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A2_2 Why So Blue?

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Abstract
We determine that the probable source of the blue glow emitted by Dr Manhattan, a character in the graphic novel "Watchmen", is the ionisation and excitation of nitrogen in the air around him. Through comparison with a filament lightbulb his minimum power output from photon production is estimated. Taking into account the dissociation and ionisation energies of each of the fluorescing molecules provides an upper limit on his power output. These limits are ≈ 470 W and ≈ 3300 W, respectively.

Introduction

Dr. Manhattan is a god-like being from the graphic novel "Watchmen" [1]. In a sequel to "Watchmen" it is revealed that he is constantly leaking high energy β-particles [2]. It is a popular fan-theory that these β-particles produce Cherenkov radiation, and hence his blue glow. In this paper we test this theory by calculating the energy required by a β-particle to produce Cherenkov radiation in air, and comparing this value to the theoretical maximum energy of a β-particle produced through spontaneous nuclear fission. We also consider the fluorescence of nitrogen ions in the air as a possible source of the glow and estimate the energy flux through Dr Manhattan's surface. These results are used to put limits on his power output.

Theory and Results

Cherenkov radiation is produced when a charged particle travels faster than the phase velocity of light in a dielectric medium. Phase velocity is given by $v = c/n$, where v is the phase velocity, c is the speed of light in a vacuum, and n is the refractive index of the dielectric medium. For air, $n \approx 1.0003$ [3]. The energy of a relativistic particle is given by:

$$E = \frac{m_0 c^2}{\sqrt{1 - v^2/c^2}}, \tag{1}$$

where E is the total energy of the particle, v is its velocity (taken to be the phase velocity of light in air) and m_0 is its rest mass. Substituting the calculated phase velocity of light in air and the rest mass of an electron (9.11×10^{-31} kg) into equation 1 gives that the minimum energy required by a β-particle to produce Cherenkov radiation in air is 20.9 MeV. The maximum β-particle energy obtainable through spontaneous nuclear fission (which we assume to be analogous to Dr. Manhattan's atomic disintegration) is 20.6 MeV from the fisson of Boron-14 [4], making Cherenkov radiation highly unlikely as the source of his glow.

The other likely glow-mechanism is the ionisation of air around Dr. Manhattan, and the fluorescence of singly ionised nitrogen II at 443.4 nm, 444.7 nm, and 463.0 nm [5]. We assume that each of these transitions occur at equal rates. From $E_\gamma = \frac{hc}{\lambda}$, where E_γ is photon energy, h is Planck's constant, and λ is photon wavelength, the mean photon energy produced by Dr. Manhattan is 4.41×10^{-19} J. By eye he appears capable of glowing with roughly the same surface brightness as a filament lightbulb. We consider a standard A60 E26 filament lightbulb as producing around 2.6 W of light energy and model it as a sphere of radius 3.75×10^{-2} m. The visible light flux through its surface is then ≈ 147 Wm^{-2}. The surface area of a humanoid is difficult to calculate but can be very roughly approximated as the surface area of a cuboid with the height of the human, a width equal to their shoulder-to-shoulder measurement, and a depth measurement. Using this model for Dr Manhattan and dimensions of $1.8 \times 0.5 \times 0.3$ m - his total light energy production to match the surface flux of a lightbulb is then ≈ 470 W. This corresponds to the production of 1.07×10^{21} photons s^{-1}. Given that the dissociation energy of nitrogen is 945 kJ mol^{-1} [6] and its first ionisation energy is 1402.3 kJ mol^{-1} [7], Dr. Manhattan's maximum required power output is ≈ 3300 W if he has to dissociate a nitrogen molecule and ionise each atom to produce a pair of photons.

Conclusion

We have established that Cherenkov radiation is not the likely mechanism of Dr Manhattan's glow, as β-particle energies greater than those obtainable through spontaneous fission would be required in air. We calculated two limits on his power output by comparing his surface area and flux to that of a lightbulb. At the lower limit only the energy required to excite N II ions to produce this flux is taken into account, which does not account for the initial ionisation and dissociation or any recombination of ions taking place. At the upper limit we assumed that Dr. Manhattan would have to dissociate and ionise a nitrogen molecule anew each time he excited an ion. At ≈ 470 W and ≈ 3300 W the two limits were accordingly almost an order of magnitude apart. This broad range of possible power outputs is partly due to the many other assumptions made - Dr. Manhattan's surface flux is not known, and we have over-simplified the geometry of both his person and of a lightbulb. We assume that the entirety of his power output is either as light, or goes into breaking apart and ionising nitrogen molecules, and also that N II ions alone are responsible for the light he produces. As such, it is not possible to quantify the uncertainties on these numbers. Also of note, when Dr Manhattan travels to Mars in "Watchmen" he retains his glow despite the thin, nitrogen poor atmosphere. This suggests that either ionised nitrogen is not the source of his glow, or the series fell short of scientific accuracy in depicting the character.

References

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