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P3_10 An Alkali Metal Water Bomb

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Abstract

When exposed to water, alkali metals react violently with water to produce a metal hydroxide and hydrogen. Here, we will explore how much energy is released in a typical reaction, and find out how much lithium and water are needed to release the energy equivalent of 'Gadget'; an atomic bomb dropped in the Nevada Desert in 1945, as part of the 'Trinity' project [1]. We find that the total mass of this lithium-water bomb would be around 9.01 $\times 10^9$g.

Introduction

In 1945, the USA dropped an atomic bomb named 'Gadget' in the Nevada Desert, one of several bombs tested here. This explosion released the equivalent of 19 kilotons of TNT (79.5TJ), marking the start of The Atomic Age [1]. Two decades later, the Partial Nuclear Test Ban Treaty was introduced in 1963, banning all overground tests [2].

Alkali metals are well-known for their violent reactions with water and air, and as you go down the group, the reactivity increases. Here, we will explore how much lithium and water are needed to produce the energy equivalent to this test bomb (79.5TJ of energy), as mentioned above.

Method and Results

To begin, we must write out the balanced chemical equations for the reaction of lithium with water, which produces lithium hydroxide and hydrogen.

$$2\,\mathrm{Li}\,(s) + 2\,\mathrm{H_2O}\,(l) \longrightarrow 2\,\mathrm{LiOH}\,(aq) + \mathrm{H_2}(g)$$

where the molar ratio of Li:H_2O:LiOH:H_2 is 2:2:2:1.

This reaction is exothermic and releases approximately 440 kJmol^{-1} [3]. We can find the total number of moles of lithium and water needed to release 79.5TJ of energy by dividing this energy by the amount of energy released per mole in this reaction (440 kJmol^{-1}). Doing so yields an amount of 1.81 $\times 10^8$ mol. However, this value needs to be doubled as the molar ratio of lithium and water is 2, so the number of moles of lithium and water needed is 3.61 $\times 10^8$ mol.

Now we can find the total mass of lithium and water needed to produce 79.5TJ of energy. We can do this by using the following equation:

$$m = nM_r, \tag{1}$$

where m is the mass (g), M_r is the molar mass of the molecule (gmol^{-1}), and n is the number of moles. This molar mass of lithium is 6.94 gmol^{-1} [4], and for water, it is 18.0 gmol^{-1} [5]. Plugging into Eqn. 1 means that 2.51 $\times 10^9$g of lithium and 6.50 $\times 10^9$g of water are needed for the reaction. Converting to kilograms and adding these two masses together gives a total mass of 9.01 $\times 10^9$g.

However, as mentioned in the introduction, the heavier alkali metals react more violently with water, as can be seen in a Brainiacs episode where a small amount of caesium blows up a bathtub [6]. In theory, less caesium should be needed to produce 79.5TJ due to how reactive this element is, compared to lithium.

If we plug in the energy released per reaction with caesium, the second most reactive of the alkali metals, (406 $\mathrm{kJmol^{-1}}$)[3], and its molar mass (133 $\mathrm{gmol^{-1}}$)[4], we find that the mass of caesium needed is 5.21 $\times 10^{10}$g, much higher than the mass of lithium, due to its higher atomic mass, but similar value for the energy released per reaction. However, this calculation doesn't represent what we expected to find, and we shall explore why this is in the next section.

Discussion and Conclusion

Here, we will discuss the viability of an alkali metal bomb. For lithium, the bomb appears to be viable, with estimated global reserves at 1.40 $\times 10^{13}$g [7]. The amount of lithium required is about 2.51 $\times 10^{9}$g, just 2.51% of the 1 $\times 10^{11}$g extracted in 2021 [7]. By comparison, the amount of caesium required is 5.21 $\times 10^{10}$g. The Earth's crust contains 1.65 $\times 10^{11}$g of caesium [8], thus there is just about enough caesium on Earth to supply three bombs. However, as well as reacting violently with water, it also reacts violently with air, making it both incredibly dangerous and expensive to store in these quantities.

We've seen how much damage caesium can cause, blowing up a bathtub with a test tube of caesium, implying a lower mass would produce a more violent reaction. In the episode, they mention that the substantial buildup of hydrogen produces a violent reaction [6]. However, the energy released per reaction remains constant as you go down the group, perhaps in the form of heat over kinetic energy. We have also assumed a 100% efficient reaction and have not accounted for the energy released from the buildup of hydrogen. While a less efficient reaction would increase the mass required, accounting for the hydrogen buildup might decrease it. A future paper could explore to what extent these factors play in the final answer.

In conclusion, we have found that we would require 2.51 $\times 10^{9}$g of lithium for our theoretical alkali bomb. This value might not be entirely accurate as lithium tends to react slowly, releasing most of its energy as heat, making it a less viable candidate. We could use more reactive alkali metals, but this would be incredibly expensive and dangerous to store, even in small quantities. Future papers could explore the impacts that a less efficient reaction and the energy released due to hydrogen buildup have on our final calculation.

References

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