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## Phase Change and Space Travel

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### **Author's contribution**

*The sole author designed, analyzed, interpreted and prepared the manuscript.*

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### **ABSTRACT**

Here we discuss the implications of phase change equations and what bearing they might have on interstellar space travel. The phase change equations are derived from either thermodynamics or statistical mechanics and have a similarity. Then, the main equation for limit of superheat is posited to be a solution to the problem of propulsion in space travel. There are two matter-antimatter systems considered: electron – positron and hydrogen – antihydrogen. What is involved in the space travel problem is harvesting of antimatter in magnetic bottles and keeping it separate.

*Keywords: Interstellar space travel; phase change; limit of superheat; boiling point elevation; viscosity; magnetic bottle; positron; antihydrogen.*

### **1. INTRODUCTION**

Here we present equations that have to do with phase change and their possible relevance to interstellar travel. The equation for limit of superheat bears a similarity to the one for boiling

point elevation. The derivation for limit of superheat is complicated, but it is easy to derive boiling point elevation. Because the increase in temperature,  $\Delta T$ , is much larger for limit of superheat, we propose that using the limit of superheat is a better way to measure polymer

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molecular weight than boiling point elevation. Conceivably, antimatter can be harvested in outer space and kept separate in magnetic bottles for matter-antimatter propulsion. The candidates for antimatter have to be either the positron or antihydrogen.

## 2. PHASE CHANGE

In a 2020 paper [1], Jennings mentions his 2012 equation, here as Eq. (1), for limit of superheat by addition of polymer in terms of concentration.

$$\lim_{c \rightarrow 0} \frac{(dT/dc)s, \text{ polymer}}{3kTs^2MW_1/\rho_1\sigma_1aMW_2(p)} = \quad (1)$$

Blackmore [2] has the formula for boiling point elevation by addition of polymer, also in terms of concentration.

$$\lim_{c \rightarrow 0} \frac{(dT/dc)b, \text{ polymer}}{RT_b^2MW_1/\rho_1\Delta HvapMW_2(p)} = \quad (2)$$

Equations (1) and (2) are dealt with in paper [1].

Notice how these two equations echo each other in that the absolute temperatures of the phase change ( $T_s$  and  $T_b$ ) are squared in the numerator and multiplied by the molecular weight solvent. In addition, the density of solvent is multiplied by the molecular weight polymer in the denominator and they differ by the factor 3.

The derivation for eq. (2) just takes a few steps and is found in thermodynamics textbooks, such as Wall [3], page 363, and comes from a thermodynamic argument based on the Clausius-Clapeyron relation combined with Raoult's law. However, to derive (1) the math is involved and stems from putting statistical mechanics by Prigogine and Marechal [4] for the surface tension of a polymer solution with classical nucleation theory (CNT), as perfected by Blander and Katz [5].

It seems remarkable that Eqs. (1) and (2) have a correspondence. This shows an agreement between thermodynamics and statistical mechanics with regard to phase change. Maybe it could be shown that there are similar equations for solid-liquid, solid-gas, and in rain clouds where water vapor goes to droplets. It is well-known that classical nucleation theory applies to rain formation, but here we speculate that Jennings' theory is the germ of a general theory for phase change.

The initial data for bubble nucleation in polymer solutions was provided by Jennings and

Middleman [6] in 1985 using the system of polystyrene-cyclohexane. The first theoretical breakthrough was Jennings [7] with his 2012 equation aforementioned. Later, Jennings eliminated the prefactor A in the Blander and Katz expression eq. (4) in CNT for liquid→gas in a 2019 paper [8].

In the 1985 published data, there are straight rays (like vectors) for 2000 and 4000 MW. This led the author to prove the following simple differential equation (3) in the T direction and the  $w_2$  direction in [7].

$$\ln A/dK = 1/(6K) \quad (3)$$

Blander and Katz's equation for nucleation, in its simplified form, has A as the prefactor and K as the exponent. Thus, J, the nucleation rate, is presented as.

$$J = A \exp K \text{ bubbles/cc-sec} \quad (4)$$

Jennings was able to get  $A = f(K)$ , get an exact value for K, and calculate the integration constant for (3). Also, Jennings established by calculation that only K matters. This completed the study.  $K = -64.56$ , as evaluated for 10 polar and non-polar solvents, denoted in papers [9] and [10].

So, what is the upshot of all this? Clearly, there is a use for boiling point elevation and rise in limit of superheat in determining the molecular weight of polymer. However, there is a difference in the rise in T between the two. The  $\Delta T$  for boiling point elevation is measured by a special thermometer that can detect millidegrees in change, but the apparatus used by Jennings and Middleman gave a result for  $\Delta T$  of up to +10-15 °C. This leads the author to believe that superheat will be a superior way of measuring polymer molecular weight.

### 2.1 Space Travel

Using the imagination, one could dream that Eq. (5) could be employed in a spaceship using electron-positron annihilation for propulsion. A Google Scholar search was made and at the top of the list there were no papers using ("phase change" and "space travel"), so here we present novel ideas. Electrons and positrons may be harvested by appropriate magnetic filters in outer space, using the fact that the two species rotate in opposite directions. They would be kept in separate magnetic bottles, each in a bath of

neutrinos. Species 1 is the electron/positron and species 2 is the bath of neutrinos.  $w_2$  would be close to one (weight fraction neutrinos) and magnetic bottles would keep the dilute electrons/positrons apart. See the Appendix for the possibility of using hydrogen-antihydrogen instead. We are talking about the following equation from Jennings' 2014 article [11] for interstellar travel! At Berkeley Lab, antihydrogen was stored for the first time in 2010, Internet reference [12].

$$\Delta T = T - T_1 = 3kT_1^2 w_2 MW_1 / \sigma_1 a_1 MW_2 \quad (5)$$

Another use for Eq. (5) might be that added polymer will allow the temperature to be increased during fuel injection giving lowered viscosity and higher flow rate.

### 3. CONCLUSIONS

In this brief paper, we outlined the implications of the phenomenon of phase change in terms of limit of superheat as contrasted with boiling point elevation. It is noted that these two have similarities, even though they are derived in different ways. Possibly Jennings' equation will apply to space travel in that the antimatter can be kept below its superheat temperature after being collected in the interstellar medium. Proper engineering will be required, but this is the chemistry.

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### COMPETING INTERESTS

Author has declared that no competing interests exist.

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## APPENDIX

For harvesting antihydrogen during space travel, it may be done in the following way.

In hot, diffuse regions of the interstellar medium, the atoms are ionized. 91% of the atoms are hydrogen, so presumably there would be Liederfrost areas between the protons and antiprotons. They could be captured in the same way previously described for electrons and positrons.

The temperature of interstellar space is 3K and the critical temperature of H<sub>2</sub> is 33.25K. From Blander and Katz [5], we know that  $T_1 = 0.89 \times 33.25 = 29.59\text{K}$ .

This means that antihydrogen and hydrogen have to be kept at a low temperature to be liquid. Some engineering will have to be perfected to do this. This is the chemistry.

Nomenclature

Equations (1)-(4)

a, a<sub>1</sub> surface area of solvent molecule at Ts, T<sub>1</sub>

A prefactor

c concentration of solute

J nucleation rate

k Boltzmann constant

K exponent

MW<sub>1</sub> molecular weight of solvent

MW<sub>2</sub> molecular weight of solute

MW<sub>2(p)</sub> molecular weight of polymer

R universal gas constant

T limit of superheat of solution

T<sub>b</sub>, T<sub>s</sub> boiling temperature, limit of superheat of solvents

T<sub>1</sub> limit of superheat of solvent

ΔH<sub>vap</sub> enthalpy of vaporization

ΔT equals increase in limit of superheat, T – T<sub>1</sub>

ρ<sub>1</sub> density of pure solvent at T<sub>b</sub>, T<sub>s</sub>

σ<sub>1</sub> surface tension of solvent at T<sub>s</sub>, T<sub>1</sub>

Equation (5)

1= solvent (taken to be electron/antielectron)

2= solute (taken to be neutrino)

w<sub>2</sub> = weight fraction of neutrinos (close to 1)

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