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P5_8 Tea Time in the Solar System

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Abstract

This paper explores the varying boiling temperatures of water on different bodies in the Solar System required to make a cup of tea. We calculated this value for Venus, Earth, Mars, Titan, Triton and Callisto as these have atmospheres with measured atmospheric pressures at their surface. It was found that Callisto required the lowest temperature to boil water at 126K whilst Venus required the highest at 569K. The temperature calculated on Titan was relatively similar to that on Earth with a difference of 11K.

Introduction

A stereotypical British pastime is drinking tea. This paper investigates the various boiling temperatures of water on six rocky bodies in our Solar System such that one could have a cup of tea on them.

Theory

The behaviour of the phase transition between water and steam is best described using the Clausius-Clapeyron relation. It is defined as

$$\frac{dP}{dT} = \frac{L}{T(V_1 - V_2)}, \qquad (1)$$

where P is the pressure of the phase, T is the temperature, L is the specific latent heat, V_1 is the volume of the water vapour and V_2 is the volume of the liquid. In this case $V_2 \ll V_1$, and hence V_2 is negligible in equation (1). For water the latent heat of vaporisation for one mole is $L = 40.6$kJmol^{-1} [1]. Assuming the gas will act as an ideal gas we can use the relation

$$PV_1 = nRT, \qquad (2)$$

where n is the number of moles and R is the ideal gas constant, $R = 8.314$ Jmol^{-1}K^{-1}. Re-arranging for V_1 and substituting into equation (1) we get

$$\frac{dP}{dT} = \frac{LP}{nRT^2}. \qquad (3)$$

The molecular weight of water is 18.01gmol^{-1} [2]. As there are 8 ounces in one cup and 28g in one ounce [3], we will assume a cup of tea will have $\frac{8\times 28}{18.01} \approx 12.5$mol. However, the latent heat of vaporisation varies with respect to the number of moles [4]: in this case $L = 507.56$kJmol^{-1}. The number of moles, n, and the factor in the latent heat cancel in equation (3) [4]. Re-arranging and integrating this equation we find

$$P = Ce^{-\frac{L}{RT}}, \qquad (4)$$

where C is the constant of integration. To determine this value we set $P = 1$atm. The liquid at this pressure will boil at $T_0 = 373$K. Substituting these values into equation (4) and re-arranging gives

$$C = e^{\frac{L}{RT_0}}. \qquad (5)$$

Therefore, equation (4) becomes

$$P = \exp\left[-\frac{L}{nR}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]. \qquad (6)$$

Results

Table 1 - the calculated temperatures at which water will boil under respective atmospheric pressures on the bodies in the Solar System.

Body	Atmospheric Pressure at the surface (atm)	Boiling temperature (K)
Venus	92 [5]	569
Earth	1 [5]	373
Mars	0.008 [5]	273
Titan	1.45 [6]	384
Triton	1.3×10^{-5} [7]	201
Callisto	7.4×10^{-12} [8]	126

The bodies considered in this paper are those which have an atmosphere and known atmospheric pressure. The final list of bodies included Venus, Earth, Mars, Saturn's moon Titan, Neptune's moon Triton and Jupiter's moon Callisto. Using the atmospheric pressure at the surface of each respective body, we were able to calculate at what temperature the 1mol of water would have to boil to make tea. The results are listed in Table 1.

Conclusion

It is possible to boil water to make tea on all bodies in our Solar System which have an atmosphere. Boiling water on Saturn's moon Titan is relatively similar to boiling water on Earth, with a temperature difference of 11K. Due to Venus' high pressured atmosphere it would require the highest temperature of 569K to boil water. Conversely, the lowest temperature of 126K is required to boil water on Jupiter's moon Callisto.

Further study could compare the temperatures for boiling and freezing water to see whether the water would sublime directly on the respective bodies, omitting the liquid phase.

References

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