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P1 6 Excalibur: Sword of Promised Victory

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Abstract

In this paper, we discuss the energy and intensity of the beam of light emitted by the sword *Excalibur* in Kinoko Nasu's *Fate* series of works. The energy of the beam of light was found to be 9.4 $\times 10^{15}$ J and therefore the intensity of the light on perfectly absorptive surfaces is 1.1 $\times 10^{25}$ W m^{-2}.

Introduction

In the *Fate* series, the sword Excalibur is a magical blade producing a tall yellow light that pierces the clouds when unleashing its full power [1]. In this paper, we calculate the energy of the beam of light from the sword and intensity of the light using the damage caused by deployment of its power.

Theory

In the *Fate/Stay Night* visual novel, it is said that previous deployment of the sword's power evaporated the local river [2]. Since we know that the river in question is 665 m wide [3], and 12 m deep [4] (due to it being based off the area around the port of Kobe), and assuming that the length of water evaporated was equal to the length of the beam of light, 457 m [5], the volume of the water evaporated is calculated as 3.65×10^6 m^3. Using this value and the formula

$$\rho = m/V \tag{1}$$

where the density of water $\rho \approx 1000$ kg m^{-3} [6]. The mass of the water is, therefore, approximately 3.65×10^9 kg.

Therefore, the energy of the beam of light can be estimated by calculating the energy required to evaporate the water of the river, found using the following formula:

$$E = mc_p\Delta T + mL \tag{2}$$

where m is the mass of the water, c_p is the specific heat capacity of the water (4190 J kg^{-1} K^{-1} [6]), ΔT is the change in temperature from base temperature (20.6°C [7]) to the boiling point of water (100°C), and L is the specific latent heat of vaporization (2.26×10^6J kg^{-1} [6]).

Using equation 2, the energy required to evaporate our volume of water is 9.46 $\times 10^{15}$ J.

Considering how the light is yellow and therefore has an average wavelength of 575 nm [8], each photon within the beam of light would have an energy of 3.45 $\times 10^{-19}$ J due to the formula:

$$E = hc/\lambda \tag{3}$$

Therefore, there would be 2.74 $\times 10^{34}$ photons present within the beam.

Since the beam of light is the width (12 cm [1]) and depth (4.5 mm [9]) of the sword, propagated upwards towards the sky and hitting the lowest clouds (457 m [5]), its volume is found as 2.47×10^{-1} m ^{3} and therefore would have an energy density of 3.83×10^{16} J m^{-3}. From this, and assuming that water is a perfect absorber of photons, the radiation pressure exerted upon the surface of the water by the photons can be found as $p = u$, where u is the energy density, and would therefore have the same value.

To find the intensity of light on a perfectly absorptive surface, which we assume the water to be, the following formula is used [10]:

$$I = pc \tag{4}$$

where p is the radiation pressure exerted on the surface and c is the speed of light in vacuum (2.998×10^8 m s^{-1}). This value was found to be 1.15×10^{25} W m^{-2}.

Discussion

The energy of the beam of light is very much a minimum estimate, and because we don't know the length of the river due to it being fictional, the length of the beam of light was used. In reality the volume of the water evaporated would likely be much larger, especially considering the light was able to evaporate the depth and width of the river despite the beam of light being so thin. Another reason why this is the minimum is because it ignores any heating of air around the sword due to the light.

Another assumption made in this paper is that water fully absorbs photons, in reality this is not the case as a significant portion of the photons would be reflected instead. This would require changes to both the conversion between energy density and radiation pressure, where the conversion ranges from $p = u$ for perfect absorbers to $p = 2u$ for perfect reflectors [10], and for the formula connecting radiation pressure and intensity, where $I = pc$ for perfect absorbers and $I = pc/2$ for perfect reflectors. Therefore, while the energy density of the beam of light would change, the radiation pressure would not, as the two changes to the formulae would cancel out.

Conclusions

Overall, the minimum energy of the beam of light produced by the sword *Excalibur* was found to be 9.46×10^{15} J, equivalent to 2.74×10^{34} photons in the yellow wavelength. The intensity of the light on an absorptive surface as shown in the works was also found as 1.15×10^{25} W m^{-2}, equivalent to 8.33×10^{21} times the intensity of sunlight on the Earth's atmosphere [11].

References

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