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P3_2 Can it Ever Rain on Venus?

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Abstract

Venus is well known to be an extremely hot planet where water does not fall as rain. We investigated whether there were regions where liquid water could form in Venus' atmosphere, which was found to be between 40 km and 60 km. We then calculated how long it would take a raindrop to fall from this region, by finding its terminal velocity. It was found that it would take at least 2.3 hrs for rain to fall, enough time for any raindrop to reach boiling point.

Introduction

Though the surface of Venus is too hot for liquid water [1], it may be possible for liquid water to exist in its atmosphere. If such a region exists where liquid water can form, can this liquid ever reach the surface?

The extremely high pressures of Venus mean that the density of the atmosphere is many times greater than Earth's [1]. This in turn means the terminal velocity of a drop of rain may be low enough that it boils before hitting the surface.

Regions of Liquid Water

The atmosphere of Venus varies little with latitude or time of day; altitude is the largest factor in determining temperature and pressure [1].

To find where liquid water can exist in Venus' atmosphere, a phase diagram of water was used [2]. Atop this, pressure against temperature was plotted and labelled with the altitude, showing which state water will be in at each height [3]. This is shown in Figure 1, where it can be seen that liquid water exists between above 40 km, and up to roughly 60 km.

Terminal Velocity

To find if rain can land, the region below 40 km must be investigated. Due to the high pressure, the terminal velocity, v, within Venus' atmosphere is much lower than on Earth. By finding where gravitational and drag forces are in equilibrium [4], for a given body, v is given by,

$$v = \sqrt{\frac{2mg}{\rho A C_d}}, \tag{1}$$

where m is the body's mass, g is the acceleration due to gravity, ρ is the density of the air, A is the body's projected area, and C_d is the coefficient of drag. A drop of water has $m = 0.04\ mg$, $A = 0.002\pi\ m^2$ [5] and is assumed to be a streamlined body with $C_d = 0.04$.

The ideal gas law gives $PV = nRT$, for a gas with pressure P, volume V, number of moles n, and temperature T, where R is the gas constant. Hence ρ is given by,

$$\rho = \frac{MP}{RT}, \tag{2}$$

where M is the molar mas of the gas. M was taken to be that of CO_2, 0.044 kg/mol, as 96.5% of Venus' atmosphere is CO_2 [1].

From the data for Venus' atmosphere [3], it is possible to find relations for T against H and P against H; linear and exponential regression being used to find formulae for said relations below 40 km. Due to the limited space of this format, plots are not shown. For H in km, and T and P in SI units, best fits (given with the lowest degree of precision which still produces the correct relation), for these relations were found as,

$$P = 10^{\left(\frac{7}{400}H - 3.511\right)}, \tag{3}$$

$$T = -8.1H + 738. \tag{4}$$

A relationship between altitude and terminal velocity can now be found. As Figure 2 shows, v varies between 5.13 and 1.37 m/s. This relationship is treated as linear between its maximum and minimum values. Using the standard equation of motion, the time, t taken to travel this distance is,

$$t = \frac{2(H_{max} - H_{min})}{v_{min} + v_{max}}, \tag{5}$$

Substituting in the minimum and maximum values for v gives the final time as $t = 3.4$ hrs.

Errors

The relationship between H and v is not linear and the acceleration will not be constant. The maximum percentage error this introduces is 30%, meaning $t > 2.4$ hrs.

The large values for H mean the acceleration due to gravity changes between 0 and 40 km. As $g \ \alpha \ R_V$ (Where R_V = the distance from Venus' centre of gravity = H + 6,051.8 km [1]), the change in g is only 1.3%.

Venus' atmosphere is assumed to be an ideal gas, comprised of CO_2. At these pressures, CO_2 would begin to stop behaving as an ideal gas. However, this effect is less than 3% [6], so when accounting for this, gases being present other than CO_2, and a change in g, $t > 2.3$ hrs.

Conclusion

In Venus' atmosphere, there exists a region between 60 km and 40 km where liquid water can exist. If a drop of rain were to fall from this region, it would take it at at least 2.3 hrs to hit the ground. In this time the raindrop would always reach equilibrium with the atmosphere, and boil.

Figures

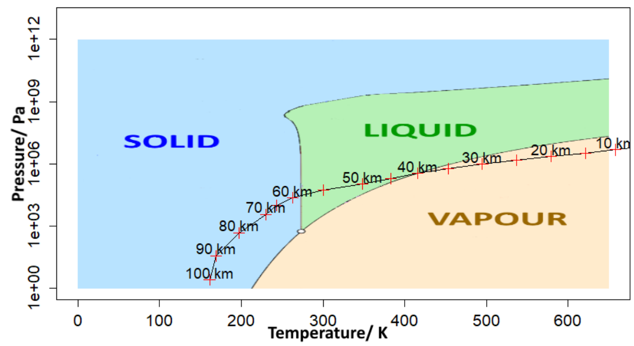

Figure 1: A phase diagram of water, overlaid with points showing T and P at different altitudes on Venus. By coincidence, the 40 km data-point is almost exactly on the liquid-gas boundary, giving a more precise value for the boiling height than was expected.

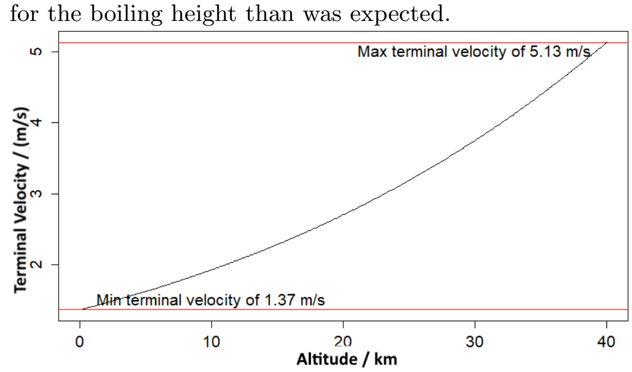

Figure 2: Variation of terminal velocity of a water drop on Venus with altitude.

References

[1] Basilevsky and Head, Rep. Prog. Phys. **66**, 1699 (2003).

[2] https://tinyurl.com/hr77ou5 [7/11/19]

[3] Blumenthal et al., 'Understanding Our Universe' p.167 (2012).

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[5] https://tinyurl.com/y6fsjp8g [7/11/19]

[6] https://tinyurl.com/y4qvtmod [7/11/19]