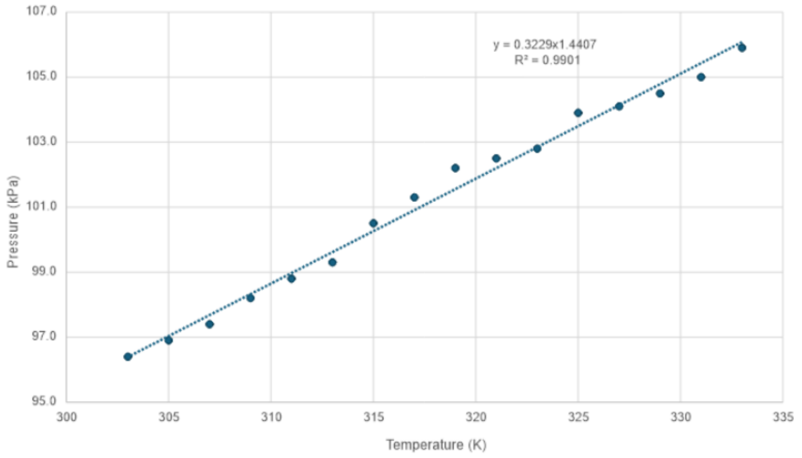
Solutions

Part A. [4 pt] Isochoric process

A1. [0.5pt] Record the pressure P as a function of the temperature T.

T(K)	P(kPa)
303	96.4
305	96.9
307	97.4
309	98.2
311	98.8
313	99.3
315	100.5
317	101.3
319	102.2
321	102.5
323	102.8
325	103.9
327	104.1
329	104.5
331	105.0
333	105.9

A2. [0.9pt] From the data obtained in A1, plot the behavior of pressure as a function of temperature.



A3. [0.9pt] Determine the mass m, number of moles n, and total number of air molecules N of the **CA.**

For H = 9.5±0.1 cm; $V = 85 \pm 2\ mL$; $m = 0.94 \pm 0.02$ g

$n = m/\mu$; $n = 3.24 \pm 0.7$ mmol.

N = $(1.95 \pm 0.05) \times 10^{21}$.

A4. [1.0pt] Use a graph to determine the experimental value of the universal gas constant R.

Constant R = 8.4 ±0.4 J/mol·K.

A5. [0.7pt] Determine the value of the thermal coefficient of expansion β_0 at constant volume.

$\beta_0 = 0.0034 \pm 0.0007$ K^{-1}

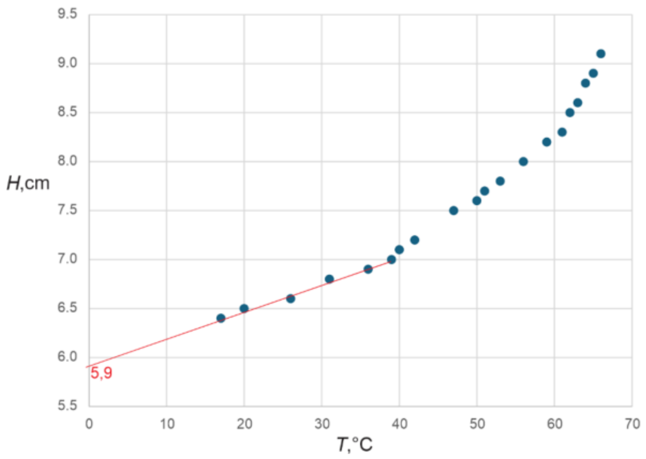
β_0 theory (1/273.15K) = 0.0037 K^{-1}

Part B. [8.0pt] Water vapor pressure. Latent heat.

B1. [0.5pt] Record the data relating the temperature T with the height H.

H cm	T K	Pv kPa
9.1	339	18.6
8.9	338	17.1
8.8	337	16.4
8.6	336	14.8
8.5	335	14.1
8.3	334	12.4
8.2	332	11.9
8.0	329	10.6
7.8	326	9.2
7.7	324	8.7
7.6	323	7.8
7.5	320	7.4
7.2	315	5.2
7.1	313	4.5
7.0	312	3.5
6.9	309	3.1
6.8	304	3.3
6.6	299	2.0
6.5	293	2.5
6.4	290	2.0

B2. [1.0pt] Plot H as a function of T.



B3. [0.5pt] Use the graph from B2 to extrapolate the value of H_0 at 0 °C.

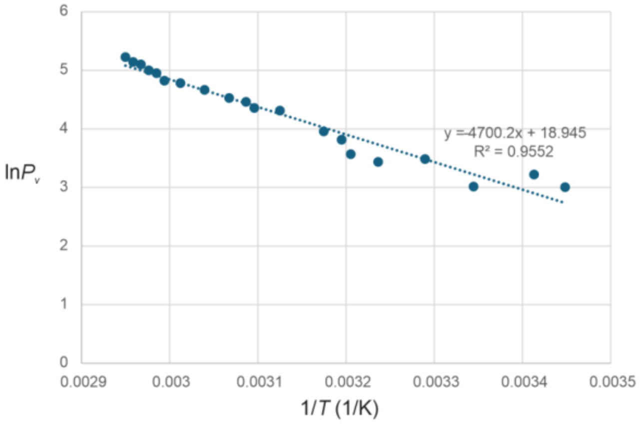
The extrapolation in the graph gives us that $H_0 = 5.9$ cm, at this height corresponds $V_0 = 53.4$ ml for $T_0 = 0$ °C.

B4. [1.5pt] Assuming that air behaves like an ideal gas and taking $T_0 = 0$ °C, deduce an expression for vapor pressure P_v in terms of P_{atm}, H_0, H, T_0, and T.

$$P_v = P_{atm} - n\frac{RT}{V} = P_{atm} - \frac{P_{at}V_0}{T_0}\frac{T}{V} = P_{atm}\left(1 - \frac{V_0}{T_0}\frac{T}{V}\right) = P_{atm}\left(1 - \frac{H_0}{H}\frac{T}{T_0}\right)$$

B5. [4.0pt] Using equation (3), construct an appropriate graph to determine the molar latent heat of vaporization of water ΔH_v. Find the value of ΔH_v.

$$\ln\frac{P_v}{P_{atm}} = \frac{\Delta H_v}{R}\left(\frac{1}{T_0} - \frac{1}{T}\right) \Rightarrow \ln P_v = -\frac{\Delta H_v}{R}\frac{1}{T} + \frac{L}{R}\frac{1}{T_0} + \ln P_0 = -\frac{\Delta H_v}{R}\frac{1}{T} + C$$



The slope a =- 4700±200 K.

The value of ΔH_{vap} =39±2 kJ/mol.

B6. [0.5pt] From the value of ΔH_v, determine L_v, indicating the formula that you used. Show your uncertainty calculation explicitly

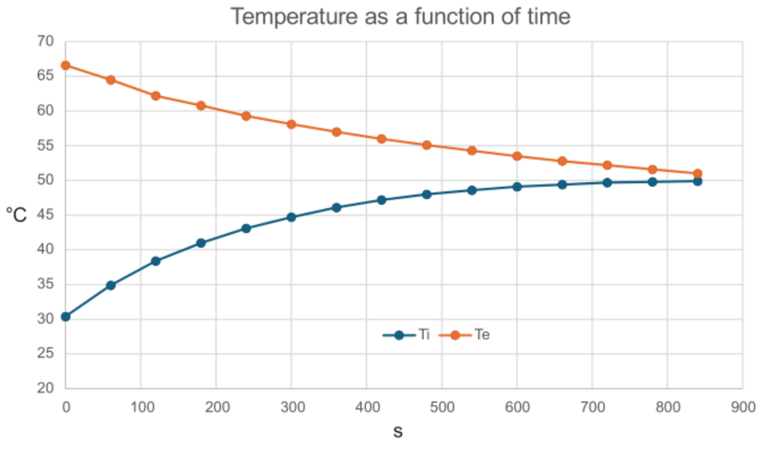
The specific heat of vaporization is $L_v = \dfrac{\Delta H_{vap}}{\mu_w} = 2190 \pm 110$ kJ/kg.

PART C [8.0pt]. Heat conduction

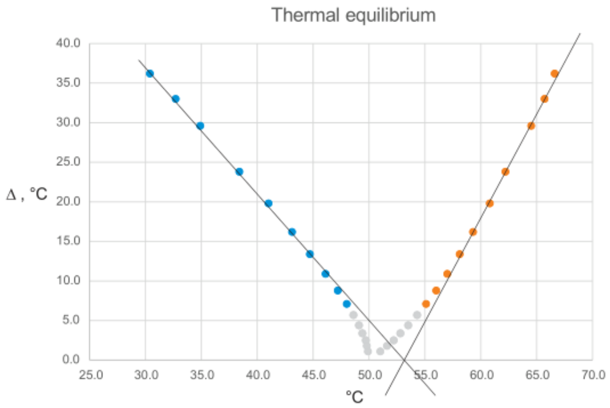
C1. [0.5 pt] Record the values of time t, internal temperature T_{IC}, and external temperature T_{OC}.

t	***Tue***	***Te***
s	**°C**	**°C**
0	30.4	66.6
60	34.9	64.5
120	38.4	62.2
180	41.0	60.8
240	43.1	59.3
300	44.7	58.1
360	46.1	57.0
420	47.2	56.0
480	48.0	55.1
540	48.6	54.3
600	49.1	53.5
660	49.4	52.8
720	49.7	52.2
780	49.8	51.6
840	49.9	51.0

C2. [1.0 pt] On a single graph, plot T_{IC} and T_{OC} as functions of time t.



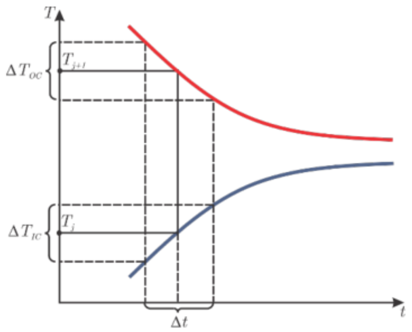
C3. [1.0 pt] On the same set of axes, plot ($T_{OC} - T_{IC}$) as a function of T_{OC} and ($T_{OC} - T_{IC}$) as a function of T_{IC}.



C4. [0.8 pt] From the graphs constructed in C3, determine T_{eq}. It is not necessary to calculate uncertainty for this question.

By extrapolation $T_{eq} = 53$ °C.

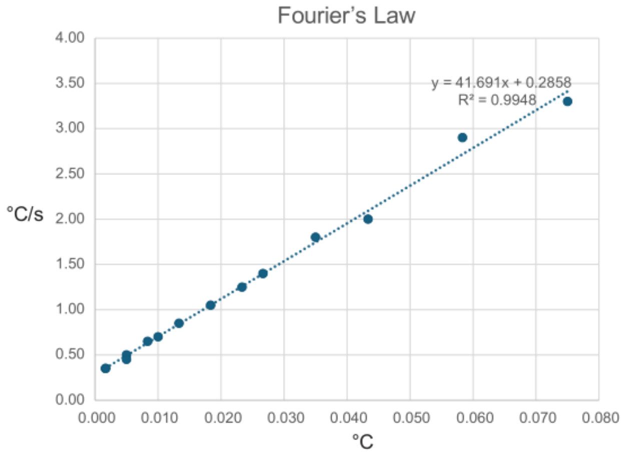
C5. [1.5 pt] Construct the graph indicated by expression (5).



$$\frac{(T_j - T_{j-1})_{IC}}{t_j - t_{j-1}} = \frac{1}{c_0 m R_{Th}} \cdot \frac{\Delta T_{OC(j,j-1)} - \Delta T_{IC(j,j-1)}}{2}$$

Here j represents the measurement number, $(T_j - T_{j-1})_{IC}$ is the variation in the temperature of the water contained in **IC** during the time interval $(t_j - t_{j-1})$ between two consecutive measurements and $\Delta T_{OC(i,i-1)}$ is the variation in the temperature of the hot water in OC and $\Delta T_{IC(j,j-1)}$ in the IC in the same time interval.

C6. [1.6 pt] Express the value of the effective thermal conductance of the wall and determine the value of R_{Th} from the graph constructed in C5.



The slope turns out to be $a = (2.28 \pm 0.06) \times 10^{-5}$ 1/s. This is the same thermal conductance of the wall.

The body of water $m = (89 \pm 1)$ g.

R_{Th} Thermal Resistance $= c_0 m a = (1.17 \pm 0.03)\ \frac{\text{K}}{\text{W}}$.

C7. [1.6 pt] Using equations (4) and (6), determine the value λ of the thermal conductivity of acrylic, indicating the formula that you used. Show your uncertainty calculation explicitly.

$\lambda = 0.25 \pm 0.01$ W/(m·K)

$$dT = -\frac{{}^{dQ}/_{dt}}{2\pi h\lambda}\frac{dr}{r} \qquad T_e - T_i = -\frac{{}^{dQ}/_{dt}}{2\pi h\lambda}\ln\frac{r_2}{r_1} \qquad \frac{dQ}{dt} = \frac{2\pi h\lambda}{\ln\frac{r_2}{r_1}}\,T_e - T_i$$

$$\lambda = \frac{\ln\frac{r_2}{r_1}}{2\pi h T R_{Th}}$$

$$\left(\frac{\Delta\lambda}{\lambda}\right)^2 = \left(\frac{\Delta[\ln(r_2/r_1)]}{\ln(r_2/r_1)}\right)^2 + \left(\frac{\Delta h}{h}\right)^2 + \left(\frac{\Delta R_{Th}}{R_{Th}}\right)^2$$

Is valid (R_{th} uncertainty is dominant) $\frac{\Delta\lambda}{\lambda} \approx \frac{\Delta R_{Th}}{R_{Th}}$

$$\Delta[\ln(r_2/r_1)] = \sqrt{\left(\frac{\Delta r_1}{r_1}\right)^2 + \left(\frac{\Delta r_2}{r_2}\right)^2}$$

Or

$$(\Delta\lambda)^2 = \left(\frac{\partial\lambda}{\partial r_1}\Delta r_1\right)^2 + \left(\frac{\partial\lambda}{\partial r_2}\Delta r_2\right)^2 + \left(\frac{\partial\lambda}{\partial L}\Delta L\right)^2 + \left(\frac{\partial\lambda}{\partial R_{Th}}\Delta R_{Th}\right)^2$$

$$\lambda = \frac{\ln\frac{r_2}{r_1}}{2\pi h R_{Th}} = \frac{\ln\left(\frac{\Delta r}{r_1} + 1\right)}{2\pi h R_{Th}} \simeq \frac{\Delta r}{2\pi h r_1 R_{Th}}$$

$$\left(\frac{\Delta\lambda}{\lambda}\right)^2 = \left(\frac{\Delta r}{r_1}\right)^2 + \left(\frac{\Delta h}{h}\right)^2 + \left(\frac{\Delta R_{Th}}{R_{Th}}\right)^2$$

Not integrated

$$\frac{dT}{dr} = -\frac{{}^{dQ}/_{dt}}{2\pi h\lambda}\frac{1}{r_1} \Rightarrow T_e - T_i = \frac{\frac{T_e - T_i}{R_{Th}}}{2\pi h\lambda r_1} \Rightarrow \lambda = \frac{dr}{2\pi r_1 h R_{Th}}$$