure cooker works and why the class really should take it along to the hut.

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Answer 6

In a pressure cooker, the boiling point of water increases to over 100 °C due to the increased pressure, which is why cooking goes faster.
At high altitudes, cooking takes longer in a normal pot because the boiling temperature of water falls below 100°C.
Therefore a pressure cooker is especially advantageous at high altitudes.

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