Problem No. 15

Heat and Temperature

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Struture

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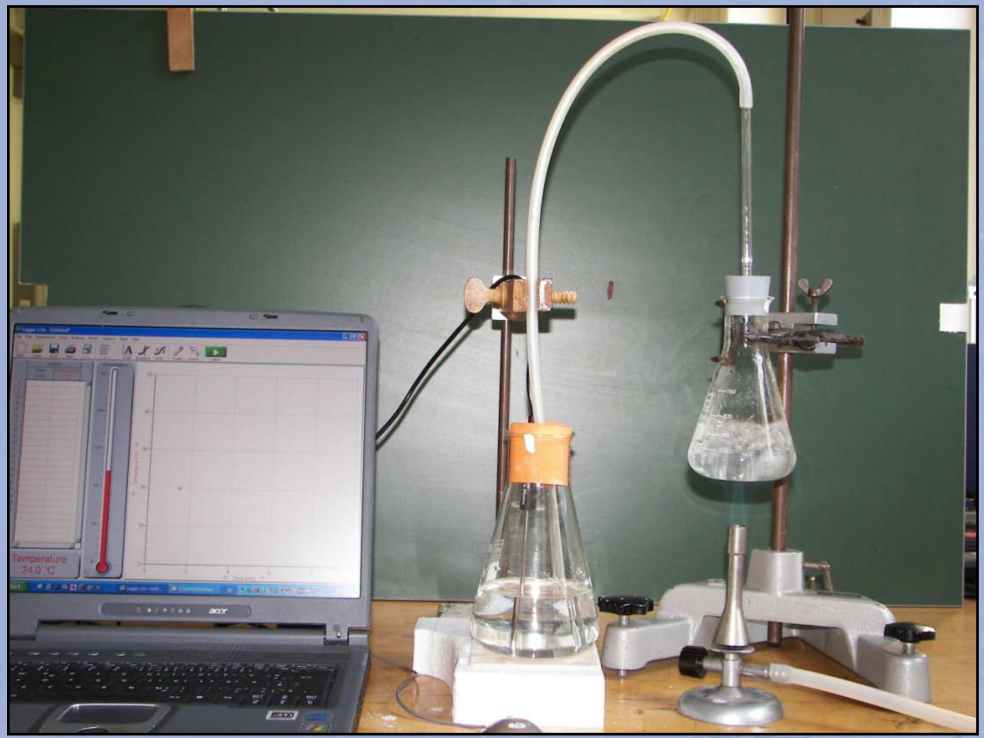
The Task

A tube passes steam from a container of boiling water into a saturated aqueous salt solution. Can it be heated by the steam to a temperature greater than 100°C? Investigate the phenomenon.

Experimental Setup



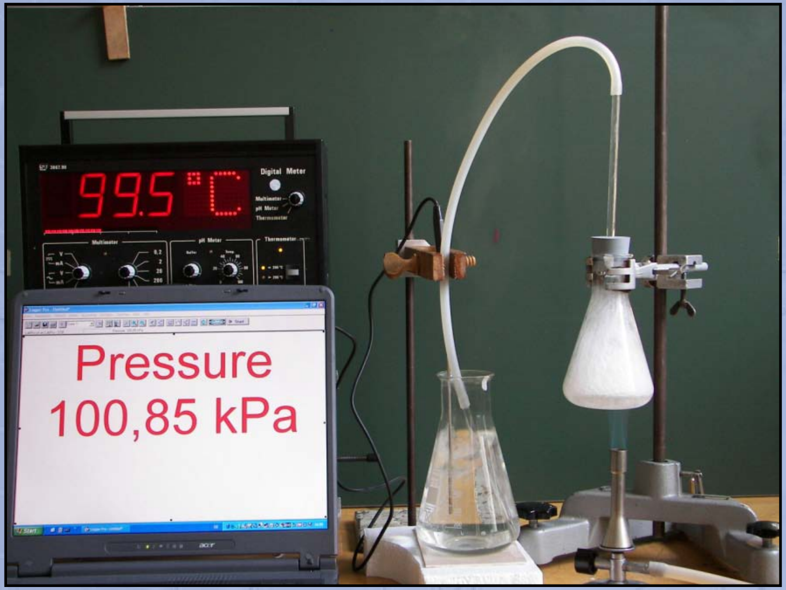
- A tube passes steam from a container of boiling water into a saturated aqueous salt solution.
- The temperature is logged on a PC
- Different solutions are tested

Measurement

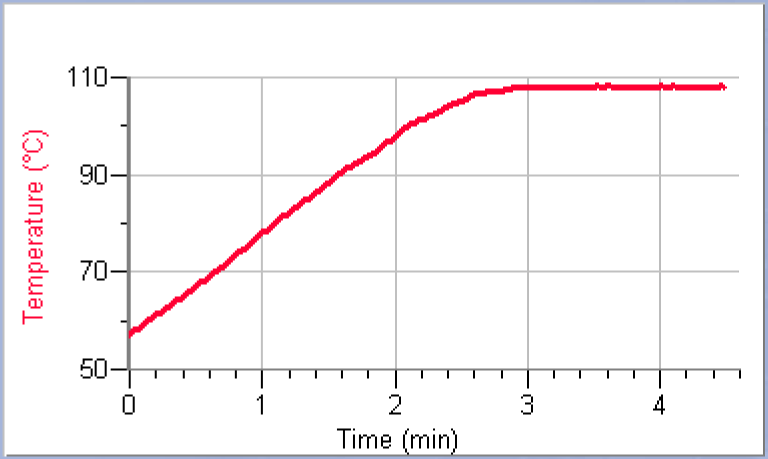
- Conditions: 100,85kPa
  - First test: Pure water: 99.6°C

No standard conditions: pressure < 101.325 kPa => slightly lowered BP

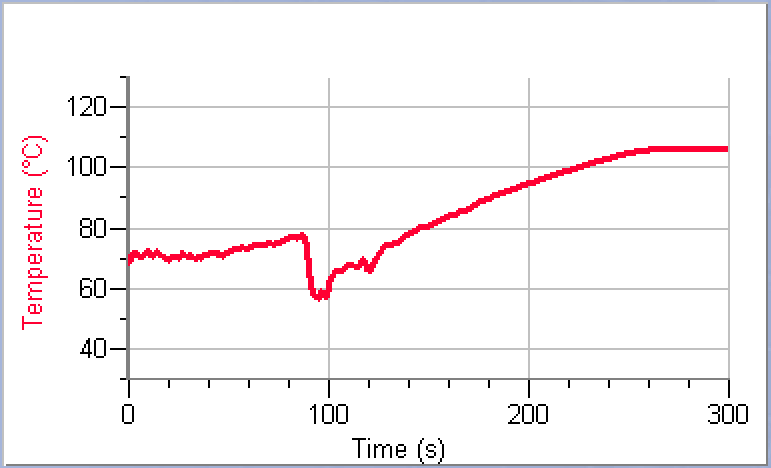
- Saturated solutions of:
  - NaCl: 108.1°C
  - CuSO4 99.9°C
  - KMnO4: 99.8°C
  - Na2SO4: 102.5°C
  - NaNO3: 106.3°C



Graphs



pronounced BP for all solutions depending on solute



Stirring ($NaNO_3$):

The endotherm reaction cools down the solution

Measurement: NaCl

- NaCl gave the best results
- Highest temperature: 108.1°C

- We investigated:
  - 1) Boiling point > 100°C
  - 2) Energy to reach > 100°C (steam < 100°C)

(from now on NaCl is refered to as „salt“)

Boiling point elevation > 100°C

Raoult's law: A solution has a higher boiling point than the pure solvent.

$$\Delta T_{\text{B.P.}} = Kb \times m \times i$$

$$\Delta T_{\text{B.P. salt in water}} = 0.52 \times 6{,}70 \times 2$$

$$= 7°$$

Experiment: 8,5° (99,6° -> 108.1°)

Difference between calculated value and experiment: 1,5°

T...temperatur
m...molality of the solute (mol/kg)
Kb...ebullioscopic constant (depends on solvent)
i… Van't Hoff factor (2 as salt the salt dissociates and separates in anions and cations)

saturated: 28% salt

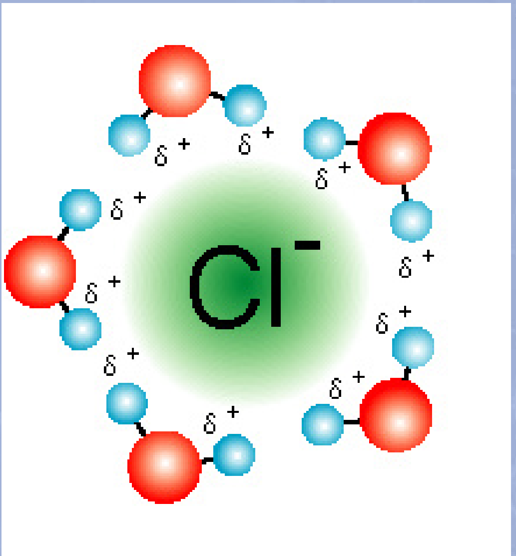
-> 1kg water solves 389g

1 mol salt = 58,4 g

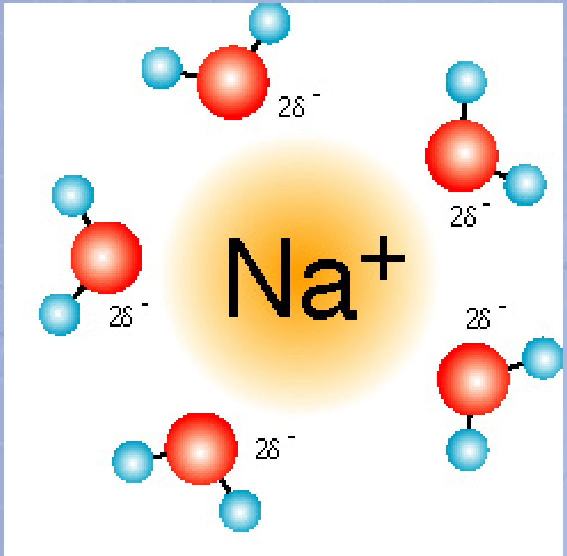
-> 6,7 molality

Boiling point elevation: Salt

When the salt dissociates and separates in anions and cations, water molecules form clusters around it



Slightly positive hydrogen are attracted to chlorine anions



Slightly negative oxygen are attracted to sodium cations

Energy to reach 108°C

saturated salt solution
28% salt, 72% water

$$c_{salt} : 0{,}854 \ {}^{kJ}\!/_{(kg \cdot K)} \qquad c_{water} : 4{,}17 \ {}^{kJ}\!/_{(kg \cdot K)}$$

$$E = Q = m \cdot c \cdot \Delta t$$

$$E = E_1 + E_2$$

$$(m_w + m_s) \cdot c \cdot \Delta t = m_w \cdot c_w \cdot \Delta t + m_s \cdot c_s \cdot \Delta t$$

$$c = \frac{m_w \cdot c_w + m_s \cdot c_s}{m_w + m_s}$$

$$c = \frac{0{,}72 \cdot 4{,}19 + 0{,}28 \cdot 0{,}854}{1} \approx 3{,}26 \ {}^{kJ}\!/_{(kg \cdot K)}$$

8,5° => 8.5 · 3.26 = 27,71 kJ are needed

Values form Halliday/Resnick/Walker:
Physik, extended 6th edition, 2001

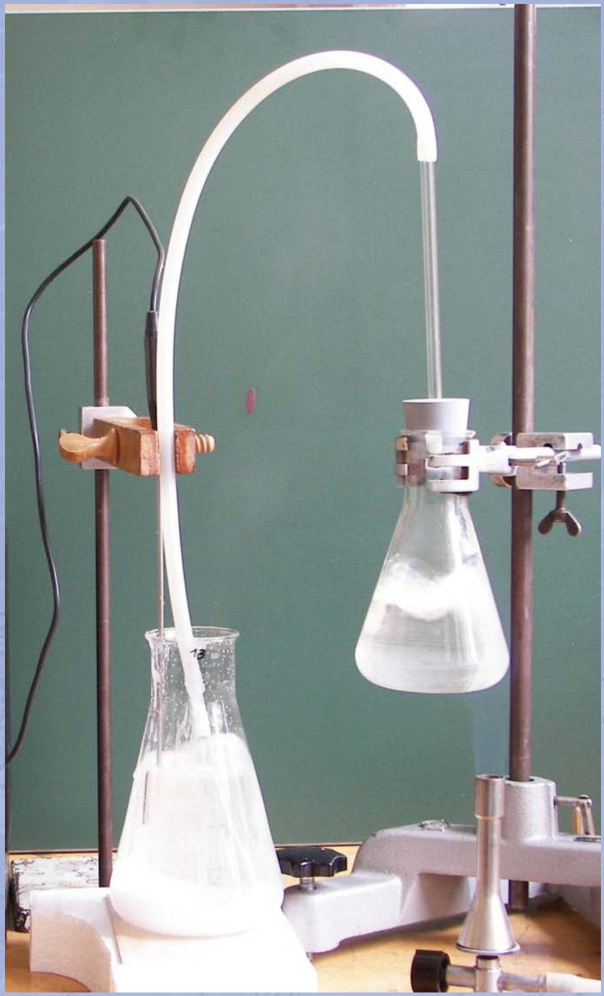
Water condensates, salt is solved

1 mol salt is solved	+3.89kJ
Salt is solved in 1 mol water	+0.479kJ
1 mol water (steam) condensates	-40.7kJ
1 mol water that condensates, salt is solved	-40,221kj

27,71 kJ are needed
1mol water = 18g
18g => 40,221kJ
=> There should be about 12,4g more water after the experiment.

Experiment

- 500g saturated salt solution
- 28% salt
- Measurement:
  - 6,3g more water
  - 12,6g for 1kg



Alternative experiment

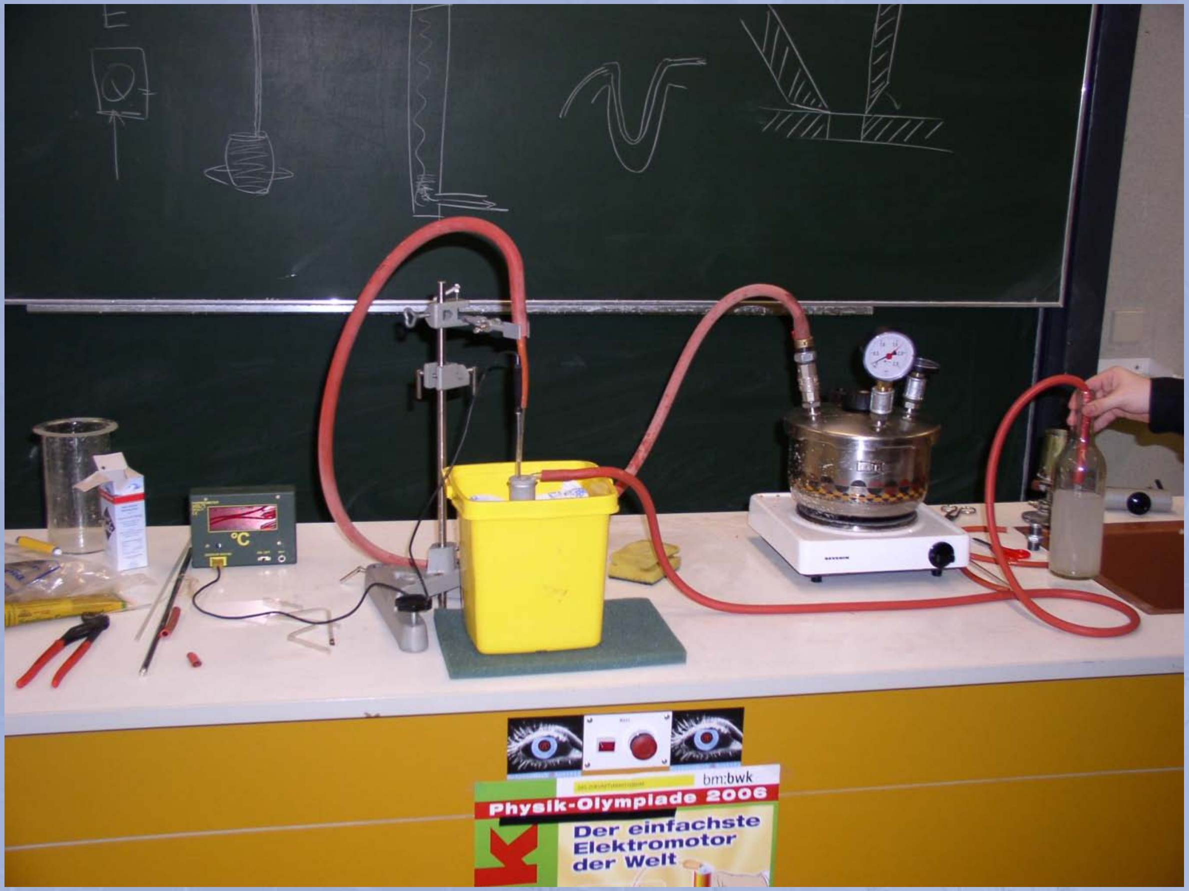
- Higher pressure -> hotter steam
- Temperature should be >100°C when it reaches the container

The Experiment

Pressure cooker
for creating steam

Tube
equiped with thermometer

Container
filled with salt solution
equiped with thermometer



Results

Pot	120 °C
Steam	115 °C
Salt solution	108 °C
Pressure (absolute)	180 kPa

- This way the salt solution can easily be heated by the steam to a temperature greater than 100°C!
- A higher temperature cannot be reached as the BP (108°) does not change

Conclusion

- Yes, it is possible to heat the solution to a temperature greater than 100°C.
- The water's BP is elevated to about 108° when salt is added
- The solution is heated by the energy the condensing steam provides
- 1mol of steam (18g) provides 40,221kJ
- Works faster using a pressure cooker