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P2_4 A Very Light Balloon

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Abstract

In this paper we have performed an experiment to verify whether the pressure inside a party balloon is equal to ambient atmospheric pressure, and then performed further calculation to find how powerful a light source would be needed to inflate a party balloon using radiation pressure alone. It was found that the pressure inside a balloon was within five percent of ambient atmospheric pressure, and that a light source of multiple terawatt light output would be needed to inflate a balloon, with a specific value of 8.9x10^{12} W for it to inflate to a standard size.

Introduction

Party Balloons are decorations most commonly made of latex rubber, and inflated with natural air or another gas. Many people often wrongly assume that the air pressure inside a balloon is much greater than the ambient air around it. We sought to provide a definitive answer to the question of the pressure inside a balloon, and then extend this question further to ask how powerful a light source you would need to inflate a party balloon using radiation pressure alone?

The Pressure Inside a Balloon

College Physics [1] claims that the pressure inside a balloon is greater than ambient pressure due to the air inside the balloon having to exert a force against the elastic potential of the balloon surface as well as the external pressure of the ambient air. We conducted our own experiment to find a value for the pressure inside a balloon. We assumed the air inside a balloon to be an ideal gas, and used the rearranged form of the ideal gas law to calculate the pressure:

$$P = nRT/V \tag{1}$$

A balloon was used that very closely approximated a sphere when inflated, which allowed the volume to be calculated easily. This was found to be 0.027 m^3. The temperature used was a measured value of room temperature of 293 K. The number of moles of air inside the balloon was calculated by first measuring the weight of the inflated balloon, and using the Archimedes principle to calculate the buoyant force on the inflated balloon from its volume and a given value for the density of ambient air of 1.2 Kgm^{-3} [2]. The buoyant force value and the weight of the inflated balloon were added together, and then a measured value for the weight of the uninflated balloon was taken away. This value was then converted into moles using a given value for the molar mass of dry air of 29 $gmol^{-1}$ [2]. The number of moles was calculated to be 1.15 moles. The final value of the pressure was calculated to be 104000 Pa, or 1.02 atm. Though there may have been a few sources of error in this calculation, the result is within five percent of ambient atmospheric pressure. The Santa Cruz Institude of Particle Physics [3] found similar results from direct measurement of the pressure inside a weather balloon. These both point toward the pressure difference caused by the elastic potential of the balloon being negligible enough to merit the exclusion of it when calculating the power of the light source.

Power of Light Source

To calculate the power of light source needed to inflate the balloon, it was assumed that we would be using a spherical balloon with a point light source in the centre, and that the pressure inside the balloon would always have to match ambient atmospheric pressure at sea level. The balloon is also assumed to have a perfectly reflecting inner surface, to ensure the light source is perfectly efficient. Radiation pressure is given by equation 2

$$P_r = I/c, \tag{2}$$

where I is the intensity of light, and c is the speed of light [4]. For the pressure inside the balloon to always equal ambient air pressure, the intensity of the light always has to equal 3.04x10^{13} Wm^{-2}. The power of the light needed to inflate the balloon, as a function of the radius of the balloon, will therefore follow equation 3

$$P = 4\pi I r^2. \tag{3}$$

Using equation 3, a graph is plotted showing the power needed to inflate a balloon to a specific radius (Figure 1)

For figure 1, the value of I used was the value quoted earlier in this paper. Figure 1 shows that the light source must be of multiple terawatt power output to inflate the balloon. A common party balloon has a radius of 0.153 m [5], and so to inflate a balloon to this size using only radiation pressure, a light source of 8.9x10^{12} W would be needed.

Conclusion

The first set of calculations showed that the pressure inside a regular party balloon is within five percent of ambient atmospheric pressure. The next set of calculations showed that to inflate a balloon at sea level using only radiation pressure, a light source that has a multiple terawatt power output would be needed. To inflate the balloon to a radius of 0.153 m, a light source of 8.9x10^{12} W would be needed.

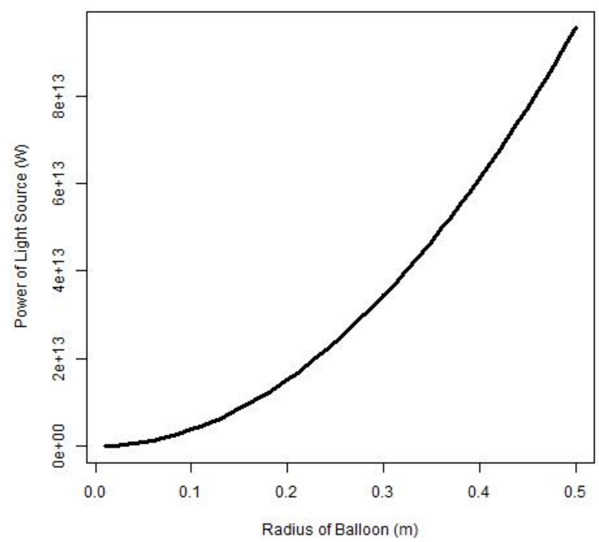

Figure 1: A graph showing the relationship between the inflation radius of a balloon and the power of the light source.

References

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[5] `https://www.signatureballoons.co.uk/balloon-sizes/` [accessed 9/10/2017]