A1 8 How To Build Your Own Aurora

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Abstract

This paper presents a framework for a large-scale (100 m^3), contained artificial aurora. We derive the energy required to sustain a low-pressure plasma via an external radio frequency field, deriving the required power density of 267 Wm^{-3} for an argon plasma, which results in a feasible input power of 26.7 kW. This is briefly taken further in considering other gases, linking the photon output to the energy cost. Finally, we establish the principles of plasma control through the use of the Lorentz force, showing how this could be used to shape the glow.

Introduction

The Aurora Borealis and Australis are striking examples of plasma physics, occurring when energetic particles from the solar wind collide with and excite atmospheric gases, primarily atomic oxygen and molecular nitrogen [1]. The subsequent de-excitation of these atoms and molecules releases photons of discrete energy.

This paper explores the theoretical framework for inducing a similar phenomenon within a defined, bounded low-pressure region of gas, energised by an oscillating electromagnetic field. The basis of this relies on three processes: the acceleration of free electrons by the field, the transfer of their kinetic energy to neutral gas atoms via collisions, and the radiative de-excitation of those atoms, which produces light. We aim to establish the first-order physics and energetic requirements for such a system.

We model a bounded volume (V) containing a working gas at a low pressure (p) ($1 - 100$ Pa). An external radio frequency (RF) source is assumed. This creates an oscillating electric field ($\vec{E}(t)$) within the volume, accelerating the ambient free electrons. At sufficiently low pressure, the electron mean free path allows for electrons to gain significant kinetic energy (K_e) from this acceleration before they collide with a neutral gas atom, exciting them to raised energy levels. Through spontaneous emission, this neutral atom will then de-excite, releasing a quantised, monochromatic photon of energy equal to the energy level gap. The observable glow is the macroscopic sum of these individual quantum events.

Analysis

To ignite a self-sustaining plasma, the rate of electron generation must equal or exceed the rate of electron loss. The minimum voltage (V_B) required to achieve this is a function of the gas pressure (p), and a characteristic system separation (d) (such as the distance between field applicators). This relationship is described by Paschen's Law [2] and is met by a standard RF power system.

Once the plasma is formed, the input power (P_{in}) must compensate for all power losses (P_{loss}). For large, low-pressure systems, the

dominant loss is from diffusion at the walls [3], where the particles subsequently recombine.

The power density (ρ_P) is this wall loss divided by the volume (V). This is derived from the global power balance equation [4, Ch. 10], which in power density form is:

$$\rho_P = \frac{P_{\text{loss}}}{V} = \frac{\epsilon_c \times \Gamma_i \times A}{V}. \tag{1}$$

Here, A is the wall surface area, Γ_i is the ion flux to the wall, and ϵ_c is the collisional energy cost (the energy lost for each ion-electron pair lost to the wall). The ion flux can be approximated as $\Gamma_i \approx 0.6 n_0 u_B$ [4, Eq. 15.5.3], where n_0 is the plasma density and u_B is the Bohm velocity [5]:

$$u_B = \sqrt{\frac{k_B T_e}{m_i}}. \tag{2}$$

Combining these gives the predictive equation:

$$\rho_P \approx \epsilon_c \times (0.6 n_0 u_B) \times \left(\frac{A}{V}\right). \tag{3}$$

This equation shows that power density is not fixed. Instead, it is a function of the plasma parameters (n_0, T_e), the gas type (ϵ_c, m_i), and the chamber geometry ($\frac{A}{V}$).

For argon, we can apply this framework to calculate the required power. We assume typical parameters for a glow discharge ($n_0 = 10^{16}$ m^{-3}, $T_e = 3$ eV) and our system geometry ($V = 100$ m^3, $A = 129$ m^2, giving $\frac{A}{V} = 1.29$ m^{-1}).

We combine these with argon-specific data: an Ion Mass (m_i) of 6.63×10^{-26} kg and a collisional Energy cost (ϵ_c) of ≈ 80 eV at $T_e = 3$ eV.

These values yield a u$_B$ of 2690 ms^{-1} and, from Equation(3), a power density of 267 Wm^{-3}. This results in a total required power of 26.7 kW, confirming the energetic feasibility of this system

The choice of gas is not only relevant to the colour of light, but also a key factor in the power requirement. The ion mass (m_i), and the collisional energy cost (ϵ_c), vary significantly. ϵ_c is high for molecular gases like N$_2$ due to additional energy loss channels (e.g., vibrational and rotational excitation) [4, Pg. 82].

Beyond simply sustaining the plasma, its structure can be manipulated by introducing an external static magnetic field ($\vec{B}$). The motion of the charged particles (electrons and ions) is governed by the full Lorentz force:

$$\vec{F} = q(\vec{E} + \vec{v} \times \vec{B}). \tag{4}$$

In this model, the oscillating $\vec{E}$ field acts as the primary energy source. The magnetic term, $\vec{F}_B = q(\vec{v} \times \vec{B})$, acts as a guiding or confining force. This force is always perpendicular to both the particle's velocity ($\vec{v}$) and the magnetic field ($\vec{B}$), so it does no work on the particle. Instead, it forces the electrons and ions into gyrations around the magnetic field lines.

The consequence is a significant reduction in plasma diffusion across the magnetic field lines, while motion along them remains largely unrestricted. The plasma is magnetised and will tend to flow along the magnetic field. Since the visible glow is located within the plasma, this mechanism allows the glow to be sculpted. By engineering the vectorial components of the applied $\vec{B}$ field (through the use of external coils), the plasma can be directed, providing a direct mathematical basis for shaping the artificial aurora.

Discussion and Conclusion

This framework establishes the theoretical and energetic feasibility of a large-scale, artificial aurora system. The analysis shows that the power requirements of 26.7 kW for argon are energetically feasible with current technology and would produce a violet colour [6]. This framework can also be used with data from other gases, the results of which would allow for photon emissions of a range of energies and colours dependent on the discrete energy levels of the chosen medium, for example, using pure Neon would produce a red glow [6], as its strongest emissions are in the 585–650 nm range. The change in properties, however, would also have a consequence to the power input necessary, with lighter elements needing greater power sources.

References

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