

# Vapor pressure of water at high temperature

- **Related topics**

Boiling point, heat of vaporization, Clausius-Clapeyron equation, Van't Hoff law, Carnot cycle.

- **Principle**

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

- **Equipment**

High pressure vapor unit	1
Heat conductive paste, 50 g	1
Heating apparatus	1
Pipette, with rubber bulb, long	1
Tripod base -PASS-	1
Bosshead	1
Support rod, stainless steel, l= 250 mm	1



*Fig. 1: Experimental set-up for measuring vapor pressure as a function of temperature.*

- **Tasks**

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

- **Set-up and procedure**

Set up the experiment as shown in Fig. 1. 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 fastened with a boss-head 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.

- **Theory and evaluation**

The thermal energy which must be taken up by one mole of liquid, to vaporize at constant temperature is called the molar heat of vaporization. At a given temperature  $T$  respectively  $\vartheta$  in degrees Celsius there is a vapor pressure  $p_{at}$  which liquid and gaseous phase are in equilibrium (Fig. 2). When a liquid boils the vapor pressure is equal to the external (atmospheric) pressure. The Clausius-Clapeyron differential equation

$$\frac{dp}{dT} = \frac{\Lambda}{T(V_{vap} - V_{liq})} \quad (1)$$

where  $V_{vap}$  and  $V_{liq}$  are the molar volumes of vapor and liquid respectively and  $\Lambda$  is the heat of phase transition, applies here to the bi-nodal curve bounding two phases.

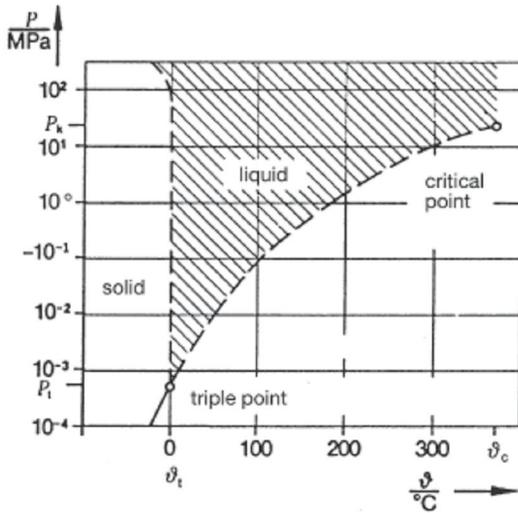


Fig. 2: Vapor pressure curve: water

$$p_t = 6.1 \text{ hPa} \quad \vartheta_t = 0.01^\circ \text{C}$$

$$p_c = 22.12 \text{ MPa} \quad \vartheta_c = 374.2^\circ \text{C}$$

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

$$V_{\text{vap}} = \frac{RT}{p} \quad (2)$$

where  $R = 8.3141 \text{ J/K}\cdot\text{mol}$ , the universal gas constant.  
From (1), therefore:

$$\frac{dp}{p} = \frac{\Lambda}{R} \cdot \frac{dT}{T^2} \quad (3)$$

Assuming  $\Lambda$  to be constant, by integrating we obtain the Van't Hoff equation

$$\ln p = -\frac{\Lambda}{R} \cdot \frac{1}{T} + \text{const.} \quad (4)$$

The semi-logarithmic plot of the measured values (Fig. 3) shows an almost linear relationship between  $\ln p$  and  $\frac{1}{T}$ . The heat of vaporization changes with the temperature.

By fitting to a regression line in the ranges  $190^\circ\text{--}250^\circ\text{C}$  and  $150^\circ\text{--}190^\circ\text{C}$ , for example, we obtain the heat of vaporization at  $220^\circ\text{C}$  and  $170^\circ\text{C}$  by computing the slope of the line times  $R$ .

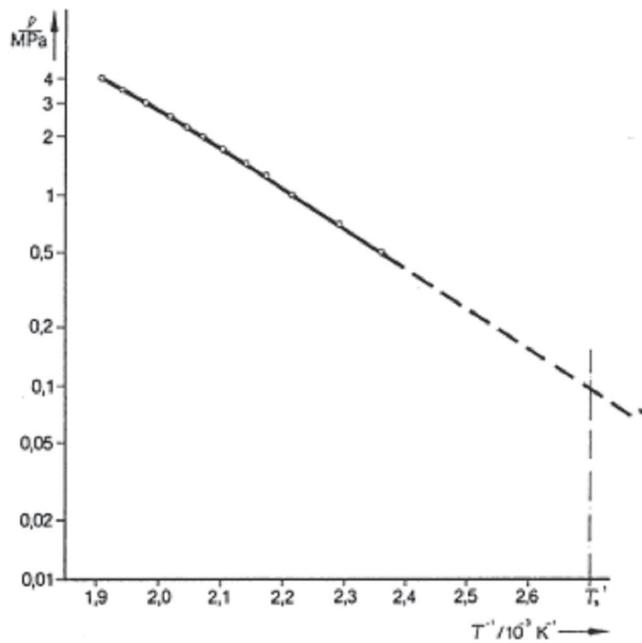


Fig. 3: Natural logarithm of vapor pressure  $p$  as a function of the reciprocal of the temperature ( $1/T$ ):  $T_b$  = boiling point at normal pressure.

Heat of vaporization (water)		
$\vartheta(^{\circ}\text{C})$	Molar $\Lambda / 10^3 \text{ J} \cdot \text{mol}^{-1}$	Specific $\lambda / \text{J} \cdot \text{g}^{-1}$
220	36.2	2012
170	38.3	2126

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:

$$\vartheta_b = 97^{\circ}\text{C}$$

The boiling point determined by extrapolation is too low because the curve for  $\ln p = f(T)$  (Fig. 3) is slightly convex owing to differences in the heat of vaporization.