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P1_4 Matchstick Magic

K. Roberts, N. Holt, J. Murphy, J. Tranter
Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract
Magicians often perform a trick where they appear to strike a match in thin air. The purpose of this paper is to examine the feasibility of lighting a match by means of only the friction provided by air. While the original trick is successful via misdirection, our results reveal that in order to legitimately perform such a feat, one would need to strike a match at a speed of $84.32ms^{-1}$. Simply dropping the match, even if it could reach terminal velocity, would fail to ignite it.

Introduction

A common matchstick magic trick is one where a magician seemingly lights a match in midair. The trick of course is to throw a single match up in the air with one hand, and as it falls, light a secondary match using your thumb and the striking surface in your other hand.

"Strike-anywhere" matches are useful and pretty neat, but do they really mean strike *anywhere*? This brings forth the motive for this article: is it possible to light a match in midair? We shall be exploring two scenarios. The first is simply dropping a matchstick from high enough so it can reach terminal velocity, and the second is holding a match stick and making a quick striking motion through the air.

The outcomes suggest that neither method will be added to a magician's repertoire anytime soon. Reasons for this are that scenario one fails to light the match, and scenario two is impossible for a human to perform.

Method and Results

Whilst moving an object a distance d through air, the work done, W, to overcome air resistance, F, causes the object to heat up.

$$W = -Fd \tag{1}$$

In both hypotheses we assume that all work done is transferred to thermal energy. The tip of a strike-anywhere match has approximately 0.01g of phosphorus sesquisulfide (P_4S_3), which has an ignition temperature of 100℃[1]. Thermal energy is calculated using equation 2, in which we have used a standard start temperature of 25℃:

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

Where,

$$n = \frac{mass/molar}{mass} = \frac{0.01g}{219.81\text{gmol}^{-1}} \tag{3}$$

The number of moles of P_4S_3, $n = 4.549 \times 10^{-5}$mol[2], is multiplied by the molar specific heat capacity of P_4S_3, $c = 23.824\text{Jmol}^{-1}\text{K}^{-1}$[3], and the change in heat, $\Delta T = 75$℃. Thus, we found that the thermal energy required to light a match is 0.081J.

Figure 1 shows a diagram of a matchstick that is falling from an arbitrary height, $h > 10$m.

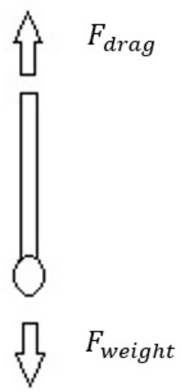

Figure 1: Matchstick falling vertically downwards, affected by the drag force from air. Credit: J.Tranter

Equating the drag force and the weight force, the terminal velocity of a matchstick was found to be 9.28ms^{-1}[4].

$$F_{drag} = -\frac{1}{2} C_d \rho A v^2 \tag{4}$$

$$F_{weight} = mg \tag{5}$$

Where the drag coefficient, $C_d = 0.5$, the density of air, $\rho = 1.184 \text{kgm}^{-3}$[5], the area of the matchstick head, $A = \pi(3.5)^2 \text{mm}^2$, the gravitational constant, $g = 9.81 \text{ms}^{-2}$ and the matchstick's mass, $m = 0.1$g. Using standard equations of motion, the matchstick would reach terminal velocity in 0.95s after falling 4.41m. Substituting this result into equation 1, the work done is 0.00433J and since the work done is set equal to the thermal energy, $\Delta T = 4$℃.

In the second scenario, we are envisioning someone striking across 1m of air with a match. As mentioned previously, in order to light the match, the work done must equal the thermal energy. Thus, using a combination of the above equations:

$$W = \frac{1}{2} C_d \rho A v^2 d = Q = 1.14 \times 10^{-5} v^2 d$$

$$v = \frac{0.081}{1.14 \times 10^{-5}} = 84.32 \text{ms}^{-1}$$

Where the air density and temperature are the same as before.

Conclusion

The thermal energy gained by a matchstick between being dropped and reaching terminal velocity was insufficient to cause the match, or more specifically the phosphorus sesquisulfide, to spark alight. The temperature rose just 4.0℃.

However, striking a match on or in thin air at 84.32ms^{-1}, over a distance of 1m, would theoretically light it. Without mechanical aids, this would be impossible for a human to perform, let alone your average street magician. The restrictions are mainly a human's strength and speed. Other areas which could present problems include the durability of the match and the amount of phosphorus: the mass of such could be less than 0.01g, thus reducing the thermal energy required to ignite.

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