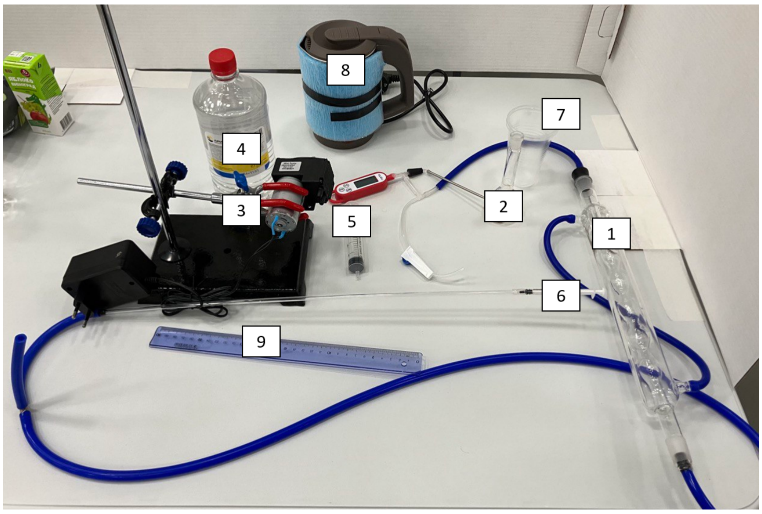
МИНИСТЕРСТВО ПРОСВЕЩЕНИЯ РОССИЙСКОЙ ФЕДЕРАЦИИ · KIPhO · МФТИ · ГИМНАЗИЯ ИМ. Е. М. ПРИМАКОВА · ВКУСВИЛЛ

M1A - Don't superheat

Equipment:

1. Vacuum system with a valve, thermometer, cooler, and capillary.
2. Flask 50 ml with sand
3. Pump with 12 V power supply
4. Bottle of isopropyl alchohol
5. Syringe 20 ml
6. Syringe 1 ml
7. Two plastic cups
8. Kittle with water, which operates like a calorimeter with controlled temperature.
9. Ruler

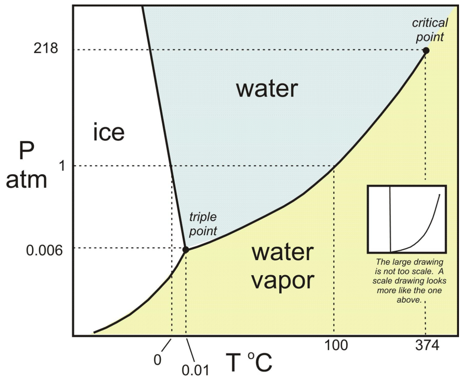


If, during a gradual change in an external parameter, the properties of a physical system change abruptly, such a phenomenon is called a **phase transition**. When a physical system depends on two parameters, X and Y, one can plot all pairs of parameters (X, Y) at which phase transitions occur. The resulting curves formed by these points will divide the X, Y plane into several phases.

In this problem, using the example of isopropyl alcohol (hereinafter referred to as IPA), we will study the liquid **(L)** $\leftrightarrow$ gas**(G)** phase transition in (p, T) coordinates. Although IPA is a common antiseptic, it must **never be ingested**! Additionally, one should avoid inhaling IPA vapors, as they can cause headaches.

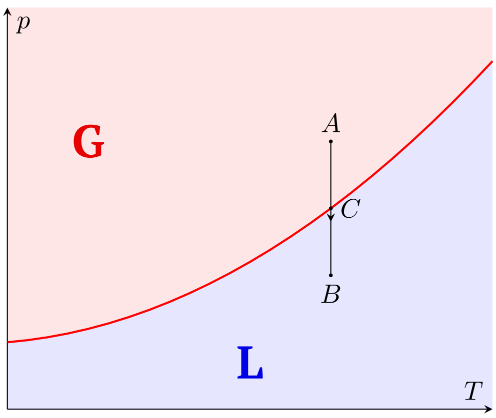
The boiling point of IPA at atmospheric pressure $p_0 = 101$ kPais approximately $83°$C.

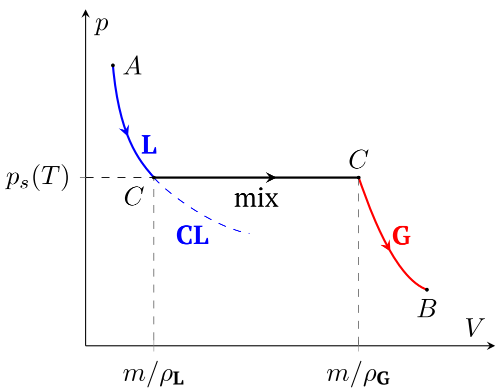
It turns out that the shape of the phase transition curve (p, T) is related to the **specific heat of vaporization** L (per unit mass) through the **Clapeyron-Clausius law**.



Phase diagram of water in p, T coordinates.

This law could by derived using only very general ideas. Consider the isotermical with temperature T compression from point A to point B.





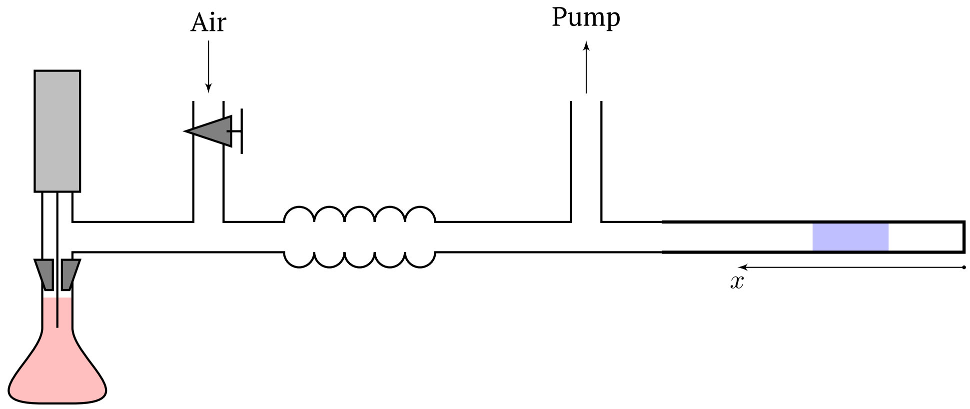
When the pressure is above saturated vapor pressure $p_s(T)$ the curve in p, V coordinates is the isotherm of the liquid **L** and its shape doesn't matter. When the pressure is equal to $p_s(T)$ the process is horizontal line in p, V

coordinates. This line corresponds to equilibrium mixtures of **G** and **L** in different proportions. When the pressure is below $p_S(T)$ the curve is the isotherm of **G**. We will assume that the gas phase obeys the ideal gas law:

$$pV = \frac{m}{\mu}RT,$$

where μ is the molar mass of the gas molecules, and $R = 8.314\ \mathrm{J/(K \cdot mol)}$ is the universal gas constant.

A1 Draw curves of process like A→B for two different temperatures: T и $T + dT$ in p, V coordinates. hoose a cycle for which Carnot's theorem can be applied to derive the relationship between $dp_s = p_s(T + dT) - p_s(T)$ and dT. The answer may include the pressure p_s, temperature T, specific heat of vaporization L, molar mass of the molecules μ and the density of the liquid phase $\rho_{\mathbf{L}}$. **2.0**



A schematic of the setup is proposed, as shown above. The left outlet has an adjustable valve that allows regulating the pressure inside the system. The right outlet is connected to a vacuum pump. To measure the pressure, it is proposed to use a gas manometer with a droplet inside the capillary. **Be very careful with the thermometer! A new vacuum system will not be provided.**

A2 Determine the minimum pressure $p_{\min}$ that the pump can reach in the vacuum system. For the air trapped in tha gas manometer the Boyle's law $pV = \mathrm{const}$ take place. The cylinder in the valve sometimes slips out of its grooves, so make sure that the valve, when in the closed position, completely blocks the airflow. **1.0**

Real physical systems are not always in a state of equilibrium. For example, IPA often exhibits a superheated state: that is, when, according to the phase diagram, it should be in a gaseous state, but it remains in a metastable liquid state. To make superheated IPA in the flask evaporate, shake it. The sand in the flask is added for the same purpose.

A3 Obtain the most accurate value of the IPA boiling temperature under atmospheric pressure. **1.0**

A4 Measure the dependence of T on p_s for not fewer than 10 values of $p_s < p_0$
To do this, use the following measurement scheme. At atmospheric pressure, heat the IPA inside the flask to a temperature that is definitely higher than the boiling point at the studied pressure p_s. Then, using the valve, set the pressure in the system to p_s and observe the temperature drop in the flask. If the temperature reaches a plateau and the boiling process does not start even after shaking, then the indicated temperature is the boiling point. **4.0**

Molar mass of IPA is $\mu = 60.1\ \mathrm{g/mol}$. Density of liquid IPA is $\rho_{\mathbf{L}} = 0.786\ \mathrm{g/cm^3}$.

A5 Graph the plot of T versus p in such coordinates that it should be linear. **1.0**

A6 Using the plot from the question **A5** obtain the value of the specific heat of IPA vaporization L. **1.0**