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A4_10 Liquid Water on Europa

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Abstract

This article investigates the possibility of liquid water existing on the surface or subsurface of Europa. Due to the comparison of the atmospheric pressure of Europa it is found that liquid water cannot exist on the surface of Europa. The subsurface conditions are investigated and the surface temperature of Europa calculated, such that a temperature gradient can be used along with a pressure gradient to calculate the distance below the surface that liquid water can exist which is found to be 1.82km.

Introduction

Europa is an icy moon orbiting the fifth planet from the Sun, Jupiter. This paper assesses the possibility of liquid water existing on the Galilean satellite. Europa is, like the Earth, thought to have an iron core, rocky mantle and a subsurface ocean of salty water [1]. One of the key signs of life on another terrestrial body is the search for liquid water. Europa is covered entirely of water, and as such it is only necessary to prove that some could be liquid [2]. This paper assumes the only sources of heat for the moon, are the radiative heat from the Sun and tidal heating, all other effects are considered negligible.

Can Liquid exist at the Surface?

To determine the state at which water exists on the surface of Europa it must be understood where on the phase diagram the conditions of the surface lay. To determine this, it is necessary to first discuss the atmospheric pressure at the surface (surface pressure of Europa). The atmosphere on the surface of Europa is comprised of mainly oxygen and considered very tenuous with an atmospheric pressure of approximately 10^{-11} times that of the Earth's atmosphere at sea level [3]. Thus for the sake of simplicity it will be considered a vacuum. At this pressure water can only exist in the forms of a vapour or a solid [4]. Thus no liquid water can exist on the surface of Europa.

Could Liquid exist under the Surface?

It is now widely theorised that liquid water exists under the surface of Europa. This is due to the internal heating caused by tidal forces. To determine whether it is possible for liquid water to exist at a given depth it is necessary to consider the temperature and pressure at a depth under the ice, i.e. the amount of ice required to create liquid water.

To calculate the temperature and pressure at a certain depth in the ice, thermal and pressure gradients are used respectively. It can be estimated [4] that the lowest point (lowest pressure and temperature value) that water can exist is approximately at a pressure of 1kPa, and temperature of 275K.

Pressure under the Surface

With increasing depth into the surface of Europa the pressure increases linearly (assuming that density does not vary). The pressure P at a depth h;

$$P = \rho g h\,, \qquad (1)$$

such that g is the acceleration due to gravity at the surface of Europa. The pressure gradient of Europa $\frac{dP}{dh}$ then;

$$\frac{dP}{dh} = \rho g\,, \qquad (2)$$

therefore the pressure gradient with depth of Europa is 1.3 $kPam^{-1}$[5]. So to create the lowest required pressure for liquid water to exist the ice is required to be 76.9cm thick, or approximately a depth of 77cm of ice.

Temperature under the Surface

The temperature also increases linearly with depth under the surface. This is due to the tidal friction that occurs. As before the temperature at a depth is described a gradient, in this case a thermal gradient $\frac{dT}{dh}$

which is 0.1km^{-1} [7]. To calculate the depth required to achieve 275K, it is first necessary to calculate the temperature at the surface of Europa.

The effective temperature of Europa is calculated using the blackbody approximation, equating the energy output of the sun incident on the surface of Europa and the power emitted by the moon. The initial step is calculating the power output of the Sun ($P_{S\ emitted}$). This is found using the Stefan-Boltzmann law,

$$P_{S\ emitted} = 4\pi {R_{Sun}}^2 \sigma T_{Sun}^4 \ . \quad (3)$$

R_{Sun}, T_{Sun} are the radius (6.96 x 10^8 m) and temperature of the Sun (5780 K) respectively [6] and σ is the Stefan-Boltzmann constant found to be 5.6703 10^{-8}($Wm^{-2}K^{-4}$) [8]. The power emitted from the Sun is found to be 3.85 x 10^{26} W. Then, to calculate the power incident on the surface of Europa ($P_{E\ incident}$),

$$P_{E\ incident} = P_{S\ emitted}\left(\frac{\pi {R_{Europa}}^2}{4\pi D^2}\right) . (4)$$

In which R_{Europa} is the radius of Europa (1,560.8 km) [1] and D the distance between the Sun and Europa (7.8 x 10^{11} m) [1]. Thus the power incident on the surface has been found to be 3.8 x 10^{14} W. Equation 4 assumes that Europa is facing the Sun, with no other body casting any shade on the moon.

Only a portion of this light is absorbed ($P_{absorbed}$), as due to the albedo (α) of ice some of the power is reflected,

$$P_{absorbed} = (1-\alpha) P_{E\ incident} \ . \quad (5)$$

Some of the power is also emitted away from the surface. Europa, unlike the Sun cannot be assumed to be a perfect black body; instead it is approximated as a grey body. Thus the Stefan Boltzmann equation becomes;

$$P_{E\ emitted} = 4\pi {R_{Europa}}^2 \sigma T_{Europa}^4 \ \varepsilon \ , (6)$$

in which T_{Europa} is the temperature of the surface of Europa, ε the emissivity of the surface, other symbols are as previously described. Assuming the moon is in radiative exchange equilibrium, the rate at which it emits is equal to the rate it absorbs energy. Thus using this assumption and substituting the equations for power emitted by the Sun and Europa into equation 5 the following relationship can be found

$$T_{Europa} = T_{Sun}\sqrt{\frac{R_{Sun}\sqrt{\frac{1-\alpha}{\varepsilon}}}{2D}} \ , \quad (6)$$

in which α (the albedo value of Europa) is approximately 0.67 [9] and the emissivity of smooth ice (which will be assumed in this case) is 0.966 [10]. Therefore the surface temperature of Europa is found to be 93K.

So the required change in temperature is 275K- 93K which is 182K. The depth required to accomplish this change in temperature is then 1.82km. Since this value is much greater than the required pressure, the depth at which water can exist is 1.82km.

Conclusions

This paper assesses the possibility of liquid water existing on Europa. It has been found that liquid water cannot exist on the surface due to the atmospheric pressure, however that it could exist at a depth of 1.82km below the surface.

References

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