IV. GEOPHYSICS

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A. PLASMA DIFFUSION IN A MAGNETIC FIELD

Experiments on the diffusion of plasma across a homogeneous magnetic field have been continued since last reported.[1] The experiments with argon discharges were followed by studies of helium and helium-mercury low-pressure arc discharges. The results lead to the following tentative conclusions:

1. Of the discharges studied, only those in He show a clear onset of instability where the axial electric field E_z and radial potential drop V_r change radically as a function of axial magnetic field B. The Ar and He-Hg discharges have a gradual transition of $E_z(B)$ and $V_r(B)$ from apparently "normal" to "anomalous" diffusion across the magnetic field lines.

2. Two modes of operation have been found in Ar discharges at magnetic fields greater than the "critical field" of Kadomtsev and Nedospasov.[2] In the low-voltage mode, $E_z(B)$ is much smaller than $E_z(0)$ and the discharge tube is almost dark throughout the magnetic field region. In the "turbulent" mode, $E_z(B)$ is approximately the same magnitude as $E_z(0)$ and the tube is completely filled with bright plasma. The transition to the turbulent mode is abrupt, and in some cases the discharge will not stabilize because of rapid fluctuations between the two types of operation. The two-mode operation may be related to similar behavior in cesium plasmas in a magnetic field.[3]

3. Plasma diffusion at magnetic fields much greater than the critical field is not well described by Kadomtsev's analogy with hydrodynamic turbulence.[4] These experiments indicate that the coefficient of transverse diffusion D_t is an inverse function of B even when $(\mu_i B)^2 \gg 1$ (μ_i represents positive ion mobility). Kadomtsev's theory would predict a constant value of D_t for this case.

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B. PERTURBATION OF A PLASMA BY A PROBE[1]

An experiment was carried out to examine the validity of Waymouth's theory[2] for Langmuir probe analysis when Langmuir's requirement that probe dimensions be smaller than the mean-free paths of all plasma particles is not valid (see Quarterly Progress Report No. 73, p. 42). As a result of this violation (i) plasma density gradients are set up which cause the ions and electrons to diffuse to the sheath region and (ii) the probe's electric field penetrates the plasma.

Waymouth treats the perturbation as a problem in ambipolar diffusion, subject to the assumptions that the mean-free paths of all plasma particles are comparable to or smaller than probe dimensions and much greater than the thickness of the probe sheath. The results are expressed in terms of a parameter Q_T that, at zero sheath potential, is approximately equal to the sum of the ratios of probe size to electron mean-free path and of probe size to ion mean-free path. Predictions of the theory consist of:

1. A $1/r$ density dependence whose magnitude depends upon Q_T, which in turn depends upon sheath voltage.

2. A perturbation of the plasma potential, which (for calculations based upon the discharge tube used in the experiment) is negative for probe potentials near floating potential and positive for probe potentials near plasma potential.

Using a small probe for which Langmuir's conditions were valid, we examined the plasma perturbation caused by a large probe that violated Langmuir's conditions. By reversing the discharge, small probe data could be taken on both sides of the large probe. Results for cathode-side data consisted of:

1. A definite $1/r$ density dependence. The correct functional dependence of the density perturbation upon the large-probe sheath voltage was also well established.

2. The perturbation of the plasma potential was negative for large-probe voltages near floating potential and positive for large-probe voltages near plasma potential, in agreement with theory. These perturbations also appeared to be of the correct order of magnitude.

Anode-side results did not agree as well. They are:

1. The density perturbation did not have a $1/r$ dependence. Although the density perturbation increased with increasing voltage, it did not have the correct large-probe sheath voltage dependence.

2. Although the potential perturbation caused by a large probe became less negative with increasing voltage, it remained negative for all potential values.

In most instances, disagreement between theory and experiment could be accounted for by the wake phenomena that were present in the discharge. The wakes were caused by drift effects that are necessarily present in a discharge tube of cylindrical geometry. Waymouth's theory, which is the solution of a one-dimensional problem in spherical coordinates, does not consider the wake phenomena. The validity of the extension of Waymouth's theory to Langmuir probes in magnetic fields[2] is doubtful since in that case the wake effects would be much more pronounced and would probably dominate any experimental data.

We applied Waymouth's correction to the apparent density, as determined from the experimental large-probe curve "knee," and compared the result with the electron density determined from small-probe data. The comparison showed good agreement.

In order to calculate the Q parameters, the ion temperature was needed. This temperature, as determined from the calculated large-probe curve fit, was too high to be plausible. Yet, this result may indicate that the ion temperature is greater than is usually assumed in similar discharges.

This experiment has established the validity of Waymouth's theory for the perturbation of a plasma by a probe. Although discrepancies did arise, they were probably due to wake effects present in the discharge. Waymouth's theory can be expected to give an accurate prediction of a plasma disturbance by a probe especially under more nearly normal conditions when the ratios of probe size to mean free paths are more reasonable. When Langmuir's condition is violated, Waymouth's theory can be used to predict true plasma density within the error of experiment.

R. G. Little

References

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2. J. F. Waymouth, Perturbation of a Plasma by a Probe, Technical Report 406, Research Laboratory of Electronics, M. I. T., December 26, 1962.

C. LINE-SHAPE STUDIES OF MERCURY RESONANCE RADIATION AT ZERO MAGNETIC FIELD

The details of our experimental procedure and some preliminary results have been described in Quarterly Progress Report No. 74 (pages 44-47).

Application of certain of the results of Barrat[1] and Omont[2] gives a linewidth for the microwave resonance as

$$(\Delta\nu_{1/2})^2 = \left(\frac{1}{2\pi T_{12}}\right)^2 + 4A^2\,\frac{T_{11}+T_{22}}{T_{12}}$$

where A^2 is proportional to the microwave power and T_{12} is the coherence time given

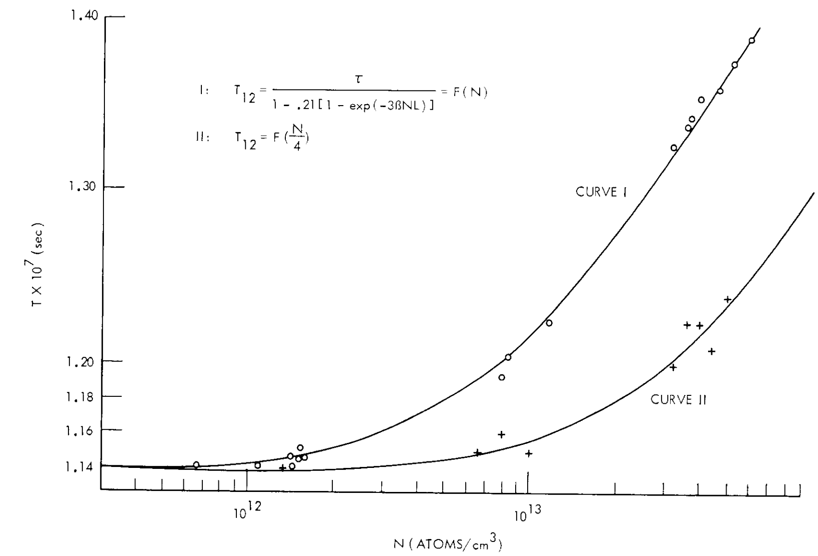

Fig. IV-1. Variation of coherence time with atom density. Curve I: Zero magnetic field. Curve II: Small magnetic field.

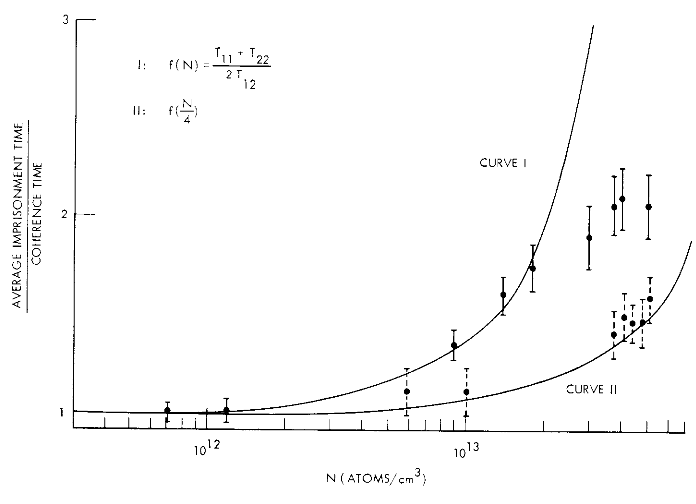

Fig. IV-2. Variation of power broadening with atom density. Curve I: Zero magnetic field. Curve II: Small magnetic field.

by $T_{12} = \tau[1-\alpha(1-e^{-3\beta NL})]$. T_{11} and T_{22} are the imprisonment times for the F = 1/2 and F = 3/2 levels, respectively, and are given by $T_{11} = \tau e^{2\beta NL}$, $T_{22} = \tau e^{4\beta NL}$; τ is the true lifetime of the $^3P_1$ state in mercury. N is the atom density and L is a length related to the cell size. The constant α relates the multiplicity of the involved states to the probability of coherent excitation transfers from atom to atom, and β is dependent upon the average absorption coefficient K of the Doppler-broadened line as follows:

$$\frac{1}{2}[(2F+1)\beta] = K = \frac{\pi^2}{4}\,\frac{2F+1}{2I+1}\,\frac{1}{\tau k_o^3 v}$$

where k_o is the wave number $\left(\frac{1}{\lambda\!\!\!^{-}}\right)$ of the optical radiation and v is the rms velocity of the atoms.

Variation of coherence time with atom density is shown in Fig. IV-1 for both a zero magnetic field (Curve I) and for a small magnetic field of ~15-30 gauss (Curve II). The curves are plots of the theoretical functions indicated on the figure with α = 0.21, L = 0.35 cm.

The apparent increase in the effectiveness of the power broadening with increasing atom density is explained by the ratio of imprisonment time to coherence time appearing in the power term in the equation for the linewidth. The imprisonment time increases

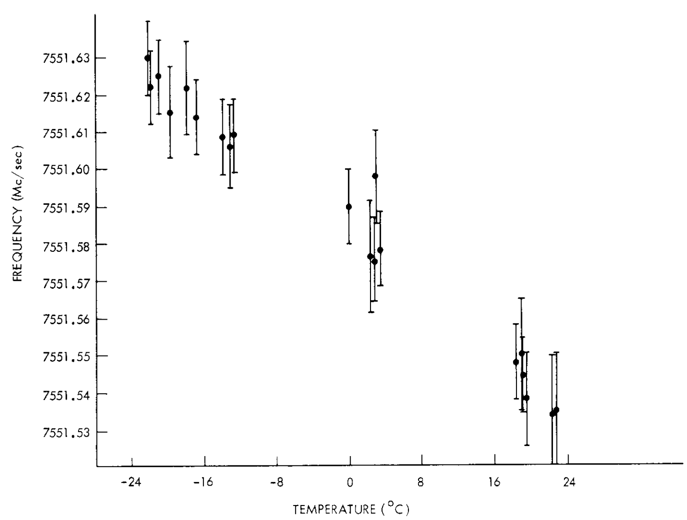

Fig. IV-3. Frequency vs vapor pressure for zero field.

more rapidly than the coherence time with increasing atom density. Fig. IV-2 illustrates the relation of the experimental points to the theoretical curves, both in zero magnetic field and in a small magnetic field. The deviation of measured values from the theoretical curve at the higher densities in zero field may be due to the fact that some of the approximations made in Barrat's theory begin to lose their validity at densities greater than 2×10^{13} atoms/cm^3 or possibly to collisions of the second kind.[3]

Figure IV-3 illustrates the displacement of the resonance frequency with increasing atom density or vapor pressure. This variation appears consistent with the predictions of Omont,[4] and is due to the slight phase changes caused by the finite transit time of the photon from one atom to the next. Similar resonance displacements have been observed by Omont for the even isotopes of mercury in standard double resonance experiments.

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References

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