Cooling by evacuation with SMARTsense

Students will be able to understand the cooling by evacuation process.

Physics > Thermodynamics > Temperature & Heat

Difficulty level	Group size	Preparation time	Execution time
medium	2	10 minutes	20 minutes

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General information

Application

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Experimental setup

In the laboratory, water evaporates at an air pressure of 1.013 bar up to a temperature of 100 °C; only above 100 °C water boils. Evaporation is determined by the temperature of the liquid and air pressure.

Evaporation requires energy, which is mainly taken from the evaporated substance. The evaporating liquid cools down in the process. In general: the lower the air pressure, the lower the boiling temperature and the higher the evaporation rate.

In this experiment students examine the correlation between air presse and temperature of a liquid. They determine the temperature curve of water during lowering the air pressure by a vaccuum pump.

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Other information (1/2)

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Prior knowledge

Students should already be familiar with the principles of vacuum, gas pressure and boiling temperatures.

Scientific principle

When the air pressure above a water surface is reduced, the water begins to boil at a certain temperature. The temperature of the water is hereby reduced and further evacuation can finally bring it to 0 °C and even lower.

Other information (2/2)

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Learning objective

Students will be able to understand the cooling by evacuation process. They learn about the influcence of the air pressure on a liquid (and their temperature). Students can explain the cooling effect wih the kinetic gas theory.

Tasks

The students will determine the temperature curve of water during pumping.

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Safety instructions

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- For this experiment the general instructions for safe experimentation in science lessons apply.

Theory

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When a liquid boils, molecules of the liquid exit from the liquid into the gas space above it. The heat of evaporation that is required for this is drawn from the water. To be able to exit from the water, the molecules of the liquid must have a defined kinetic energy that is greater the higher the gas pressure above the liquid is.

According to the kinetic gas theory, the square of the average speed of the molecules of the liquid is proportional to the temperature of the liquid. This means on the one hand that the boiling temperature is reduced at lower gas pressures, and on the other hand that the molecules having the most kinetic energy exit the liquid, so that the temperature of the remaining liquid is reduced. The "hottest" water molecules are pumped off, so that average speed of the molecules of liquid, and so the temperature of the liquid, continually decreases.

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Equipment

Position	Material	Item No.	Quantity
1	Cobra SMARTsense - Temperature, - 40 ... 120 °C (Bluetooth)	12903-00	1
2	Rubber tubing,vacuum,i.d.8mm	39288-00	2
3	Hose clamp for 12-22 mm diameter	41002-00	2
4	Rotary valve vacuum pump, two stages, 115 V / 230 V	02741-95	1
5	Pump plate, complete	02668-88	1
6	Support base DEMO	02007-55	1
7	Bell jar, with knob and sealing ring	02668-10	1
8	Protection cylinder for bell-jar	02668-14	1
9	Beaker, Borosilicate, tall form, 1000 ml	46030-00	1
10	Boiling beads, 200 g	36937-20	1
11	measureAPP - the free measurement software for all devices and operating systems	14581-61	1
12	Felt sheet, 100 x 100 mm	04404-20	2

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Setup and procedure

Setup (1/3)

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To measure the temperature, you need the Cobra SMARTsense Temperature sensor and the measureAPP. Check whether "Bluetooth" is activated on your device (tablet, smartphone) (the app can be downloaded free of charge from the App Store - QR codes below). Now open the measureAPP on your device.

measureAPP for

Android operating systems

measureAPP for

iOS operating systems

measureAPP and

Tablets and PCs with Windows 10

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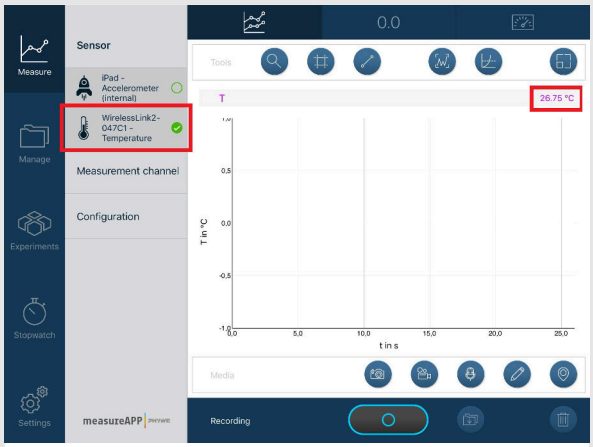
Setup (2/3)



Sensor "Temperature"

- Switch on the SMARTsense sensor "Temperature" by pressing and holding the power button.
- Connect the sensor to the device in the measureAPP under the item "Measure" as shown in the illustration on the left.
- The SMARTSense sensor "Temperature" is now displayed in the app.

Setup (3/3)

Experimental setup

- Set up the experiment as shown in Fig. right.
- Fill about 100 ml of water (room temperature) in the beaker and add two boiling stones.
- Place the beaker on the pump plate and lay the felt sheets under the beaker as insulation.
- Dip the temperature sensor in the water.
- Place the bell jar with rubber sealing ring and the protection cylinder on the pump plate.
- Fit the oil mist filter to the vacuum pump and connect the vacuum pump to the manometer and the pump plate.

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Procedure

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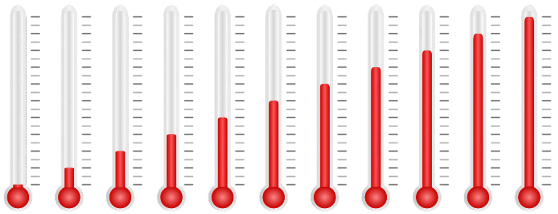
- Start measuring the temperature with clicking on "Start".
- Switch on the vacuum pump and check on the manometer that there is no leak in the vacuum line that would be detrimental to evacuation. The pressure should drop below 100 mbar within the first minute of pumping.
- Switch the vacuum pump off after about 40 minutes.
- End measurement in the app with clicking on "Stop".



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Evaluation

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Evaluation (1/6)

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Results

- It can be seen that the water starts to boil after about 1-2 minutes.
- After about five minutes the water has cooled by about 10°C.
- After about half an hour the temperature of the water reaches the freezing point, a layer of ice starts to form on the water surface.

When a liquid boils, molecules of the liquid exit from the liquid into the gas space above it. The heat of evaporation that is required for this is drawn from the water. To be able to exit from the water, the molecules of the liquid must have a defined kinetic energy that is greater the higher the gas pressure above the liquid is.

Evaluation (2/6)

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According to the kinetic gas theory, the square of the average speed of the molecules of the liquid is proportional to the temperature of the liquid.

This means on the one hand that the boiling temperature is reduced at lower gas pressures, and on the other hand that the molecules having the most kinetic energy exit the liquid, so that the temperature of the remaining liquid is reduced. The "hottest" water molecules are pumped off, so that average speed of the molecules of liquid, and so the temperature of the liquid, continually decreases.

In the last part of the curve (Fig. 2, next slide), a slight rise in the measured temperature can be seen after about 1,800 seconds. The explanation for this is that the water is first supercooled a little, but then the surface froze whereby heat of fusion was released that led to the observed temperature rise measured at the bottom of the vessel.

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Evaluation (3/6)

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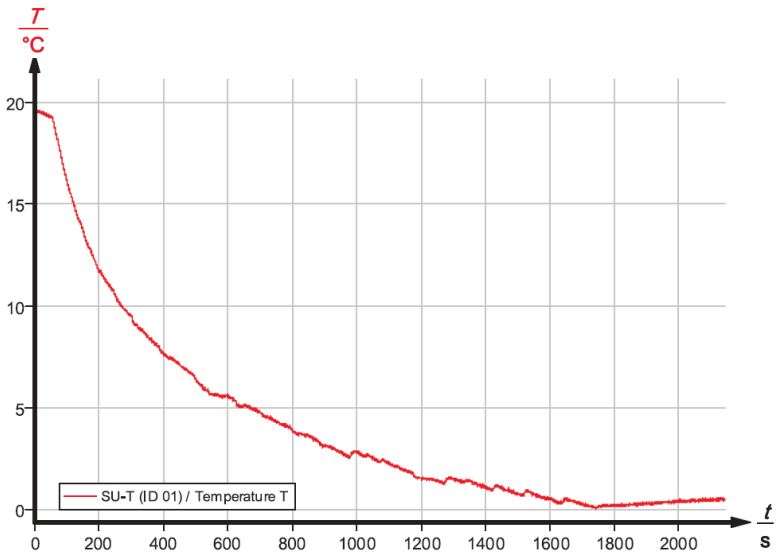

Temperature curve of the water during pumping. The boiling temperature of water is dependent on the pressure of the air that burdens it.

When the air pressure is reduced, the boiling point is also reduced. The boiling water then cools until it finally reaches a point on the steam pressure curve where it is again in equilibrium with the prevailing pressure. Cooling can so finally bring the temperature to below freezing point.

Evaluation (4/6)

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What happens about half an hour after the experiment is started?

- ○ After about half an hour the temperature of the water reaches the freezing point, a layer of ice starts to form on the water surface.
- ○ After about half an hour the temperature of the water reaches room temperature.
- ○ After about half an hour the temperature of the water reaches the boiling point, a layer of steam starts to form on the water surface.

Überprüfen

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Evaluation (5/6)

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What exactly happens, when a liquid boils?

- ○ When a liquid boils, molecules of the liquid exit from the liquid into the ice phase on the surface.
- ○ When a liquid boils, nothing happens except a faster movement of the molecules.
- ○ When a liquid boils, molecules of the liquid ill stop moving around like they do when it freezes.
- ○ When a liquid boils, molecules of the liquid exit from the liquid into the gas space above it.

Überprüfen

Evaluation (6/6)

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Choose the correct answers.

- ☐ The heat of evaporation that is required for the liquid to exit from liquid to gas space is drawn from the water.
- ☐ According to the kinetic gas theory, the square of the average speed of the molecules of the liquid is un-proportional to the temperature of the liquid.
- ☐ According to the kinetic gas theory, the square of the average speed of the molecules of the liquid is proportional to the temperature of the liquid.

Überprüfen

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Slide	Score/Total
Slide 17: After half an hour	0/1
Slide 18: Liquid boiling	0/1
Slide 19: Temperature of the liquid	0/2

Total Score 0/4

Show solutions Retry

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