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P3_5 Properties of a Kyber Crystal

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Abstract

This paper analyses the required properties for a lightsaber's "Kyber Crystal". We conclude that it must have a power output of around 63.6MW to be able to generate a lightsaber temperature of $7680K$. It must also be able to generate an intrinsic magnetic field of $10.8mT$.

Introduction

In the Star Wars universe, lightsabers are powered by small crystals known as "Kyber Crystals" (or "Kaiburr Crystals") [1]. These crystals must provide all the required energy output and magnetic field generation for the saber to operate. Lightsabers themselves are super-heated plasma directed into the shape of a blade [2]. An analysis of the logistics of a lightsaber has been performed in a previous Physics Special Topics paper [2] but an analysis on the power requirements of a Kyber Crystal has not been performed, a gap this paper intends to fill.

Theory

We start by analysing the power output as shown in the movie "The Phantom Menace" [3]. In this film we see Qui Gon Jinn use his lightsaber to melt through the centre of a thick metal blast door, after trying to cut a circular section out. We assume that this metal is steel equivalent, with an equivalent density, melting point, Specific Heat Capacity (c), and Latent Heat of Fusion (H_{fus}). This gives us values of $\rho = 7850kgm^{-3}$ [4], $M_p = 1500^oC$ [5], $c = 420Jkg^{-1o}C^{-1}$ [4] and $H_{fus} = 247kJkg^{-1}$ [6] assuming steel has a similar H_{fus} to iron. We then determine the volume of melted material. We take the door to be 1 meter thick, and assume a cylinder of melted material at the centre with diameter 0.5m. This provides a mass of melted material of

$$M = V\rho = (\pi R^2 h)\rho. \tag{1}$$

In the film the cylinder is almost entirely melted through so we assume that the steel is brought from 20^oC to melting temperature, with this difference being ΔT, and enough energy is provided to overcome the H_{fus}. We assume that all energy output is contained within the cylinder. From this we determine that the energy required from the lightsaber is

$$E = (H_{fus} \times M) + (\Delta T \times M \times c). \tag{2}$$

It takes 20 seconds for the lightsaber to melt the door to this point so we get a power output of

$$P = E \div t \tag{3}$$

in order to generate enough energy to do this. We can assume that this is the steady amount of power given off as there is no obvious change in saber operation.

We use the Stefan-Boltzmann law to find lightsaber operation temperature. We model the saber as a cylinder of radius $r = 0.05m$ and height $h = 1m$. We assume that all the energy is given out through the edges and top of the cylinder and none is emitted through the handle of the saber and that emissivity $\epsilon = 1$. The Stefan-Boltzmann constant is taken as $\sigma = 5.67 \times 10^{-8} W m^{-2} K^{-4}$. The emitting area is $A = 2\pi rh + \pi r^2$. The Stefan-Boltzmann law can be rearranged to give

$$T = \left(\frac{P}{A\epsilon\sigma} \right)^{\frac{1}{4}}. \tag{4}$$

Using $K_e = \frac{3}{2} KT$, where K is the Boltzmann constant and K_e is average kinetic energy, we can determine the average kinetic energy of the plasma ions. We make the assumption that the only constituent element of the plasma is nitrogen, the most readily available element in breathable atmospheres. The mass of 1 Nitrogen atom is $m_n = 2.33 \times 10^{-26} kg$. We then determine the average velocity of the particles to be

$$V = \left(\frac{2K_e}{m} \right)^{\frac{1}{2}} \tag{5}$$

Due to the difficulty in creating a containment magnetic field, as discussed in [2], we shall assume that the plasma is contained by an infinitely thin magnetic field line from the center of the saber handle. This means the only major deviations will be thermal oscillation. We assume the nitrogen is only ionised a single time. To grant the blade a defined edge, we assume all particles have the average velocity. The gyroradius equation can be rearranged to

$$B = \frac{m_n V_p}{q r_g} \tag{6}$$

where B is the magnetic field strength, m is the mass of the particle, V_p is the perpendicular velocity, q is the charge, and r_g is the gyro-radius. To ensure all particles are contained within the beam radius of $r_g = 0.05m$, we assume that it must be able to contain particles where $V = V_p$.

Results

We obtain a mass of $M = 1540kg$. The energy requirement was $E = 1.27GJ$ and then using the 20 seconds we obtain a power of $P = 63.6MW$. The emitting area is $A = 0.322m^2$ and combining this with our power we get $T = 7680K$ (putting the saber colour in the UV range rather than the depicted green colour). The average particle kinetic energy is therefore $K_e = 1.59 \times 10^{-19} J$ and the velocity is $V \approx 3700ms^{-1}$. Finally, using this in equation(9) we find that the magnetic field strength requires is $B = 10.8mT$

Conclusion

We conclude that a Kyber crystal must be able to output a steady 63.6MW of energy for lightsaber operation. In addition, in order for the plasma to be contained, it must be able to generate a magnetic field of 10.8mT. Future papers could use this energy output to analyse other uses for Kyber crystals. For instance, the "Death Star" is powered by Kyber Crystals so an analysis of requirements for such a fully armed and operational battle station could be done.

References

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