Temperature

- Temperature scale was originally defined by how much mercury expands between the freezing and boiling points of water, defined as $0°C$ an $100°C$.

$$T_C = C_1 \frac{\Delta V}{V_0} + C_2$$

Traditional thermometers work by monitoring volume changes

- Inbetween $0°C$ and $100°C$ a thermometer based on mercury and one based on Alcohol gave slightly different answers.

Ideal gas thermometers: work by measuring how pressure changes (at constant volume)

- For low densities, it was found that the ratio of pressures $P_{steam} / P_{freezing}$ at constant volume was nearly the same independent of the gas type. It thus gave a universal (gas independent) scale

(Psteam = Pressure at boiling point of water)

$$\star \quad T = T_{ref} \frac{P}{P_{ref}} \qquad \text{(const volume)}$$

So we need to pick a reference temperature, measure gas pressure at very low density (so $P_{ref} \to 0$), then, keeping the volume of gas fixed, measure the press. at some other point. This defines the temperature using $\star$

- In practice, the reference temperature was when the temperature when water, ice and water vapor are in equilibrium, the triple point.

T_{ref} was chosen to be $273.16\,^\circ K$ to agree with the Celsius scale and Celsius' definition of degree as a unit between freezing and boiling

- All other thermometers, were then calibrated against the ideal gas one. For instance, one could measure the resistance of platinum, this resistance varies with temperature, and thus knowing the resistance determines the temperature, Platinum Resistance Thermometry (PRT)

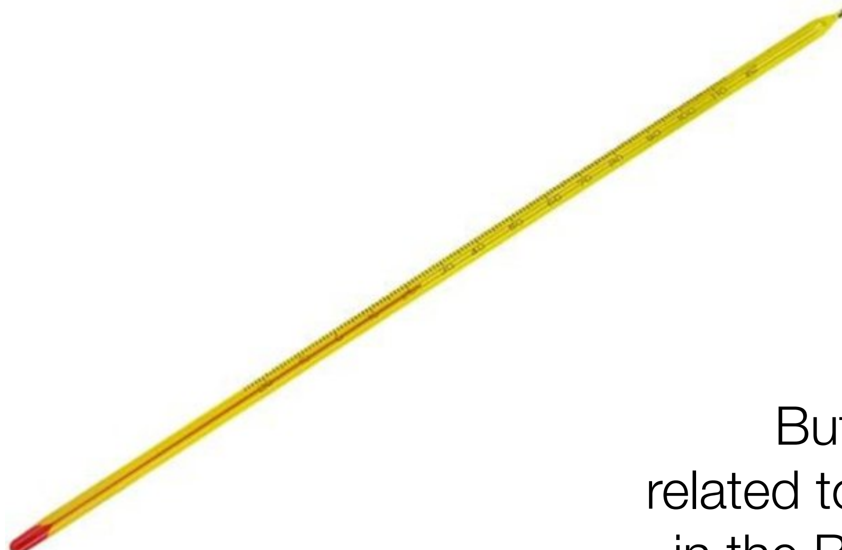
- Slides

  1. How to measure pressure at constant volume
  2. The triple point of water
  3. Measuring the temperature of Steam
  4. A Platinum resitance thermometer.

Temperature define by the volume expansion of mercury

$$T_{\text{Celsius}} = C_1 \Delta V / V + C_2$$

The constants are chosen so that freezing is 0 and boiling is 100.



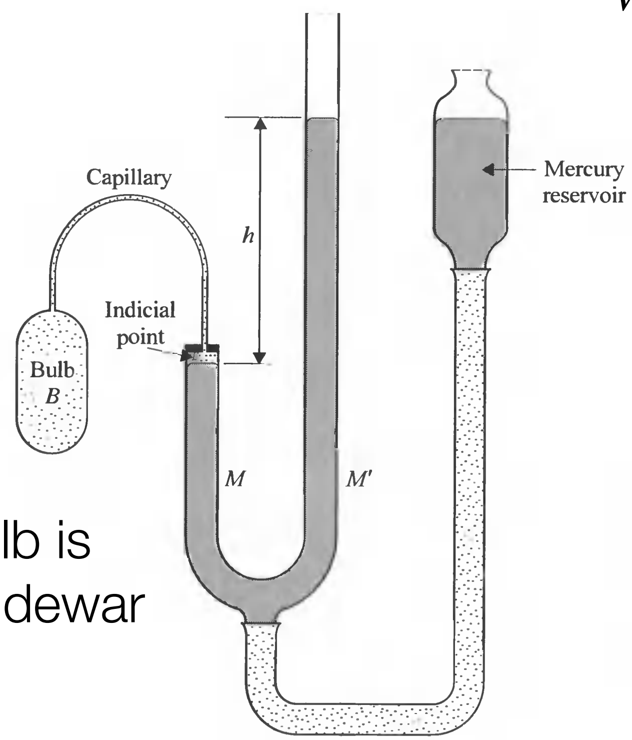
But how is this
related to the temperature
in the Boltzmann factor,
$e^{-\epsilon/k_B T}$?

The constant volume gas thermometer

Changes in pressure in the bulb (at constant volume) defines a temperature scale:

$$T_V \equiv T_{\text{ref}} \frac{P}{P_{\text{ref}}}$$

T_{ref} is a conventional constant



Gas bulb is placed in dewar

Place the bulb in the sample. If the sample is hot, then the gas will try to expand. But we can then increase the height of the mercury column h, increasing the pressure on the gas, to keep the volume of the gas fixed (at the indicial point). The pressure of the gas can be measured from the height of the mercury column.

The measured pressure P relative to a reference point P_{ref} defines the temperature scale.

The temperature scale depends weakly on the density of gas in the bulb, and the type of gas.

The triple point of water is used as the reference point.

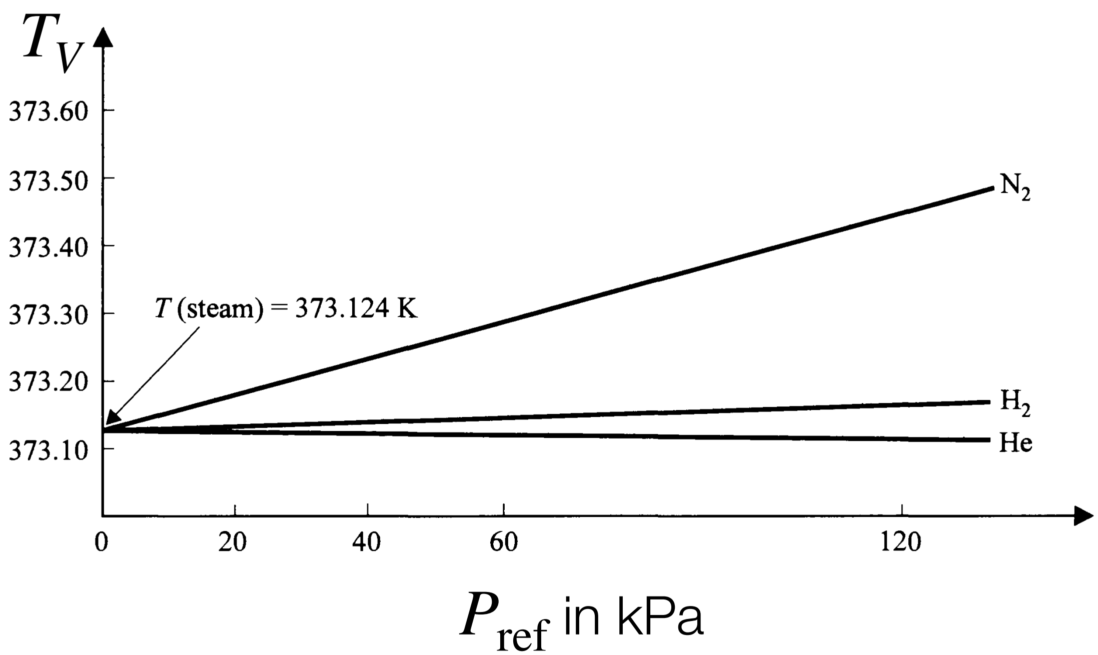
This is the temperature and pressure where ice, water, and vapor are in equilibrium

The gas bulb at a given density (see previous slide) is surrounded by water at the triple point, and then its pressure, P_{ref}, is measured.

At the triple point, $T_{\text{ref}} \equiv 273.16\,\text{K}$, was defined to have agreement with the celsius and gas thermometers.

An example: measuring the temperature of steam

$$T_V \equiv 273.16 \, \frac{P_{\text{steam}}}{P_{\text{ref}}}$$

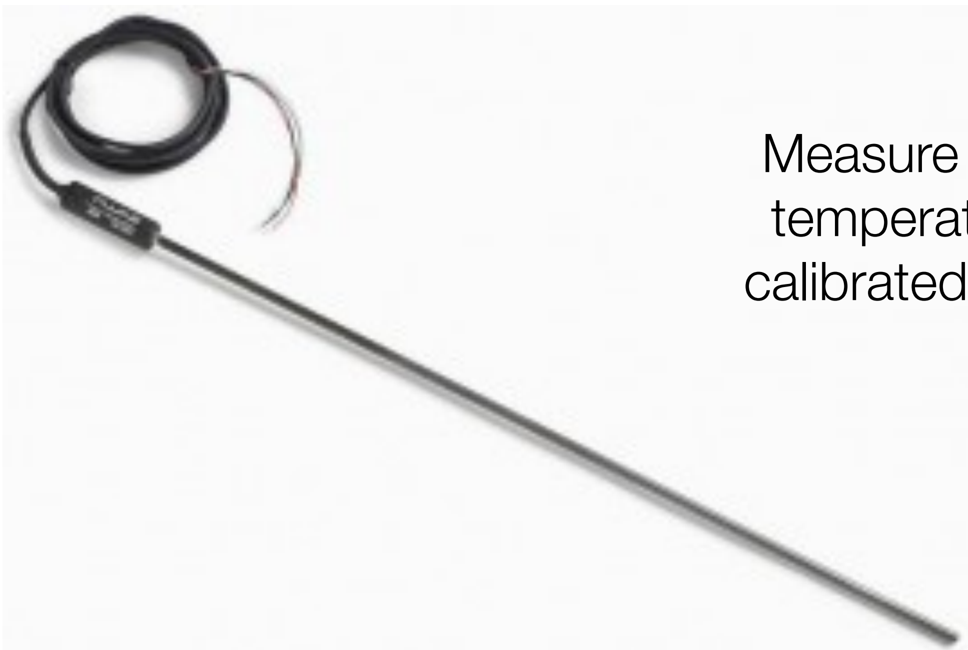


T_V depends weakly on the gas used, and the density in the bulb or P_{ref}, because no gas is ideal.

The pressure in the gas bulb at the triple point P_{ref} is lowered (by reducing the number of atoms in the bulb), extrapolating to the ideal gas limit (infinitely low density).

In the limit, all gasses give the same value for the T_V parameter, which is what we call T that appears in the Boltzmann factor, $e^{-\epsilon/k_B T}$.

Platinum Resistance Thermometer $4500



Measure the resistance as a function of temperature. This temperature scale is calibrated against some kind of ideal gas thermometer