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A3_8 Injecting particles into the atmosphere

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Abstract

This paper investigates size restrictions on potential particles that could be injected into the atmosphere to absorb some of the solar spectrum, the purpose in mind being to reverse the effects of the loss of ozone. It finds that, were they above the micron length scale, they would be unlikely to remain in the atmosphere for any considerable length of time.

Introduction

Increasingly, there is a trend not only to prevent climate change through human activity, but to reverse some of the effects caused that will prove most harmful to us in the future [1]. Removal of carbon dioxide from the atmosphere is being seriously considered, so, why not also the introduction of particles into the atmosphere? Over the past few decades we have heard many reports of the large hole that has been produced in the ozone layer of the Earth's atmosphere [2]. Ozone itself is very difficult to produce in significant concentrations due to its volatility [3], so an alternative candidate that could be produced to absorb at similar wavelengths is put forward.

The current advances in nanotechnology [4] mean that now, more than ever, materials can be designed to have certain properties, such as absorption and emission spectra fit for purpose. Quantum dots, produced of different metal alloys, can be "tuned" to produce one of a large range of possible wavelengths [5]. A possible application in the context of the atmosphere is that we could "fill in" the ozone hole by producing particles that have a strong absorption band at around 255nm [6] and pumping them into the atmosphere. The question this paper will address is whether or not they will stay there.

Discussion

Particles in a gas have an average kinetic energy [7]:

$$K = \frac{3}{2}kT, \tag{1}$$

where k is Boltzmann's constant and T is the temperature of the gas. The temperature in a given region of the atmosphere is approximately constant. So, assuming that the particles being released into the atmosphere can also be treated as gas particles, they will have an average velocity due to the thermal motion of the gas:

$$v_{th} = \sqrt{\frac{2K}{m}}, \tag{2}$$

where m is the particle mass.

These particles, however, are not in equilibrium with the rest of the gas as they are more massive, so they will have an additional ballistic velocity component which is given as the terminal velocity for a particle falling under gravity experiencing linear drag:

$$v_{bal} = \frac{mg'}{6\pi a\mu}, \tag{3}$$

where a is the particle radius, μ is the dynamic viscosity and g' is the net acceleration given by the difference between gravitational and buoyant accelerating forces:

$$g' = \frac{(m-\rho_a V)g}{m} = \left(1-\frac{\rho_a}{\rho_p}\right)g, \tag{4}$$

where ρ_a is the density of air, V is the volume of the air displaced by the particle = volume of the particle, and ρ_p is the density of the particle being considered.

Dividing equation (3) by (2) gives a ratio which can be used to analyse the particle's motion:

$$\frac{v_{bal}}{v_{th}} = \frac{m^{3/2}g'}{6\pi a\mu\sqrt{2K}} = \frac{(\frac{4}{3}\pi\rho_p)^{3/2}a^{7/2}g'}{6\pi\mu\sqrt{2K}}, \tag{5}$$

where it has been assumed that the particle is a sphere with uniform density. If the ratio gives a value of greater than 1 then ballistic motion dominates and the particle will be more falling than forming part of the gas. If it is less than 1 thermal motion dominates and the particle can be considered as part of the gas. The limiting case occurs when:

$$a = \sqrt[7/2]{\frac{6\pi\mu\sqrt{2K}}{(\frac{4}{3}\pi\rho_p)^{3/2}g'}}. \tag{6}$$

Inputting values for the atmosphere near Earth's surface [8],[9] and taking the density of cadmium selenide as a candidate material [10] as it is used to make quantum dots with a wide range of wavelengths [5], this gives a value of approximately a=1µm. This means that at scale sizes of 1µm or less, thermal motions will dominate and particles of this size will remain as part of airflows in the atmosphere for a considerable length of time.

Conclusion

In this paper it has been determined that if particles were developed to be pumped into the atmosphere, for example to absorb UV radiation, there would be a size restriction on such particles. They would need to be of approximately radius, a=1µm or less in order to remain stable in the atmosphere for any considerable length of time.

References

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