A. Constant Volume Gas Thermometer

Working principle: If the volume of a fixed mass of gas is kept constant, its pressure changes with temp. and ∴ can be used as a thermometric property.

Constant volume gas temp. scale:

- On the centigrade scale:

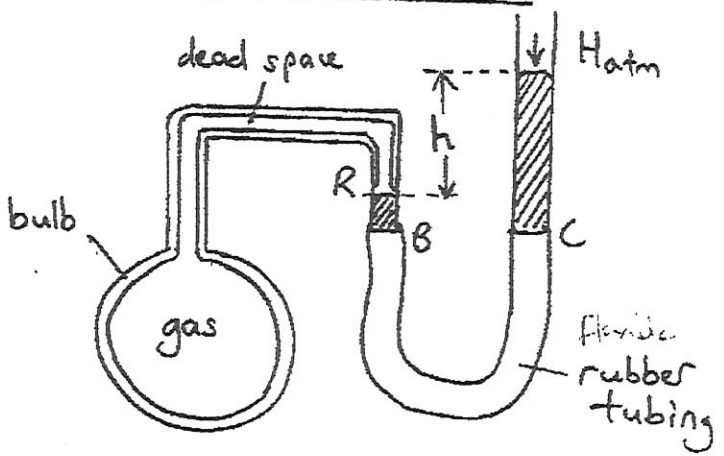
$$t/°C = \frac{P_t - P_0}{P_{100} - P_0} \times 100$$

P may be substituted for by V (at const. P) or PV (at varying P and V).

- On the Kelvin scale,

$$T/K = \frac{P_T}{P_{tr}} \times 273.16$$

Measurement of Pressure.



i). Gas used: He or H_2 or N_2

ii). Put bulb into temp. to be measured.

iii). Gas expands pushing Hg in B down.

iv). Restore Hg level in B to reference mark R to keep volume of gas constant.

v). Gas pressure,

$$P = (H_{atm} + h) \text{ cm Hg.}$$

Useful range: 3 K to 1750 K

Advantages: i) very accurate
ii) very sensitive
iii) wide range
iv) highly reproducible

Disadvantages: i) cannot measure temp of solid
ii) indirect reading
iii) bulky & cumbersome

N.B. For very accurate work, corrections must be made for ①. thermal expansion of bulb
②. gas in 'dead' space not being at same temp as bulb

Ideal Gas Scale

obeys the ideal gas equation of state separately

Thermometric substance: a fixed mass of ideal gas.

Thermometric property:

i). product pV

ii). pressure, p, if volume is kept constant.

Fixed points: i). lower fixed pt: absolute zero, 0 K

ii) upper fixed pt: temp. of triple pt. of water 273.16K

For an ideal gas,

$$pV = nRT$$

(T: thermodynamic temperature in K

n: no. of moles,

R: molar gas constant)

∴ for a fixed mass of ideal gas,

$$pV \propto T$$

$$\therefore \frac{(pV)_T}{(pV)_{tr}} = \frac{T_T}{T_{tr}} = \frac{T}{273.16}$$

tr = triple pt of water

$$\therefore T = \frac{(pV)_T}{(pV)_{tr}} \times 273.16$$

N.B. Always state the temp. scale used when giving a temp

eg. 75°C on the mercury-in-glass scale.

Thermodynamic (Kelvin) Scale.

∴ We need a standard scale to express temp.

It must be independent of the thermometric properties of any particular substance.

⟶ Absolute thermodynamic scale or Kelvin scale

i). theoretical scale

ii). totally independent of any substance.

iii). however can't be realised

iv). but shown to be identical to the ideal gas scale.

$T/K = t/°C + 273.15$

If volume of gas is kept constant,

Cancel V

then $T = \frac{P_T}{P_{tr}} \times 273.16$

$\frac{P_t}{P_{tr}} = \frac{T}{273.16}$

An ideal gas does not exist; it is however found that real gases at low pressures behave like ideal gases, such that temperature scales using different real gases give close agreement over a wide range of temperature.

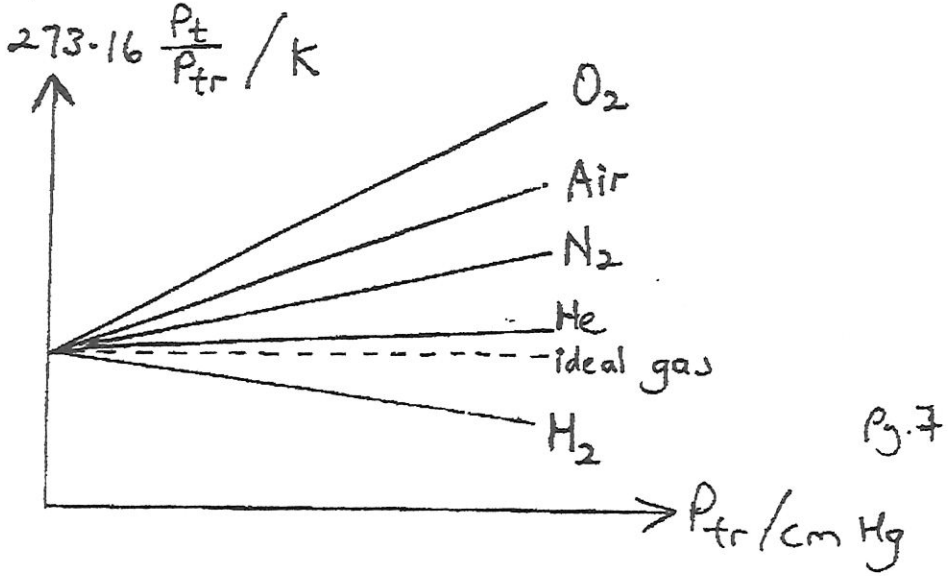


Figure above gives readings of a constant volume gas thermometer for the temp. of condensing steam, when different gases are used at various values of P.

Note that only an ideal gas produces a constant $\frac{P_T}{P_{tr}}$ for different masses (or different pressures) at a certain temp.

From graph, note that when extrapolated to <u>zero pressure</u>, behaviour of real gases becomes ideal ⟶ exact agreement.

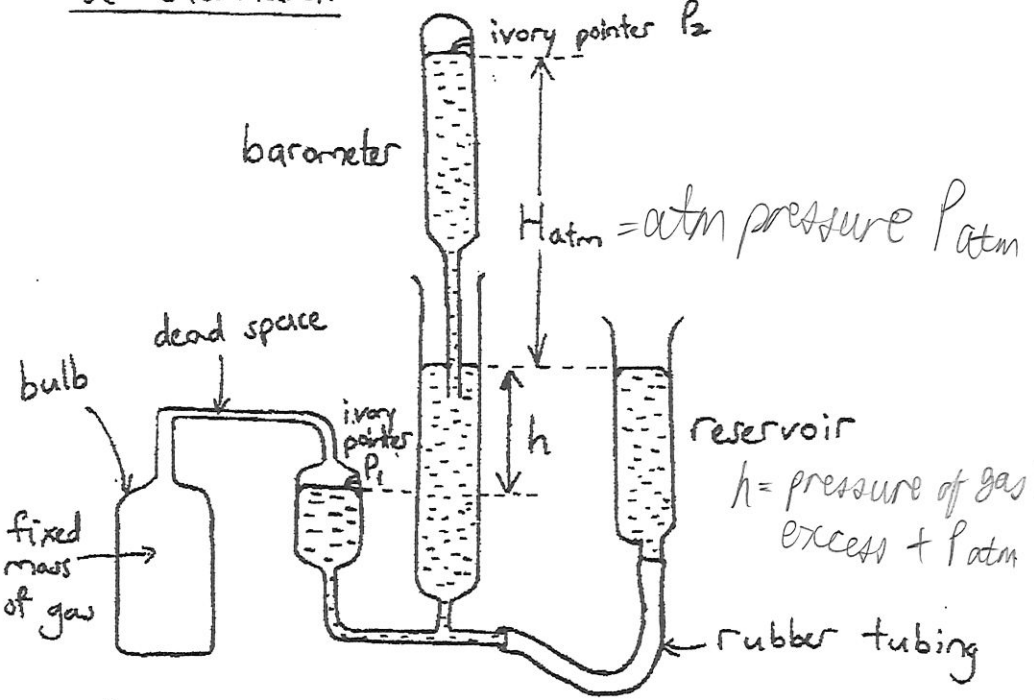
∴ For real gases,

$$\boxed{T = 273.16 \lim_{P_{tr} \to 0} \left(\frac{P_T}{P_{tr}}\right)}$$

N.B. Extrapolated value of temp. depends on general properties of gases but not on any particular gas.

Thermodynamic temp. is ∴ realised by a gas thermometer at low pressure. In this way, a constant vol. gas thermometer is used as a standard against which other thermometers can be calibrated.

Constant Volume Gas Thermometer used as a Standard.



Before reading, do 2 adjustments:

i). height of reservoir adjusted till Hg just touches pointer P_1

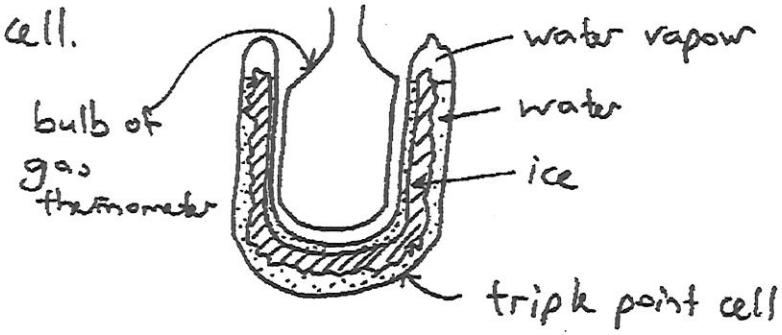
ii). adjust barometer until pointer P_2 just touches Hg surface.

Then, pressure of gas, $P = (H_{atm} + h)$ cm Hg

$= \underbrace{(H_{atm} + h)}_{\text{in metre}} \rho_g$ (in Pa

Procedure to find thermodynamic temp. T

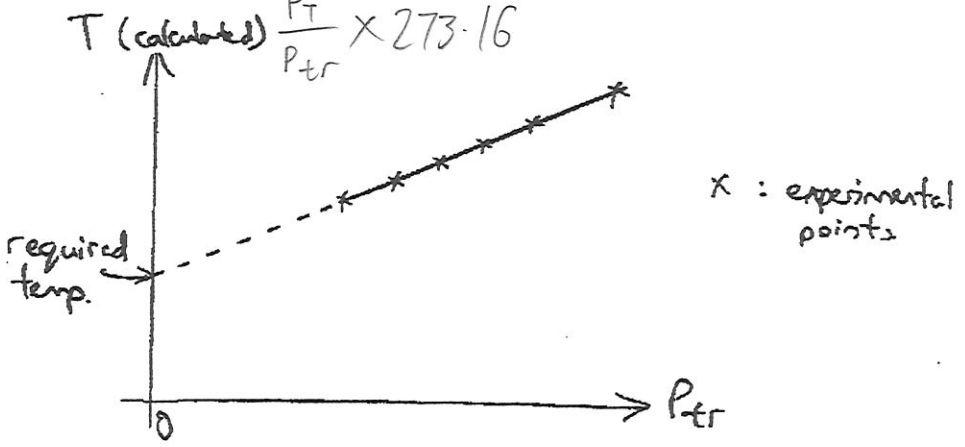
1. Find P_{tr} when bulb is surrounded by water at 273.16 K in a triple point cell.

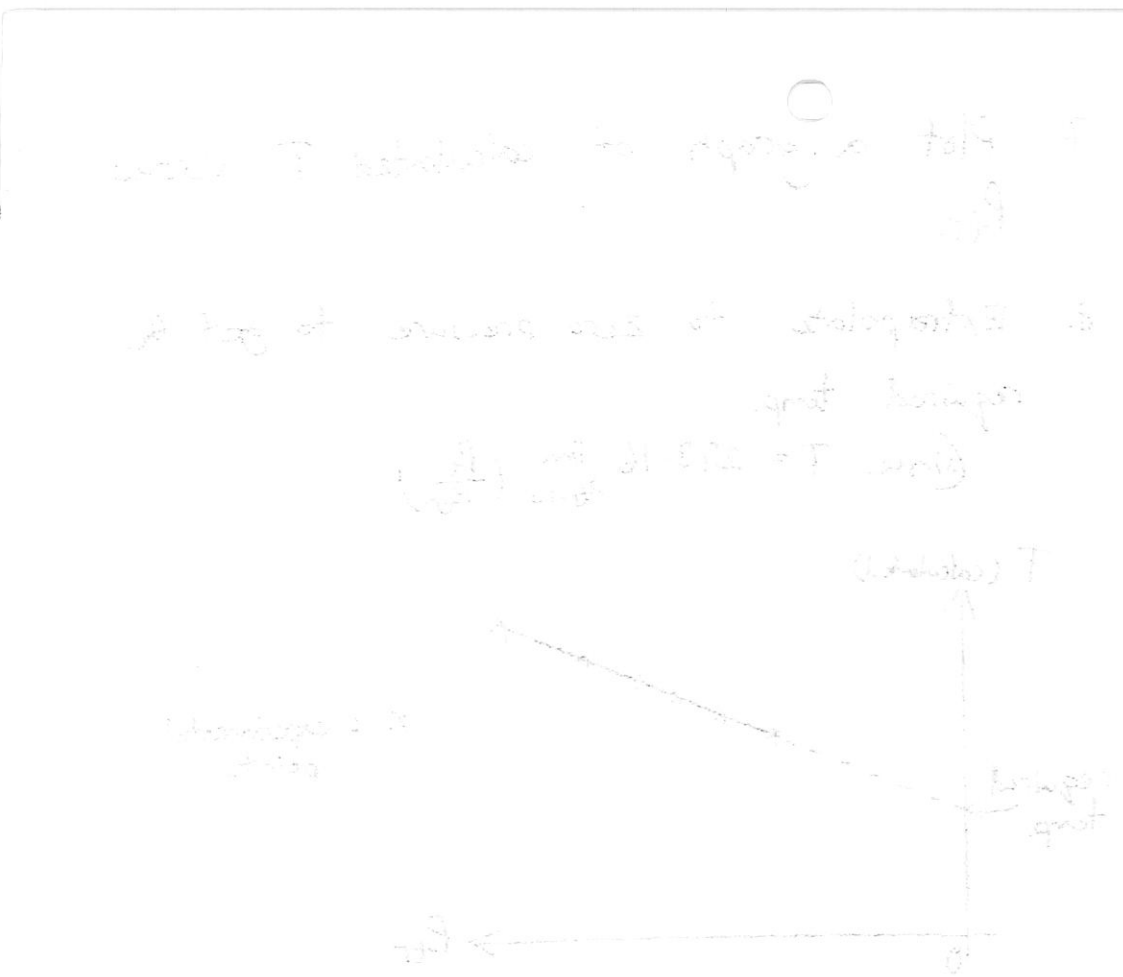


2. Find P_T at the unknown temp.
3. Calculate T using $T = 273.16 \left(\frac{P_T}{P_{tr}}\right)$
4. Repeat experiment using smaller value of P_{tr} by removing some gas.
5. Find P_T and P_{tr} again to calculate a different T.
6. Continue for a few more sets of values by further reducing P_{tr}. (by removing some of the gas from the bulb)

7. Plot a graph of calculated T versus P_{tr}.
8. Extrapolate to zero pressure to get the required temp.

(since $T = 273.16 \lim_{P_t \to 0} \left(\frac{P_t}{P_{tr}}\right)$)





Eg. 1.

	Ice point	Steam point	Unknown temp
Resistance thermometer	R_0 30.00 Ω	R_{100} 41.58 Ω	R_x 34.59 Ω
constant volume gas thermometer	P_0 1.333×10^5 Pa	P_{100} 1.821×10^5 Pa	P_x 1.528×10^5 Pa

Calculate the unknown temp. as read by each scale. Answer: 39.64°C, 39.96°C

(N.B. The 2 readings do not agree. Why?)

Eg. 2.

The pressure recorded by a const. vol. gas thermometer at a Kelvin temp T is 4.80×10^4 N m^{-2}.

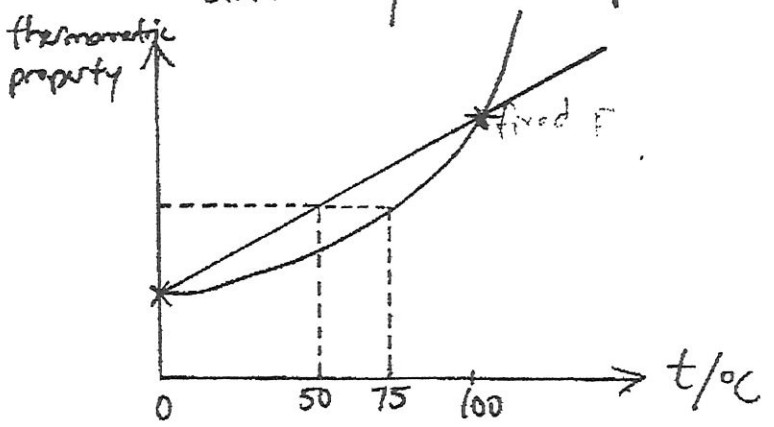
Calculate T if the pressure at triple point of water is 4.20×10^4 N m^{-2}

Answer: 312 K (to 3 sig. fig.)

Disagreement between thermometers.

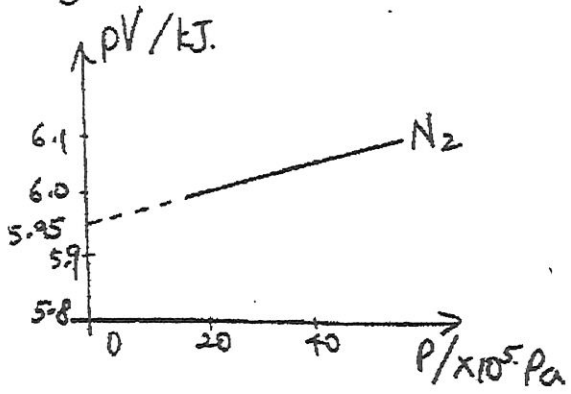
Thermometers based on different thermometric properties will not give the same reading for a given temperature, except at the fixed points where they must agree by definition.

Reason: Different thermometric properties vary differently with temp.

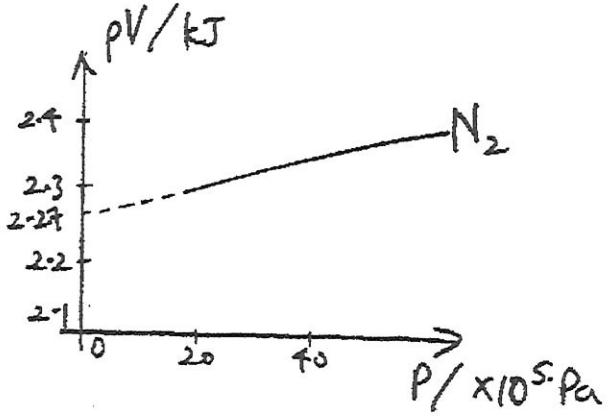


The two thermometers do not agree. A reading of 50°C on the resistance thermometer may correspond to 75°C on the Hg thermometer, although the degree of hotness is the same. However, they agree at the fixed points, i.e. 0°C and 100°C.

Eg.



At unknown temperature, T



temp. of
At triple point of water, 273.16K

$$\therefore T/K = 273.16 \lim_{P \to 0} \frac{(PV)_T}{(PV)_{tr}}$$

$$= 273.16 \times \frac{5.95}{2.27}$$

$$= 716\ K$$