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A6_1 The Suitability of Russell's Teapot for Liquid Containment at an Appropriate Temperature

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Abstract

Russell's teapot is a hypothetical teapot floating in space between Earth and Mars. The maximum and minimum temperature of tea stored in this pot was found to be 277 K and 225 K respectively using the Stefan-Boltzmann law. An optimal tea storage orbit radius is calculated to be 83.2 million km, just inside the orbit of Venus.

Introduction

Russell's teapot is a famous thought experiment by the twentieth century philospher, Betrand Russell. He used an example of a teapot orbiting the Sun between Mars and the Earth as a critique of belief without evidence [2]. The image stuck around, and is now a part of popular philosophy. However, the suitability of this teapot for the storage of tea is so far an unanswered question. This paper examines the ambient temperature of this teapot in space, and its suitability for tea containment. Its also considers the perfect orbit radius for a well brewed pot of tea, which may prove useful for future astronauts in search of a hot beverage.

Analysis

In his description, Russell imagines a teapot orbiting between Earth and Mars. This allows us to bound the heliocentric orbital radius of the teapot as $R_{min} = 1.50 \times 10^{11}$m and $R_{max} = 2.28 \times 10^{11}$m. Assuming a spherical teapot of radius 10 cm traveling in a circular orbit, the maximum and minimum incident solar power can be calculated. This is done using the power ratio of a spherical emitter:

$$\frac{P_I}{L_T} = \frac{A_{solid,pot}}{A_{sphere,R}}$$

$$\Rightarrow P_I = \frac{\pi r_{pot}^2}{4\pi R_{orbit}^2} L_T \qquad (1)$$

Where P_I is the incident power, r_{pot} is the radius of the teapot, R_{orbit} is the average distance of the teapot from the Sun, L_T is the total luminosity (power) of the sun, $A_{solid,pot}$ is the solid angle teapot area facing the sun and $A_{sphere,R}$ is the area of a heliocentric sphere with a radius of the teapot orbit. This gives an incident power of $42.53W$ closest to the sun and $18.4W$ furthest away from the sun. Assuming the teapot is a black body, radiates heat using the Stefan-Boltzmann law (Eq. 2) and all radiant flux incident on the teapot is absorbed implies the incident power will equal the power radiated by the pot. When the teapot achieves thermal equilibrium the temperature can be calculated (Eq. 3). One other assumption to note is that the teapot sealed, and storing the tea at 1 atmosphere of pressure. This prevents the tea from vaporising into space.

$$j^* = \sigma T^4 \tag{2}$$

$$\Rightarrow P_O = A\sigma T^4 \tag{3}$$

$$\Rightarrow T = \sqrt[4]{\frac{P_O}{A\sigma}}$$

Where j^* is the total flux of the teapot, σ is the Stefan-Boltzmann constant, T is the temperature of the teapot, P_O is the output power, A is the surface area of the teapot. In thermal equilibrium, $P_I = P_O$, therefore the temperature of the teapot can be calculated. This gives a maximum temperature on a 1 AU orbit to be 277 K. Tea is still a liquid at this temperature, and would still be possible to drink. However, the far teapot orbit is at a chilly 225 K. This is below the freezing point of water and therefore this orbit is not suitable for tea storage. It stands to reason that there is an orbital radius with an optimal tea temperature. According to the Yorkshire Tea Company, tea is best sampled at 100 °C [1]. To find the orbital radius to get this perfect 100 °C tea, Eq. (3) is used to find $P_O = 138.1$W. This can then be substituted back into Eq. (1) to solve for R_{orbit} giving 83.2 million km, just inside the orbit of Venus (108.2 million km).

Conclusion

In summary, if Bertrand Russell was aiming for well brewed tea in his analogy, he should have stated his teapot was roughly between Mercury and Venus. One of the other conclusions in this paper is that near the orbital radius of Earth, the temperature of black body objects is fairly close to terrestrial norms. This is no coincidence, as radiative transfer is the primary reason for Earth's $\sim$ 20 °C temperatures. Future work on this topic would include reducing some of the simplifications this paper makes. One of these is treating the teapot as a perfect absorber of radiation. Traditionally, ceramic teapots are white, and they can reflect a certain amount of radiation. This means that the tea temperatures found in this paper are likely to be too high. Another small problem is the treatment of the teapot as a sphere. More accurate results could be gained if a more complex mapping of the teapot can be examined.

References

[1] The great milk debate. `https://www.yorkshiretea.co.uk/brew-news/the-great-milk-debate`. Accessed: 2018-10-03.

[2] S Mumford. Last philosophical testament: The collected papers of Bertrand Russell, vol 11, 1943-1968. *International Journal Of Philosophical Studies*, 9(2):284–286, 2001.