Finding the Boltzmann Constant through the Evaporation of Ethanol and the Formaldehyde Clock Reaction.

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The Formaldehyde Clock Reaction – Theory.

• Solution A →
  5 g of Anhydrous Sodium diSulfite +
  1 g of Anhydrous Sodium Sulfite +
  1 L of Distilled Water.

• Solution B →
  10 cm cubed of 37% Formaldehyde Solution +
  1 L of Distilled Water + (after 24 hours)
  1 g of Phenolphthalein.
Theory – Continued.

• Mix equal volumes of both solutions.
• After some time, ‘delta T’, the solution turns pink.
The Equations and the Math.

• The rate of the reaction is governed by the Arrhenius Equation.

\[ U = A e^{-\frac{E_a}{kT}} \]
The Equation and the Math.

- $u \rightarrow$ the reaction speed.
- $A \rightarrow$ a constant.
- $E_a \rightarrow$ energy of activation.
- $K \rightarrow$ the Boltzmann Constant.
- $T \rightarrow$ the temperature (in Kelvin) at which the reaction occurred.
The Equation and the Math – The Linear Form.

\[ U = A e^{-\frac{E_a}{kT}} \]

\[ \ln(U) = \ln(A) + \ln(e^{-\frac{E_a}{kT}}) \]

\[ \ln(U) = -\frac{1}{kT} \left( \frac{E_a}{T} \right) + \ln(A) \]

\[ Y = mX + c \]
The Experimental Setup – Equipment

• A hot plate.
• Magnetic Stirrer to distribute heat uniformly.
• A Temperature Probe.
• Oil Bath.
• Test Tubes.
• Stop Watch.
• Funnel.
The Experimental Setup – A Snapshot.
The Experiment.

- 5 cm cubed of each solution was placed in separate test tubes. The test tubes were half immersed in the oil bath the temperature of which was monitored constantly.

- After 5 minutes the two solutions were mixed and the stopwatch was started simultaneously.
The Experiment – Continued.

• The stopwatch was stopped the instant the pink color appeared.
• The experiment was repeated three times at the same temperature.
• The entire procedure was repeated at 27, 40, 51 and 58 degrees Celsius.
Results

• The value of the Activation Energy was taken from literature.
• $E_a = 9.30 \times 10^{22}$ J.
• A graph of $\ln(1/time)$ against $E_a/Temperature$ was plotted.
Results – The Graph.

- Add the Graph

![Graph Image]

- Data 2
- Linear
The Boltzmann Constant.

Gradient = -6.7659 x (10)^22

\((-1/k)\) = -6.7659 x (10)^22

\(k\) = 1.478 x (10)^{-23} \text{ J/K}
Error.

- The percentage error comes to about 9.8% when compared to the literature values.

- Reasonable estimation of the Boltzmann Constant.
The Evaporation of Ethanol – Theory.

• The 4 Assumptions:
  1. The concentration of Ethanol outside the container is zero.
  2. There exists no temperature gradient within the bulk of the liquid.
  3. There exists a steady flow of air outside the container.
  4. Above the surface of the Ethanol there exist saturated vapors of Ethanol.
Theory – Fick’s Diffusion Law.

\[ \frac{dN}{dt} = -D \frac{\partial n}{\partial z} \]

\[ z \]

\[ x \]
Theory – Assumption # 1

\[ \frac{dn}{dz} = \frac{n}{H-h(c(x))} \]
Theory – Another Assumption.

Assume that the ethanol vapors behave like an ideal gas.

\[ \hat{N} = \frac{p}{kT} \]

\[ p = \text{sat. vp} \]

\[ k = \text{Boltzmann constant} \]

\[ T = \text{Abs. temp.} \]
Theory – Yet Another Assumption.

If we assume \( \varepsilon \) to be the density of the ethanol, then

\[
m(t) = \varepsilon S h(t).
\]
Fick’s Law after Assumption # 5, 6 & 7

\[
\frac{dN}{dt} = - D \frac{S}{P} \frac{E_S}{KT} \frac{E_S}{CHS-m(E)}
\]
After a Lot of Math.

By mathematical manipulation.

\[
\frac{dm(t)}{dt} = \frac{c_1 \rho \sqrt{T}}{c_2 - M(t)}
\]
Yet Another Assumption.

\[ \frac{dm}{dt} = c_3 \frac{1}{c_2 - M(t)} \]

\[ c_3 = \rho \sqrt{T} c_1 \]
After some more Math.

\[ K = \frac{9 \left( c_3 \right)^2 \left( \eta \right)^3 \text{mod} \left( p_0^2 \right)}{4 \cdot S^4 \cdot e^2 \left( M_a \right)^2 \cdot p^2 \cdot T} \]
C_3 = \frac{d m(t)}{d t} \left[ m(t) - C_2 \right]
The Experimental Setup – A Snapshot.
The Experiment – Software Used.

• Labview ➔ To check the temperature variations. It was determined that they were not significant.

• Logger Pro ➔ Interfaces Lab Pro with the computer. Lab Pro gathered information from the...

• Force Sensor (devise) ➔ Measured the weight of the alcohol after every 100 seconds.
The Disaster.

• On the 12\textsuperscript{th} of June, the experiment was started. On the 6\textsuperscript{th} day, three consecutive power failures caused the data collected to crash.

• A re-run was immediately started.

• The experiment which was scheduled to finish on the 22\textsuperscript{nd} now finished on the 27\textsuperscript{th}.
The Results on the 27th.

Weight vs. Time

Time / Days

Weight / Newtons
Some Problems.

• On Monday morning, 5 grams of the Ethanol were unaccounted for.
• On Wednesday, 1 gram of Ethanol was unaccounted for.
• Restricted to two parts of the graph and not the entire graph as a whole.
• The evaporation procedure was not yet complete.
What to do now?

1. Evaluate the Boltzmann constant for the two separate parts.
2. Theoretically account for the mass loss.
Apologies.

• I have not yet been able to calculate the Boltzmann constant through the evaporation of ethanol. However considering the nice trend of the graph and the good behavior of temperature I can be confident of a highly accurate answer.
Thank you!