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STUDY ON EFFECT OF MAGNETIC FIELD ON ELECTRON TEMPERATURE IN POLYATOMIC ORGANIC GAS PLASMA

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Abstract:

The paper outlines a study on effect of magnetic field on the velocity of sound waves and the kinetic energy of electrons (electron temperature) , using the sonic probe method. It has been observed that the electron temperature increases (from 1.08×10^4 K to 1.93×10^4 K) with increase in longitudinal magnetic field (0 to 200 Gauss)for methanol gas plasma at a pressure of 60.6 volt/mm.torr. The study reveals that electron energy/temperature and sound velocity in polyatomic organic gas plasma are higher in magnetically confined plasma under similar conditions. Additionally, the discharge characteristics of different organic gas plasmas are compared with those of air plasma.

Keywords: Electron energy/temperature, Sonic probe, polyatomic organic gas plasma.

Introduction:

The current investigation utilizes the sonic probe method, as introduced by Bhatnagar et al. (1972) to analyze plasma, which has proven effective in various studies alongside other techniques like those used for alkali plasmas and laser-induced plasmas. However, most studies have focused on plasmas in air, hydrogen, oxygen, xenon, and alkali atoms (such as sodium, potassium, lithium, and cesium), leaving polyatomic organic gas plasmas largely unexplored. Although there has been significant work in the field of plasma chemistry, particularly in studying chemical reactions and the synthesis of organic/inorganic compounds in plasma, the investigation of plasma produced by discharge through organic gases containing polyatomic molecules remains rare.

Baeva et al. (2021) created a two-dimensional magneto hydrodynamic model of an argon-operated plasma spray torch, while Yu et al. (2021) conducted research on non-equilibrium subsonic and supersonic inductively coupled plasmas (ICPs). Zhang et al. (2021) introduced a new technique in plasma micro-machining, highlighting the progress in the field of plasma physics. Despite these advancements, the kinetic energy of electrons and the density of low-temperature air plasma in laboratory settings have been primarily determined using double probes and spectroscopic methods, with few attempts made to explore polyatomic organic gas plasmas.

Plasma can support various types of oscillatory motions, including electromagnetic, electrostatic, and hydro magnetic waves. This study proposes to investigate the different modes of acoustic wave propagation in polyatomic organic gas plasma using the sonic probe method. Additionally, it aims to determine the velocity of sonic waves, electron energy/temperature, and plasma density.In plasma, charged particles act as wave carriers, and when a signal is applied, it may propagate in one of two electrostatic modes depending on the frequency relative to the angular plasma frequency.

Sonic signals pass through the plasma as ionic sound waves when the electron wave's phase velocity is imaginary for frequencies significantly lower than the angular plasma freq uency. By measuring the characteristic impedance of the plasma, the velocity of these sound waves may be determined.

Theoretical deductions for the sonic probe method have been made under the assumption that the plasma contains air ions (nitrogen, oxygen) and electrons in an isotropic state with charge neutrality and negligible resistance, energy losses from viscosity, etc.In the present situation of polyatomic organic gas, plasma may be assumed to contain ions of air (nitrogen/ oxygen) and heavy ions of polyatomic organic gas. Under these conditions plasma will no longer remain isotropic. The heavy ions may cause damping of sound wave energy. Since the acoustic wave propagation depends on the medium where charge particles act as carriers. An applied signal may choose the mode of propagation depending on its frequency. The mode of propagation as an electron wave becomes imaginary for frequencies much higher than plasma frequency. As a result, the sonic signal uses heavy polyatomic gas ions or air, oxygen, and nitrogen ions as wave carriers to flow through plasma as ionic sound waves. By measuring the distinctive impendence of plasma, the velocity of these waves can be ascertained.

The dispersion relation between the frequency of the applied wave and the velocity of sound in an isothermal plasma, considering the assumptions of electrical neutrality during perturbation, was originally derived by Saxena, A. P., & Saxena, R. K. (1974). This relation was further refined for non-isothermal plasma conditions by Bhatnagar V, P. (1964) and Venkatrangan(1964). Their work provides a more comprehensive understanding of how ion acoustic waves propagate in plasmas, particularly under varying thermal conditions, which is crucial for accurately modeling and predicting plasma behavior in different scenarios

The experimental setup for measuring polyatomic gas plasma parameters in this study consists of the following key components:

1. Vacuum unit : By which the pressure can be reduced to a desired level
2. Generation of plasma: It typically involves a discharge chamber where organic gases are introduced and ionized using an electric discharge, to create the plasma. The setup ensures consistent plasma production with controlled variables like gas flow, pressure, and discharge voltage.
3. Probes: The sonicprobe is placed in the discharge chamber where it emits acoustic waves that propagate through the plasma. By analyzing the response of the plasma to these waves, parameters such as electron temperature, sound velocity, and plasma density can be determined. The sonic probe arrangement includes the probe itself, signal generators, amplifiers, and detectors for capturing the acoustic wave characteristics within the plasma.
4. A pair of Helmholtz coils assisted in creating the magnetic field. By altering the coils' current, the magnetic field's intensity was adjusted between 0 and 200 gauss.

Motion of charged particles in plasma is studied on the basis of two fluid model using hydrodynamic equations. In the presence of magnetic field two fluid models become quite complicated Current flowing along the magnetic field is subjected to Ohm's Law with the usual value of the conductivity. This normal conductivity in the direction of the magnetic field is known as the longitudinal conductivity in plasmas situated within a magnetic field. The plasma has anisotropic conductivity if the transverse current is solely carried by electrons that are moving in response to an externally imposed electric field. A magneto plasma is one in which the electrons undergo many cyclotron gyrations in between collisions. In magneto plasma, the transverse conductivity will be significantly lower than the longitudinal conductivity if the anisotropy of the conductivity is significant. Additionally, the Hall Current, which is the current perpendicular to the electric field, will be significantly larger than the current parallel to the electric field.

A distance moved after each collision is

$$l = vt$$

and the diffusion coefficient is

$$D_{11} = l^2/t = lv$$

The particles gyrate in cyclotron rings rather than freely moving across the field in the limiting situation of a strong magnetic field. Particles can only jump from one circle to another as a result of collisions. A particle's displacement following each impact will then be on the order of a cyclotron radius.

$$r_c = v/\omega_c$$

and the diffusion coefficient perpendicular to the field will be

$$D_\perp = r_c^2/T = v^2/\omega_c^2 t$$

In the absence of magnetic field

$$D_\perp = D_{11}$$

In a very strong magnetic field

$$D_\perp = D_{11}/\omega_c^2 t^2$$

Criterion for the condition of magneto-plasma, i.e.where the cyclotron's gyration period is significantly less than the interval between collisions, is

$$\omega_c t >> 1$$

Despite several complicated factors, the transport processes in a magneto plasma are really less anisotropic than previously mentioned. In addition to electric fields, inertial and pressure

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forces can also cause electrical currents in a plasma. The anisotropy of electrical conductivity is frequently eliminated by these forces

The schematic diagram of experimental set up using magnetic field is shown in figure.

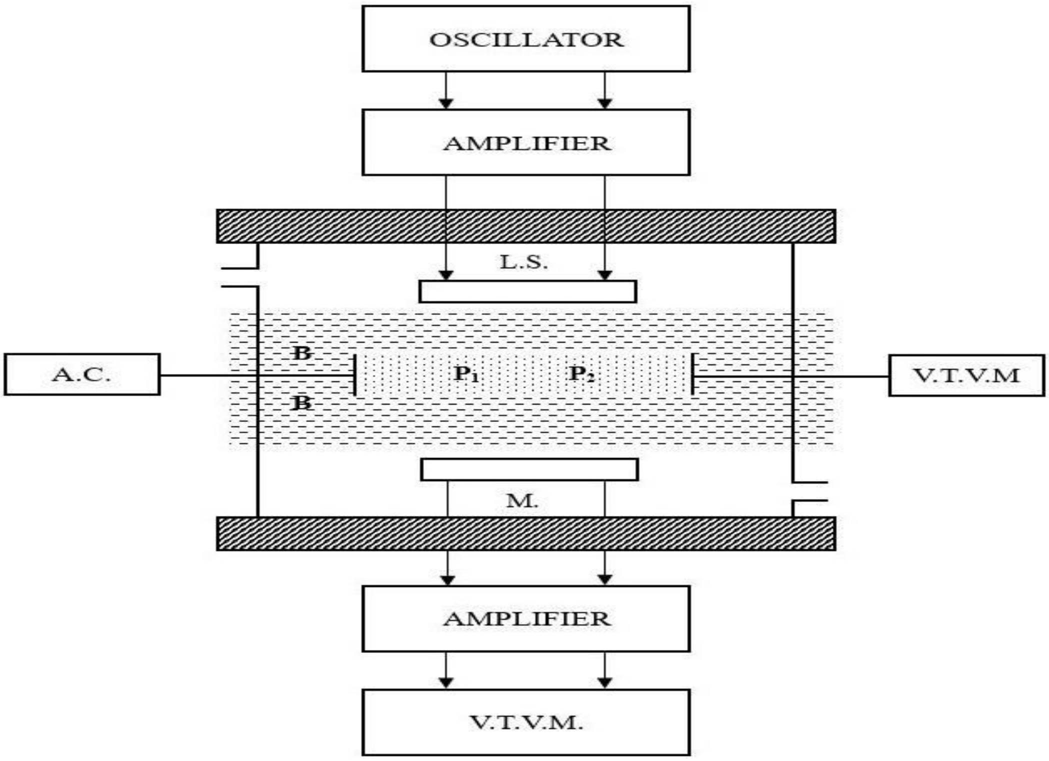

Fig.1. Experimental Arrangement Using Magnetic Field

Following evacuation, organic compounds stored in a conical jar were given permission to move by suction within the chamber. A needle valve was used to regulate the desired pressure, and a Pirani gauge that was connected to the vacuum system was used to measure it. An electric discharge in a low-pressure (0.1 torr) atmosphere inside the chamber produces plasma. With the aid of a step-up transformer, an A.C. voltage is applied across aluminum electrodes to create the discharge. The electrodes' rounded edges are crucial for preserving a consistent electric field and preventing distortion that can compromise the experiment.

An audio oscillator is used to generate sound waves (Sonics), which are then amplified and sent through the loudspeaker.A piece of equipment receives the sound wave after it passes through the chamber and the plasma. An A.C. voltmeter is then used to detect and measure the signal.

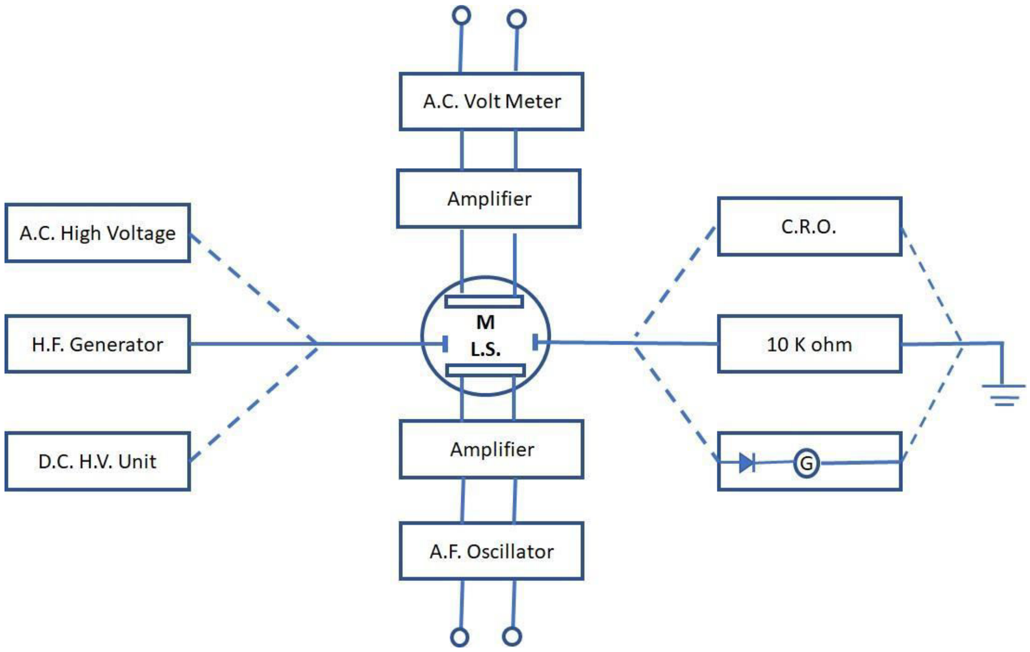

Fig. 2. Schematic Diagram of Sonic Probe Method

Sound wave pressure measurements in plasma and air Bliokh et al. (1988) and Saxena and Shrivastava (1975) were as follows:

In Air: An AC voltmeter was used to measure the appropriate sound wave pressure at the receiving end after adjusting the output of two amplifiers and an audio oscillator. Let V1 be this voltage.

In Plasma: -By transferring an electrical discharge via air, plasma was produced. The experiment was repeated by altering the voltage, the audio signal's frequency, and the stage of ionization by altering the electrode voltage. Let's say the voltage magnitude as measured by the A.C. voltmeter isV2 (V2<V1)

The percentage attenuation of sound waves was computed using V1 and V2. The characteristic impedance's value, "r," was thus determined. The value of the electron temperature was computed using the information of "r." Using organic gases, the same process was carried out, and the plasma properties were determined.

If v_1 and v_2 are the A.C. voltages without and with plasma respectively, then using relation.

$$\frac{V_2}{V_1} = \frac{A_3}{A_1} = \left(\frac{4r}{(r+1)^2}\right)$$

With the help of above equation, the value of 'r' was calculated.

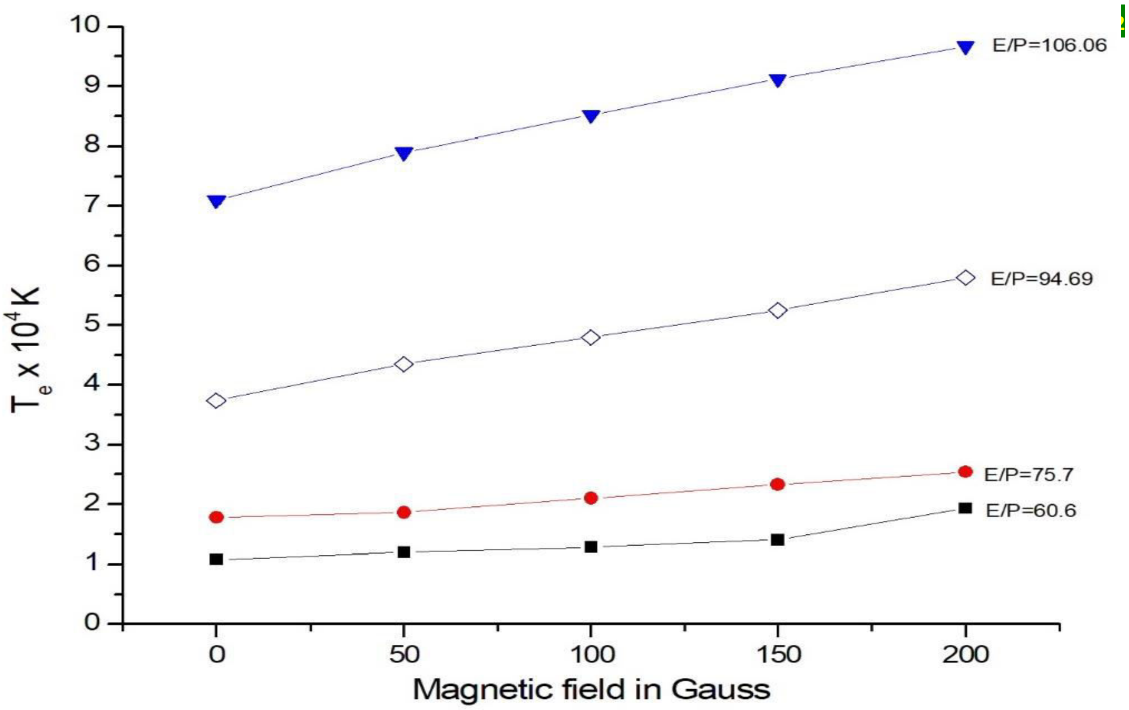

Fig.3. Study of Electron Temperature in Methanol Gas Plasma with Magnetic Field

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Results:

The experiment using sonic probe diagnostics produced the following results for various organic gas plasmas under various magnetic fields.

1. The value obtained in the presence of longitudinal magnetic fields is higher than that in presence of magnetic fields.

2. The value of the goes on increasing with magnetic field as shown graphically.

3. The velocity of sound in polyatomic organic gas plasma also increases with increase in applied longitudinal magnetic field.

Graphs are plotted for methanol plasma for various magnetic fields and E/P

Discussions

The result shows that the value of electron temperature obtained using sonic probe method shows increase in electron temperature with increase in longitudinal magnetic field. The spectroscopic method also reports the increase in electron temperature. On reviewing results obtained by using double probe method it is observed that the value of electron temperature decreases with increase in magnetic field.

When examining stationary low-pressure plasma without a magnetic field, probes are incredibly dependable diagnostic instruments. The probe method itself is severely limited in all other laboratory situations. Burrows has identified several inaccuracies that can arise in measurements done using the DP method, even in the absence of a magnetic field. When the probe characteristic is asymmetrical and the variation of the positive ion current to the probe cannot be ignored, these mistakes become considerable.

Only when the surfaces of the probe and return region are completely cleaned and hysteresis effects are removed can accurate findings be obtained. Measured quantities of T_e usually seem to be erroneously high when atomic and molecular oxygen are present, which is always the case in discharge through air.

There is no theory for the current collection of the DP system, especially when a magnetic field is present. These issues have been explored by Chen and Schott. The interpretation of the probe properties can be significantly complicated by the presence of the magnetic field. Actually, if the magnetic field is strong enough, the electrons' mean free path is significantly shortened, and their diffusion toward the probe deviates from the standard rules. Many researchers have examined the impact of magnetic fields on the floating DP method both conceptually and experimentally. Even when the gyro radius is significantly greater than the probe size, it is discovered that the magnetic field can have a significant impact on the probe's characteristics. The relationship readily demonstrates that the ambipolar diffusion falls rapidly under strong magnetic field

Experimental work shows good agreement with the drawn from theory given above. Accordingly, there should be increase in $T_e$with magnetic field.

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