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A1_6 Chocolate Orange Moon

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Abstract

In this paper we investigate whether it would be possible for the Sun to melt the Moon if it was replaced with a Terry's Chocolate Orange of equal volume. By determining the flux intercepted by the Moon from the Sun, we find that the Sun's flux alone would be insufficient to melt the entire mass. Then, considering the limiting flux case we calculate that the maximum depth of chocolate melted over one half of the surface is 0.2 m in one melting cycle. Additionally, we also establish that the chocolate orange moon does not radiate enough heat back into space for the melted material to reach its original temperature before it is illuminated by the Sun again.

Introduction

In this paper we explore the melting capacity of our Sun on an alternate moon where it has been replaced with a Terry's Chocolate Orange. Here, we assume the solid chocolate orange moon (COM) has unchanged physical dimensions and is orbiting at the same distance from Earth. Thus, receiving an equal amount of flux as the Moon in our current system. Using the flux received we can calculate the surface temperature for the day side of this COM and hence determine the total energy required to melt the mass of the COM.

Method

To be able to calculate how much of the COM would be melted by the Sun we calculate the initial surface temperature, T, of the Moon using

$$T = \sqrt[4]{\frac{S_0(1-\alpha)}{4\sigma}} \tag{1}$$

where $S_0 = 1300\,\mathrm{W\,m^{-2}}$, $\alpha = 0.05$, and σ are the solar constant, albedo, and Stefan-Boltzmann constant respectively [1]. With the surface temperature of 275 K we then establish the temperature change required to reach the melting temperature of chocolate, T_{melt}, which is 313 K [2]. Using the radius of the Moon (≈ 1700 km) and a density of chocolate, $\rho_c = 1300\,\mathrm{kg\,m^{-3}}$, we found the mass of the COM and the corresponding energy Q that is required to melt the entire mass [3, 4]. This energy has two contributions: the energy for the chocolate to reach its melting temperature,

$$Q_c = mc\Delta T, \tag{2}$$

and the energy required for the change of state during the melting process,

$$Q_L = mL, \tag{3}$$

where the parameters have their usual meanings and the specific and latent heats of chocolate are $1.6\,\mathrm{kJ\,kg^{-1}\,K^{-1}}$ and $45\,\mathrm{kJ\,kg^{-1}}$ respectively [5, 6]. Next, we compared the energy required for melting the entire COM from Eq. 2 and 3, to the energy the Moon receives from intercepting flux from the Sun (half of its surface area), E_r given its orbital distance from the Sun, R,

$$E_r = S_0 \pi R^2. \tag{4}$$

We found that the 5.6×10^{20} J received from the Sun is insufficient to melt the entire mass of the COM which would require 2.8×10^{27} J.

Instead, we investigated the depth, x, of a COM crust that could be melted, assuming that the heat does not diffuse through the COM. We considered a simple model where only half of the moon receives flux from the sun for half a day which corresponds to an energy E_{lim},

$$E_{lim} = S_0 t A \tag{5}$$

where t is the time the COM is irradiated and A is the surface area exposed to the sunlight. The layer of the COM that melts was modelled as a cylinder with a face surface area corresponding to the surface area of the illuminated half, such that we can easily solve for its depth. Taking this limiting energy case we equated it to the total energy expression $E_{lim} = Q_c + Q_L$, including a calculated mass value with respect to depth, m_{ml}. This expression can then be rearranged to give the depth of the COM that it is possible to melt,

$$x = \frac{E_{lim}}{m_{ml}(c\Delta T + L)}. \tag{6}$$

From Eq. 6 we determined that half of the COM surface up to a depth of 0.2 m would be melted within the half of the day where it receives sunlight. After this heating phase the area, A, will be subjected to half a day of 'night' conditions. During this period the surface will cool as energy is radiated away from the surface as $P_{rad} = e\sigma A T^4$, where $e \approx 0.8$ is the emissivity of chocolate [7]. If we compare the 8.3×10^{15} W radiated away during cooling to the 1.3×10^{16} W (energy intercepted by COM for half a day) that it would need to radiate to revert back to its initial state, we find that the chocolate would not have sufficient time to reach its original temperature before it reached the heating stage again. Even if we treat the COM as a black body with an emissivity of 1 we still find a power of 1×10^{16} W which is insufficient to completely cool all of the melted material.

Conclusion

In this investigation we found that if the Moon was replaced by a Terry's Chocolate Orange of equal volume, the Sun would be capable of melting the affected surface to a depth of 0.2 m in half a day. We then explored the melting and solidifying cycle and found that even if the COM was modelled as a black body, that the time the melted material spends in the dark is insufficient for the solidification and complete cool down of the chocolate. As a result, over time the COM will increasingly liquefy and evaporate, and eventually become a chocolate plasma. However, we did not consider the diffusion of the heat inside the moon and it is possible that it might reach a equilibrium state, such that it does not liquefy.

References

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