# How does “freeze-drying” 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 transition of water from the solid phase to the gaseous phase at temperatures below 0°C and at reduced pressure. From an everyday standpoint, it is related to the gentle preservation of foods by removing water when the food is in a deeply frozen state.

## 2 Learning prerequisites and level of difficulty

In addition to knowing about the states of aggregation of water and the transitions between the phases (solid to liquid, liquid to gas, and in the opposite direction), the students should be familiar with sublimation and resublimation as special cases of phase transitions. They should also be familiar with the representation of the phases in a phase diagram. Given these prerequisites, the task has a medium level of difficulty.
In principle, the task can also be worked through on an experimental level: for instance, based on the experience that wet clothes dry even if they freeze on the clothes line when the outside temperature is below freezing (although this experience is less likely to be relevant today).

## 3 Background on the task

Freeze-drying is a gentle process for preserving foods, for example, in the production of soluble instant coffee. However, it is also used in the production of medicines that would decay during heating, as well as in the production of ready-made meals and “space food,” in which water is removed without destroying the structure of the food in question. There are other applications: for example, in the restoration of books after they have been damaged by water or in the drying of archaeological findings, such as wooden parts or textiles recovered from water or wet soils.
In everyday life in the past, the evaporation effect of (frozen) water – as mentioned above – could be observed as laundry dried in winter: At temperatures below the freezing point and in cold but dry air, wet articles of clothing on the clothesline became just as dry as during other seasons, although the drying process took considerably longer.
The basis for the direct transition from the solid to the gaseous state of aggregation is the fact that water cannot become liquid below the triple point, which is at 0.01°C at approximately 6/1,000 bar. Because solid ice also has a measurable steam pressure, the sublimation of water can be accelerated at such low pressures through the careful addition of heat.

## 4 The task

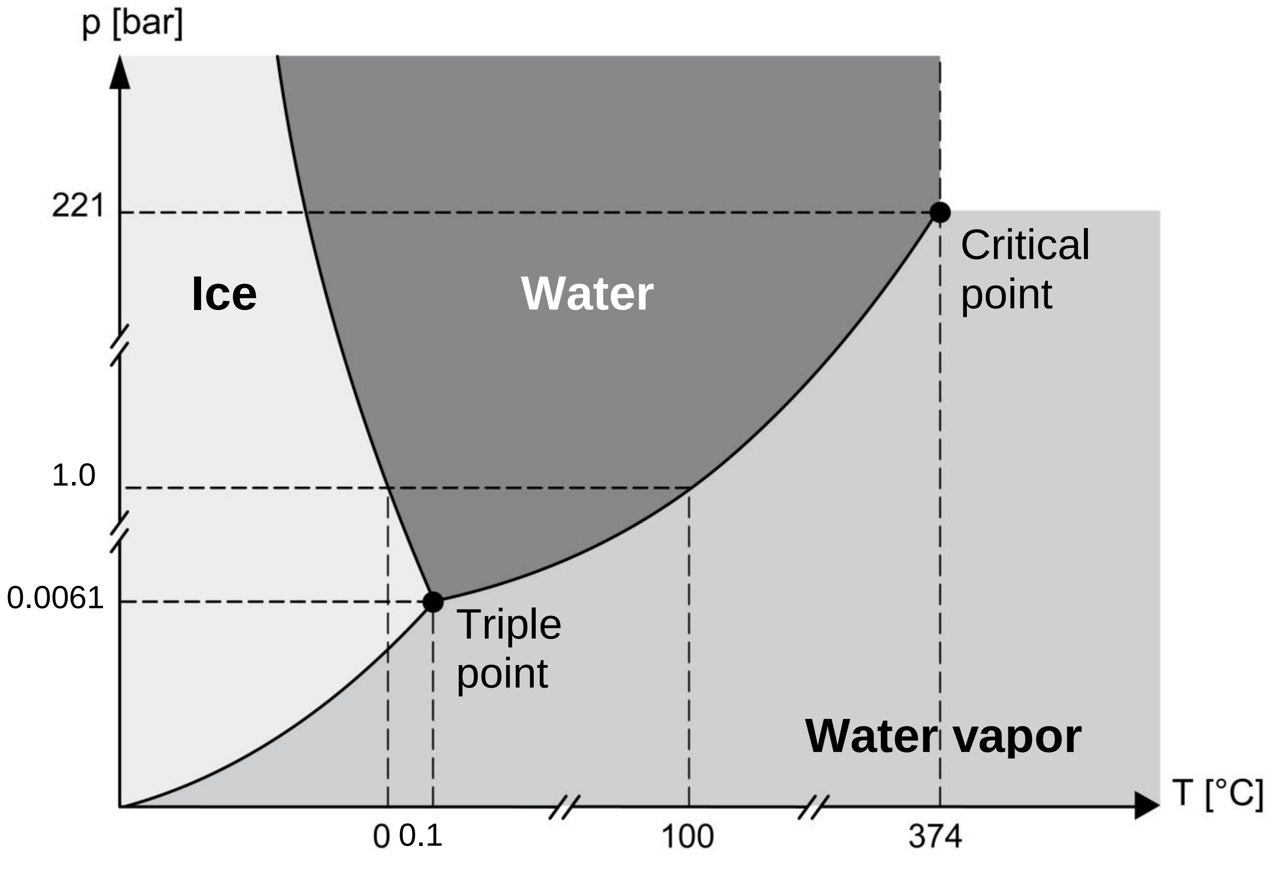
In the simplest form, the task can be formulated as follows:

> Find out how freeze-drying 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:

> Daniel and his friends are planning a camping trip. Daniel is responsible for the food. In a camping gear store, the salesperson recommends freeze-dried ready-made meals that require only boiling water to prepare. Daniel first buys one package of "Creamy chicken with pasta and spinach" and tries it out at home right away. He pours hot water on it, waits a couple of minutes, and tastes it. Not bad at all! Daniel thinks this is so great that he wants to find out right away how freeze-drying works. He reads online "first flash-freeze, then dehydrate at a reduced pressure."
> So far, so good, Daniel thinks, but if the water in the foods has turned to ice, how can it be extracted?

In addition to the worksheet and the hints, the students should also be given a copy of the phase diagram of water, where they can enter their thoughts.




Phase diagram of water.

## 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?
- What happens in a pressure cooker?
- Is there liquid water in space or, more likely, ice or water vapor?

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 teacher may also want to address with the class that because they are not working with pure water, but with solutions, the vapor pressures are different. This results in a shift of the melting and boiling points (decreased melting point, increased boiling point).

## 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.

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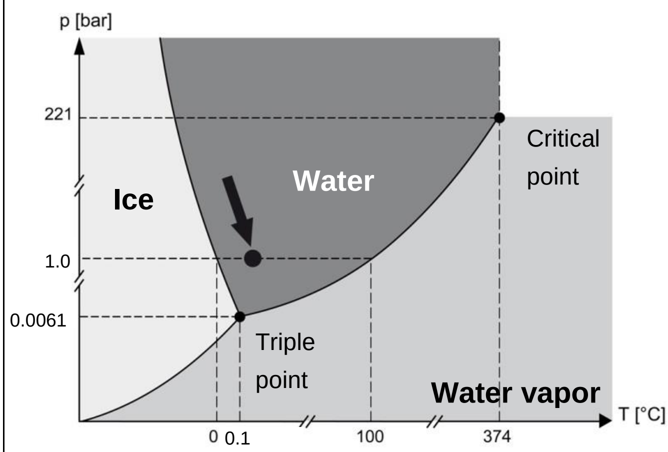
| **Hint 1**<br>Explain the task to each other again in your own words. State what you understood the task to be and what is still unclear to you. | **Answer 1**<br>Using the phase diagram of water, we're sup-posed to explain how freeze-drying works. |
| **Hint 2**<br>It's best for you to trace the freeze-drying path on the phase diagram step by step. Begin at room temperature and normal pressure. | **Answer 2**<br><br>Normal pressure means 1 bar, and we have to estimate room temperature (approx. 20°C) on the diagram. |

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**Hint 3**
The first step is to flash-freeze the food, for example, using liquid air.
Trace the path for this on the phase diagram.

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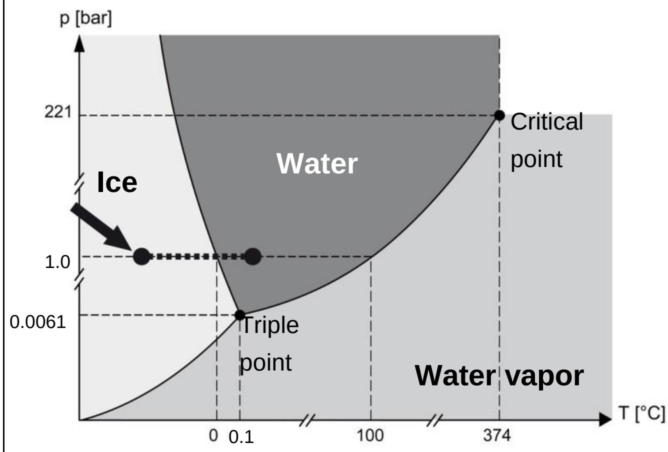
**Answer 3**




During flash-freezing, the pressure remains the same, but all the water has frozen into ice.

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**Hint 4**
Now the pressure is reduced using a vacuum pump.
Trace the further path on the diagram. What does this mean?

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**Answer 4**

At low pressure, only the gas phase and the ice phase are adjacent to each other on the phase

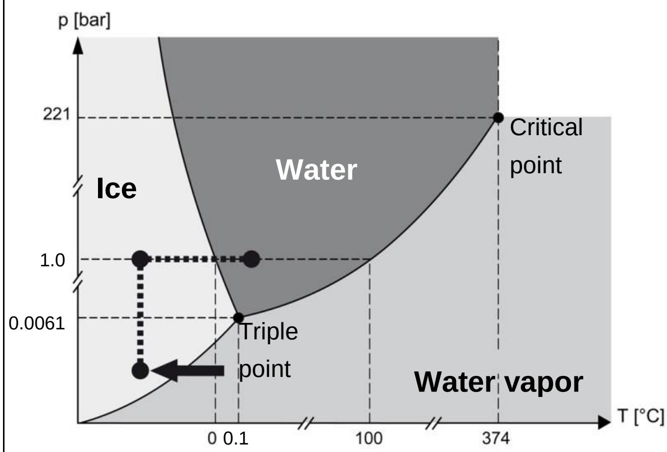


diagram. Now the frozen water cannot melt anymore even if the temperature is increased again.

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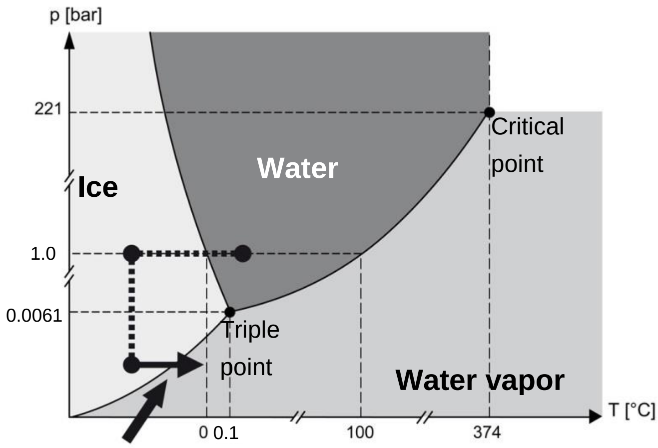
<td>Hint 5<br>You already know that ice still has a certain steam pressure even at extremely low temperatures.<br>What can you do to make the frozen water in the frozen food turn into the gaseous form a little faster?<br>Take a look at the phase diagram for help in finding the answer.</td>
<td>Answer 5<br><br><br>It’s quite simple: You must add energy again to increase the temperature somewhat. Then the frozen water will evaporate from the foods and they become dehydrated.</td>
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<td>Hint 6<br>Now you have all the information you need to answer the question of how freeze-drying works from a physics point of view.<br>Write a short, coherent paragraph.</td>
<td>Answer 6<br>The food to be frozen is quickly cooled to a very low temperature. Then the pressure is reduced using a vacuum pump until the water cannot become liquid anymore. Then the temperature is increased again and the frozen water changes directly to the gas phase; this is how the frozen food is dehydrated.</td>
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