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P4 1 Spoonfuls of Sugar Helps the Black Hole Come 'Round!

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Abstract

Mary Poppins possesses a magical carpet bag that appears to have infinite storage, as shown in the films. In this paper, we test how far we could push the limits of this bottomless bag with spoonfuls of sugar. We work out the threshold density required for the gravitational pressure to overcome the compressive strength of the sugar to form a sphere, $\rho_{thres} = 1.4 \times 10^{30}$ kg m^{-3}. We find that 1.3×10^{28} teaspoons of sugar leads to the formation of a black hole within these restricted dimensions. Significant limitations in our calculations are identified but, overall, our work provides a useful starting point in investigating the limits of this magical bag.

Introduction

Mary Poppins, a theatrical sensation capturing hearts worldwide, features a nanny who travels via an umbrella and cares for the Banks children. She is known for her magical bag that seems to have an unlimited amount of storage despite its fixed volume. We apply gravitational physics to sugar, taking into account its intrinsic properties when compressing it into a sphere. Ultimately, we calculate how many spoonfuls of sugar are required to create a black hole.

Results

Overcoming the Compressive Strength - We assume the sugar fills the rigid volume of the bag, after which additional spoonfuls increase the mass while the volume remains constant. Within our model, the gravitational pressure exerted by the sugar eventually exceeds its compressive strength, causing the sugar in the bag to compress into a sphere. In planetary formation, this transition is attributed to a threshold radius given by

$$R_{\text{thres}} = \sqrt{\frac{2\sigma_y}{\pi G \rho^2}} \tag{1}$$

where σ_y is the compressive strength, G is the gravitational constant and ρ is density [1]. The approximations used in [1] state that the pressure at half the body's radius equals the compressive strength. Here, the volume is free to change along with the mass. However, we assume constant volume due to the magical nature of Mary Poppins' bag. The sugar is free to move within that confined space. Therefore, we are looking for a threshold density rather than a threshold radius.

The effective radius of the bag remains constant until the sugar reaches sufficient density to be compressed. For simplicity, we find the effective initial radius by equating the bag's volume, estimated as a triangular prism, to that of a sphere. We take the bag's width, depth and height to be 0.49 m, 0.21 m and 0.36 m, respectively [2]. The triangular cross section forms the

side of the bag, giving $V_{\text{bag}} = 0.019\,\text{m}^3$. The equivalent spherical radius is therefore $R_{\text{eff}} = 0.16\,\text{m}$. Unlike the constant density used in [1], the density of the body we are considering changes significantly. Due to the complex and extreme nature of this thought experiment, we assume the compressive strength, σ_y, to vary simply with density according to [3],

$$\sigma_y = \sigma_0 \left(\frac{\rho}{\rho_0} \right)^n, \tag{2}$$

where $\sigma_0 = 0.5\,\text{GPa}$ [4] is the compressive strength at the initial density of crystalline sucrose (individual sugar crystals), $\rho_0 = 1600\,\text{kg m}^{-3}$ [5]. For greater realism, we take

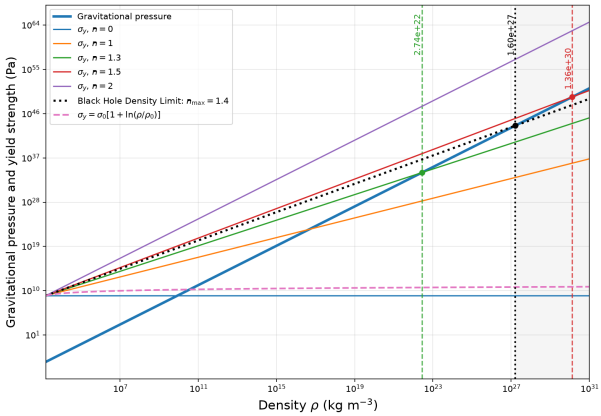

Figure 1: A logarithmic plot presenting an estimated power law for yield stress at varying densities. The body's gravitational pressure shown in blue.

n=1.3, in order for the sugar to not exceed the black hole critical density (see Black Hole Formation). Taking $n < 2$ allows gravitational pressure, which scales as ρ^2 at fixed radius, to overtake an initially greater material strength as the density increases. Figure 1 compares several power laws and a natural logarithmic relationship. At the assumed transition, we substitute (2) into (1) and solve for ρ_{thres}. For $n = 1.3$, this gives $\rho_{\text{thres}} = 1.4 \times 10^{30}\,\text{kg m}^{-3}$, comparable to that of a neutron star. We define this point at which the sugar collapses into a sphere of radius R_f. For the triangular prism bag, the largest sphere that could fit inside would have radius of $R_f = 0.079\text{m}$, calculated from depth and height.

Black Hole Formation - The final stage of our thought experiment is the production of a black hole. We assume that further addition of sugar increases the mass while the sphere's radius remains at the constant R_f. For a spherical body of mass M with no rotation or electric charge, the Schwarzschild radius is

$$R_s = \frac{2GM}{c^2}. \tag{3}$$

Setting $R_s = R_f = 0.079\,\text{m}$, gives the required total gravitational mass of sugar as $M = 5.3 \times 10^{25}\,\text{kg} = 8.9\ \text{M}_\oplus$ [6]. A teaspoon of sugar is 4 g, so this corresponds with 1.3×10^{28} tsp to create a black hole.

Discussion and Conclusions

The results should be treated as estimates due to several significant limitations. Equation 2 extrapolates a reference yield strength across many orders of magnitude in density, without describing changes in composition, phase or temperature. The choice of the exponent strongly affects the result: $n = 1$ gives $\rho_{thres} = 4.6 \times 10^{16}$ kg m^{-3}, whereas $n = 1.3$ gives $\rho_{thres} = 1.4 \times 10^{30}$ kg m^{-3}. If n were greater than 1.4 (Figure 1), the sugar would enter a spherical state after becoming a singularity, which is physically redundant. We took $n = 1.3$ as a reasonable lower estimate for the evolution of the material as its mass increases. Previous literature found n=1.5 for certain crystal lattices at regular pressures [3]. Furthermore, the black hole calculation assumes gravitational isolation, but at just 1 $\text{M}_\oplus$, the gravitational acceleration at 5 m is 1.6×10^{13} ms^{-2}, thus surrounding matter could no longer be neglected unless we introduce a hypothetical mechanism where the bag stops gravitational fields escaping. These assumptions introduce a lot of uncertainty into our calculated density and mass, but the results show the consequences of our confinement model rather than predicting the behaviour of actual sugar at extreme densities.

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