Vapour pressure of water at high temperature

P2340100

Physics	Thermodynamics	Temperature & Heat
Physics	Thermodynamics	Kinetic gas theory & gas laws

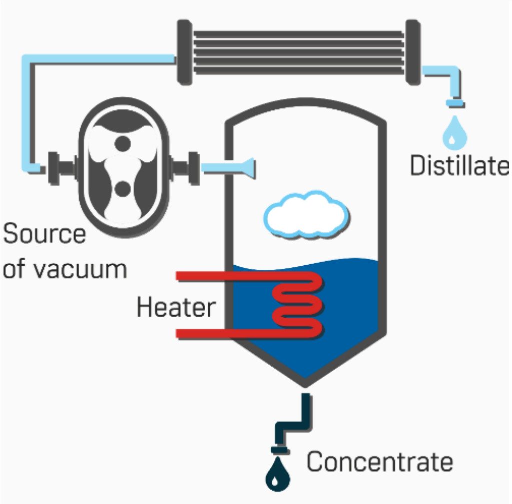
Difficulty level	Group size	Preparation time	Execution time
hard	2	10 minutes	30 minutes

This content can also be found online at:

http://localhost:1337/c/6058db69bb818d00037aa445

General information

Application



Water distillation

Liquid-gas transition can be seen in our everyday life, such as in cooking and formation of clouds. Practically its measurements and applications of heat of evaporation of liquid-gas transition are important in chemistry, chemical engineering and meteorology, for example in separation and purification of chemical compounds, vacuum evaporation and to identify climate change.

Other information (1/2)

PHYWE

Prior knowledge

Heat of vaporisation is defined as amount of energy (enthalpy) that is required for a liquid substance to transform a quantity of that substance into a gas.

Scientific principle

Water is heated in a closed pressure chamber; as much water vaporises as to make the pressure in the chamber correspond to the vapour pressure at the temperature at any time. The heat of vaporisation is determined at various temperatures from the measurement of vapour pressure as a function of temperature.

Other information (2/2)

PHYWE

Learning objective

Understanding the relationship between vapour pressure and temperature for water

Tasks

1. To measure the vapour pressure of water as a function of temperature.
2. To calculate the heat of vaporisation at various temperatures from the values measured.
3. To determine boiling point at normal pressure by extrapolation.

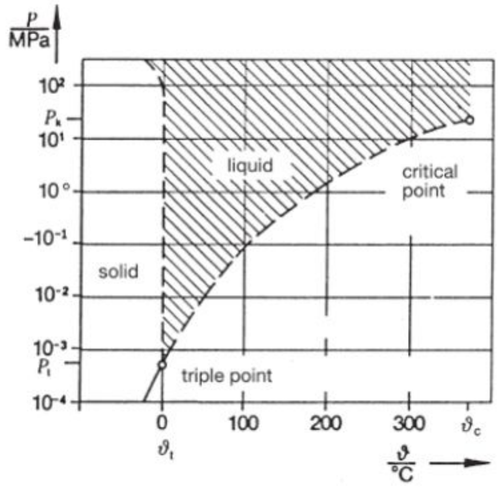
Safety instructions

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

For H- and P-phrases please consult the safety data sheet of the respective chemical.

Do not let heating apparatus come into contact with moisture.

Theory (1/5)



Vapour pressure curve: water

The thermal energy which must be taken up by one mole of liquid, to vaporise at constant temperature is called the molar heat of vaporisation Δ .

At a given temperature T resp. ϑ in degrees Celsius there is a vapour pressure p at which liquid and gaseous phase are in equilibrium. When a liquid boils the vapour pressure is equal to the external (atmospheric) pressure.

Theory (2/5)

The Clausius-Clapeyron differential equation

$$\frac{dp}{dT} = \frac{\Delta}{T\,(V_{vap.} - V_{liq.})} \qquad (1)$$

where $V_{vap.}$ and $V_{liq.}$ are the molar volumes of vapour and liquid respectively and Δ is the heat of phase transition, applies here to the binodal curve bounding two phases.

The phase equilibrium when T and p are constant is governed by the function

$$G = U + pV - TS \qquad (2)$$

where G = free enthalphy, U = internal energy, S = entropy.

Theory (3/5)

Along the binodal curve

$$G_1\,(T, p) = G_2(T, p) \qquad (3)$$

or in differential form

$$\left(\frac{dG_1}{dp} - \frac{dG_2}{dp}\right) dp + \left(\frac{dG_1}{dT} - \frac{dG_2}{dT}\right) dT = 0 \qquad (4)$$

$P_t = 6.1\,hPa$; $\vartheta_t = 0.01^{\circ}C$

$P_t = 22.12\,MPa$; $\vartheta_c = 374.2^{\circ}C$

Theory (4/5)

PHYWE

With

$$\frac{dg}{dT} = -S \text{ and } \frac{dg}{dT} = V \qquad (5)$$

It follows from (3) that

$$(V_2 - V_1)\,dp = (S_2 - S_1)\,dT \qquad (6)$$

The difference in entropy between the two phases can be expressed by the reversible latent heat of transformation

$$S_2 - S_1 = \frac{\Delta}{T} \qquad (7)$$

(6) and (7) together give (1) for the binodal curve between the liquid and the vapour phase.

Theory (5/5)

PHYWE

At low vapour pressures $p \ll pc$, $V_{liq.} \ll V_{vap.}$ can be disregarded. In this range the vapour behaves very like an ideal gas and

$$V_{vap.} = \frac{RT}{p} \qquad (8)$$

where R = 8.3141 J/(K·mol), the universal gas constant. From (1), therefore:

$$\frac{dp}{p} = \frac{\pi}{R} \cdot \frac{dT}{T^2} \qquad (9)$$

Assuming Δ to be constant, by integrating we obtain the Van't Hoff equation

$$ln\,p = -\frac{\Delta}{R} \cdot \frac{1}{T} + const\ . \qquad (10)$$

Equipment

Position	Material	Item No.	Quantity
1	High pressure vapour unit	02622-10	1
2	Heat conductive paste, 60 g	03747-00	1
3	Heating apparatus for glass jacket system	32246-93	1
4	Pipette with rubber bulb, long	64821-00	1
5	Tripod base PHYWE	02002-55	1
6	Boss head	02043-00	1
7	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
8	Lab thermometer,-10..+250C	38065-00	1

Equipment

Position	Material	Item No.	Quantity
1	High pressure vapour unit	02622-10	1
2	Heat conductive paste, 60 g	03747-00	1
3	Heating apparatus for glass jacket system	32246-93	1
4	Pipette with rubber bulb, long	64821-00	1
5	Tripod base PHYWE	02002-55	1
6	Boss head	02043-00	1
7	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
8	Lab thermometer,-10..+250C	38065-00	1

Additional equipment

Position	Material	Quantity
1	Distilled water	1

Setup and procedure

Setup

Experimental set-up

Set up the experiment as shown in the figure.

Procedure

Fill the high pressure steam unit with distilled water, with the aid of a pipette, ensuring that there are no air bubbles in the line leading to the pressure gauge.

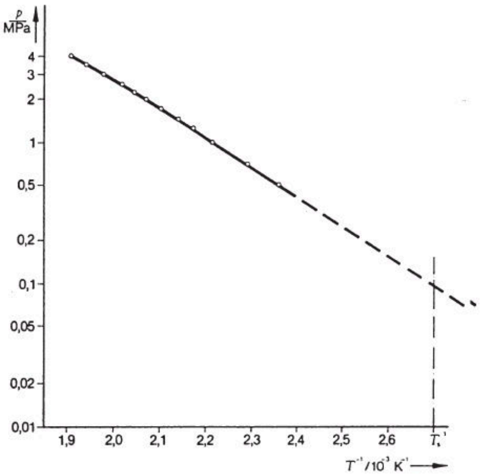
Now screw the vessel together carefully (the lead seals may need replacing).

The unit is fastend with a bosshead and lays on the electric heater. Put the thermometer in the hole provided, which should be filled with heat conductive paste.

Heat the pressure vessel until the gauge reads 4 MPa 40 bar. Now switch off the heater and record the pressure and temperature as the equipment cools down.

Check the locking screws from time to time while the equipment is being heated and cooling down and tighten them if necessary.

Evaluation (1/3)



Natural logarithm of vapour pressure p as a function of the reciprocal of the temperature (1/T)

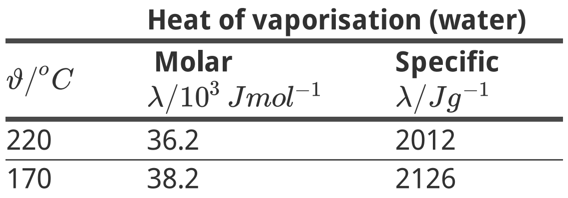
The semi-logarithmic plot of the measured values shows an almost linear relationship between $ln\,p$ and $1/T$.

By extrapolating the straight line in the low temperature range we can read off the boiling point of water at normal pressure, T_b The measurements we have taken give:

$$\vartheta_b = 97\ ^\circ C$$

The boiling point determined by extrapolation is too low because the curve for $ln\,p = f(T)$ is slightly convex owing to differences in the heat of vaporisation.

Evaluation (2/3)



Heat of vaporisation (water)

$\vartheta/^oC$	**Molar** $\lambda/10^3\ Jmol^{-1}$	**Specific** λ/Jg^{-1}
220	36.2	2012
170	38.2	2126

Heat of vaporisation of water

By fitting to a regression line in the ranges 190 °C – 250 °C and 150 °C – 190 °C, for example, we obtain the heat of vaporisation at 220 °C and 170 °C.

Evaluation (3/3)

Fill in the missing words

Molar heat of vaporisation is the thermal energy which must be taken up by one ______ of liquid, to vaporise at constant temperature. Specific heat of vaporization is defined as the amount of heat needed to vaporise one ______ of a liquid at constant temperature of the liquid.

Check

The heat of vaporization always has ________ values.

○ positive

○ positive and negative

○ negative

Check