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Abstract

The fantasy game *Dungeons and Dragons* features a spell which summons devastating meteors. We investigate the impact consequences of one of the meteors by calculating its kinetic energy and based on that, we estimate the size of a crater it would create. The estimate of the kinetic energy equates to 1.31×10^{15} J and the resulting crater measures 588 m wide and 147 m deep.

Introduction

In the fantasy tabletop role-playing game *Dungeons and Dragons* (D&D) there exists a variety of spells which can be cast. One of these spells is called *Meteor Swarm*, which as the name suggests, calls forth four meteors that cause massive damage[1]. However, the spell description makes little mention of the aftermath of these impacts. As such, the purpose of this paper is to calculate the kinetic energy of one of these meteors, after which we will estimate the size of the crater formed via its impact.

Method

We will assume that the meteor arrived from the Asteroid Belt, which is where the majority of meteors that collide with the Earth's atmosphere come from. Furthermore, the majority of meteors are made of Chrondrite, which has a density ρ_i of 3000 kgm^{-3}[2]. It will also be assumed that the meteor is a perfect sphere and will have radius of 12 m, as stated in the spell's description[1].

Due to the size of the meteor, two assumptions will be made: the meteor will not explode in the atmosphere, and atmospheric friction will be negligible[3] and thus the meteor will retain the velocity it had upon colliding with the atmosphere. The minimum velocity of the meteor, which is derived from the gravitational field strength of Earth, is roughly 11 kms^{-1}[4]; this will be the impact velocity v_i. The meteor will collide with the ground with kinetic energy:

$$T = \frac{1}{2} m_i v_i^2 \tag{1}$$

where m_i is the mass of the meteor. This impact with the ground produces a shock wave that both destroys the meteorite and a section of the impacted rock, forming the initial crater in this 'compression phase'. Furthermore, the shock wave will propagate into the ground and cause the surrounding rock from the crater to be ejected or pushed further in - which widens the crater. This is the so called 'excavation phase' and this continues as long as there is kinetic energy to be transferred; which is done in the form of potential energy. This potential energy is described by:

$$U = \rho_t g D_{tc}^4 \tag{2}$$

where ρ_t is the target density, in this case the meteorite will collide with with the Earth's upper crust which has a density of 2600 kgm^{-3}[5], g is Earth's gravitational field strength, and D_{tc} is the transient crater diameter, which is the resulting crater from the excavation phase. The value of D_{tc} can be calculated using the following[6]:

$$D_{tc} = 1.161(\frac{\rho_i}{\rho_t})^{\frac{1}{3}} L^{0.78} v_i^{0.44} g^{-0.22} sin^{\frac{1}{3}}(\theta) \quad (3)$$

L is the diameter of the meteor (24 m), θ is the angle of impact, typically $45°$[7], and the other values are the same as described previously. As a result of the gravitational collapse of the transient crater, its dimensions undergo further adjustments in a 'modification phase'. The extent of the modifications depend on the size of the transient crater and will result in either 'simple' or 'complex'. Due to the size of the meteor, it is likely to produce a simple crater, as D_{tc} will probably be less than the simple-complex transition diameter of Earth D_{sc}; which is about 3 km[6]. As such the final crater will have a bowl shape and the final radius can be calculated using[6]:

$$D_f \approx 1.25 D_{tc} \quad (4)$$

D_f is the final diameter of the crater. For the purpose of this paper, it will be assumed the diameter of the final crater is four times larger than its depth[8].

Results

Since the meteor is a perfect sphere, the volume is simply calculated to be 2304π m^3, which when multiplied by ρ_i gives $m_i \approx 2.17 \times 10^7$ kg. Substituting m_i and v_i into Equation 1 yields the kinetic energy of 1.31×10^{15} J. Following this, substituting the relevant values into Equation 3 gives $D_{tc} \approx 470$ m, which when adjusted by the correction factor in Equation 4, gives $D_f \approx 588$ m. Based on the previously mentioned assumption, this diameter would correspond to a crater depth of 147 m.

Conclusion

In summary, we found that the kinetic energy of the meteor to be 1.31×10^{15} J. This is equivalent to about 3.14×10^8 kg of TNT. This impact results in a crater with a diameter of 588 m and depth of 147 m. It should be noted that the value for the kinetic energy, while massive, is still an underestimate as we utilised the minimum possible velocity for the meteor. Furthermore, it is likely that the meteor would have simply broken up in the atmosphere, or perhaps more worryingly it might have exploded in the air. Ultimately what we find is that even for a meteorite that one might intuitively think is small, it is capable of terrifying destruction.

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