Journal of Physics Special Topics
An undergraduate physics journal

P4 4 A Gloopy Demise

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December 11, 2023

Abstract

In this paper we discuss the possibilities of Augustus Gloop from the book "Charlie and the Chocolate Factory" surviving from falling into the chocolate river. It was found that the heat from the chocolate would take 5.3 hours to raise their internal temperature to a lethal value of 42 °C. Albeit a long time, the probability of him being able to swim though the chocolate is slim due to the increased viscosity. Liquid chocolate is 40 times more viscous than water, and they would therefore probably drown before heat exhaustion.

Introduction

In the book Charlie and the Chocolate Factory a child called Augustus Gloop unfortunately slips into a river of liquid chocolate. In this paper we are discussing the implications of such an accident and the unforeseen consequences that arise. This paper does not look at the effects of being pulled up and becoming stuck in a pipe as seen later on in the book as this is out of scope.

Theory

The first factor to consider is the temperature of the chocolate. The melting points of chocolate depend on the percentage of cocoa, for milk chocolate this is placed between 40 - 45 °C [1]. We are assuming it is milk chocolate as this is one of the most common forms of chocolate, and would be needed in vast quantities in a chocolate factory. A human is not at immediate risk of death until their core temperature reaches 42 °C [2]. To work out if Augustus will survive the 'swim' we need to calculate how long a human will take to reach 42 °C from a core temperature of 37 °C. Using the following,

$$t = \frac{Qd}{\kappa A(T_f - T_i)} \tag{1}$$

where Q is energy transferred, d is depth of heat transfer, κ is thermal conductivity, A is area and T is temperature. There are a few unknowns in this formula we need to know first: Q, d, A and κ. Thermal conductivity of a human can be looked up, this is 0.23 $\mathrm{Wm^{-1}K^{-1}}$ [3]. Q can be calculated using the specific heat formula,

$$Q = mc\Delta T \tag{2}$$

The specific heat of an obese person is roughly 2.7 kJ $\mathrm{kg^{-1}\ K^{-1}}$ [4]. We chose 80 kg for their mass as this is similar to an adult, and given Augustus' size this should not be far off. Using these values with the specific heat equation gives an energy of 1.1 MJ needed to heat Augustus by 5.0 K. The depth is taken to be the distance between the surface of the skin to the vital organs, in this case the lungs. This depth is roughly 20 mm [5]. The last part to calculate is the surface area. This is a bit more complicated and requires a few simplifications and assumptions, as the exact size of Augustus is not stated anywhere in the book. We modelled Mr Gloop as a sphere as he was known for being an obese child. We know the volume of Augustus from his density and mass. The density of an obese human is 900 kgm^{-3} [4]. Using this, the radius of a sphere with this density and an 80 kg mass would be 0.28 m. Then, using this radius, a surface area was calculated to be 0.99 m^2. Substituting these values into equation 1 we get a time of 19000 s, or 5.3 hours. However, this is a simplification, not taking into account heat loss through exposed body parts - such as their head - along with heat generation from trying to stay afloat. The actual time will probably be less due to them trying to swim and therefore generating heat.

Another factor to consider, is it physically possible to swim through chocolate? The density of chocolate is greater than that of water. So, it would be possible to float, but swimming might pose a different challenge. The viscosity of liquid chocolate is up to 40 times that of water [6] making the act of swimming challenging. One way to tackle this problem is looking at the increased drag due to the higher viscosity. Stokes' law states that the drag force for a sphere,

$$F = 6\pi r\eta v. \tag{3}$$

Where r is the radius of the sphere, η is the viscosity of the fluid, and v is the velocity of the object. This shows that if the viscosity increases by 40 times then the drag force also increases 40 times. Assuming that Augustus' swimming force is constant their velocity would have to decrease up to 40 times to keep a constant balance against the drag force. Considering that Augustus was quite unhealthy, the likelihood of him being able to swim in chocolate is very low.

Conclusion

Given that the time to heat up Augustus' core temperature to a lethal value was over 5 hours, the temperature of the chocolate does not appear to pose an immediate threat. The main threat is the inability to swim in such a viscous liquid. With its viscosity being 40 times that of water, the chances of him being able to swim are slim. There is a higher likelihood of drowning rather than heat exhaustion.

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