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Building A Controlled Plasma Discharge System for Visual and Applied Physics Learning

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Abstract

Often regarded as the fourth state of matter, the term 'plasma' is important for sophisticated technologies including space propulsion and industrial cutting. During the course of the project, we created a simple plasma gun prototype to exhibit how plasma may be produced and manipulated via the laws of physics. The design includes two electrodes with an inert gas like argon flowing in between them and is connected to a high-voltage power supply. An electric arc creates ionization in the gas which gives out a stream of plasma while its exit is controlled by magnetic coils which demonstrate an electromagnetic effect on the plasma as charged particles. This setup is based on core principles like electric discharge, Joule heating, Lorentz force, and basic fluid dynamics. While quite simple, our model attempts to demonstrate the core principles of electric discharge, Joule heating, and the Lorentz force. It allows capturing first-hand experience with effects that tend to be relegated to textbooks or labs. Other versions of the system are in use for an array of applications such as plasma cutters, ion thrusters, and even as sterilizers. The target for this project is to lower the barriers for students and educators while encouraging innovation around plasma technology for future projects.

Keywords: *Plasma Gun, Electric Arc, Ionization, Magnetic Confinement Joule Heating, Lorentz Force, Plasma Applications.*

1. Introduction

Plasma is known as the fourth state of matter and plays a significant role in both natural phenomena and industrial applications. It consists of charged particles ions and electrons that can conduct electricity and respond to magnetic fields. While plasma is commonly found in lightning, the sun, and stars, its engineered form is increasingly used in technologies such as plasma cutters, sterilization systems, and space propulsion devices. Despite its vast applications, plasma behavior is rarely seen directly by students at the academic level due to safety, cost, and technical complexity [1]. This project aims to make plasma more accessible and understandable by designing a simplified plasma gun. The prototype allows users to generate plasma using high-voltage electrodes and control its flow through magnetic fields. Through this demonstration, learners can witness key physical concepts like ionization, electric discharge, and Lorentz force in action. Our goal is to provide a working model that supports learning, sparks curiosity, and serves as a stepping stone for more advanced plasma-based research and innovations.

2. Methodology

The development of the plasma gun involved a step-by-step integration of components governed by core physics principles. The methodology can be outlined as follows:

- Electrode Configuration: A pair of electrodes cathode and anode were arranged facing each

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other within a containment chamber. These were connected to a regulated high-voltage DC power source capable of generating arc discharge.

- Gas Flow Integration: An inert gas (argon) was introduced through a dedicated inlet located near the cathode. The flow rate was kept minimal to maintain visibility and control of plasma formation.
- Plasma Generation: Upon powering the system, an electric arc formed between the electrodes. This arc ionized the argon gas, transforming it into visible plasma.
- Magnetic Coil Placement: Magnetic coils were positioned around the nozzle to generate a field that influenced plasma flow using the Lorentz force.
- Safety and Testing: All electrical components were insulated, and gas handling was performed under supervision. Multiple test runs were conducted by varying voltage and magnetic field strengths to observe stability and direction of the plasma jet.

3. Applications of a Plasma Gun

- Plasma Cutting and Welding: Used in industries to cut or weld metals with high precision.
- Space Propulsion: Forms the base for plasma thrusters (like Hall-effect thrusters) used in satellites and spacecraft.
- Surface Modification: Used for cleaning, coating, and modifying surfaces at the microscopic level (e.g., in electronics and aerospace).
- Sterilization: Cold plasma is used to sterilize medical equipment and surfaces without heat damage.
- Plasma Waste Treatment: Breaks down hazardous waste into non-toxic gases through plasma arc gasification.
- Material Processing and Nanofabrication: Assists in manufacturing nanomaterials and semiconductor components. And many more. Table 1 shows Prototype Specifications and Configuration Parameters.

Table 1 Prototype Specifications and Configuration Parameters

EDM Tool	Specifications
Operating Voltage	800 – 1200 V DC
Gas Type	Argon
Gas Flow Rate	~1.0 – 1.5 L/min
Electrode Material	Tungsten (Cathode), Copper (Anode)
Electrode Gap	0.5 – 0.7 cm
Arc Generation Mechanism	High-voltage electric discharge
Plasma Jet Length	Up to 6 cm (observed visually)
Magnetic Coil Placement	Surrounding the nozzle region
Control Method	Manual triggering with safety switch

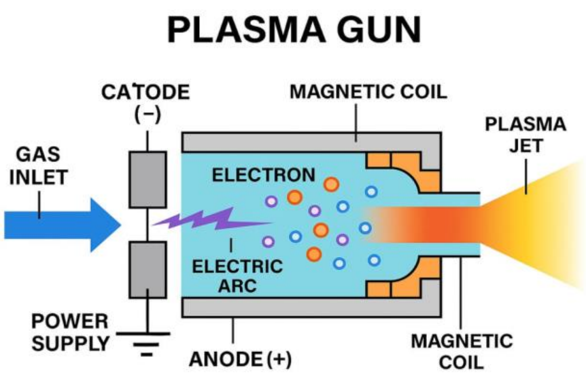

Figure 1 Basic Structure of The Prototype of Plasma Gun

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4. Results

The plasma gun prototype was tested under controlled lab conditions to analyze its performance in generating and projecting plasma. The primary focus was on observing visible plasma formation, its shape, length, and response to magnetic confinement. The system operated at voltages ranging from 800 V to 1200 V, with argon gas flow regulated between 1.0 and 1.5 L/min. Upon activation, a strong electric arc was formed between the cathode and anode, resulting in immediate ionization of the gas. The magnetic coils placed near the nozzle successfully influenced the direction of the plasma jet. The visible length of the plasma stream was approximately 5–6 cm, and the plasma beam maintained good stability during operation. The effect of changing gas flow rate and arc distance on plasma visibility and strength was also noted. The results confirmed the viability of generating a controllable plasma stream using basic engineering principles and accessible components. Figure 1 shows Basic Structure of The Prototype of Plasma Gun.

5. Discussion

The results support the theoretical basis of the project. The generation of a stable plasma stream using simple electrode and arc discharge methods highlights how core physical principles such as electric discharge, ionization, Joule heating, and the Lorentz force operate in practical settings [2]. The prototype successfully demonstrates that a magnetic field can alter the trajectory and confinement of plasma, as predicted by magnetohydrodynamics. This project not only meets its objective of visualizing plasma behavior but also serves as an educational model for illustrating electromagnetic interaction in real time. Compared to commercial plasma devices, this low-cost setup offers a safe and effective way to explore advanced physics topics. The flexibility of the design also opens possibilities for future upgrades such as automated triggering, integrated sensors, or even basic plasma diagnostics. Overall, the discussion confirms that the prototype is both technically functional and pedagogically valuable.

Conclusion

The design and testing of the plasma gun prototype confirmed the initial hypothesis that plasma can be effectively generated and directed using basic components such as electrodes, inert gas, and magnetic coils. Observations supported the application of theoretical principles such as electric discharge, Joule heating, ionization, and Lorentz force. The successful generation of a controlled plasma jet validated the educational and experimental potential of the model. The outcomes not only demonstrated the interaction between electromagnetic forces and ionized gas, but also offered a safe, accessible, and cost-effective tool for academic demonstration and future development. Thus, the project met its objective of making plasma physics both visible and understandable through a hands-on, functional device [3].

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