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I. Introduction

Because the research being conducted under this contract has recently grown to include four related problems, we report on each one separately below. All these problems are concerned with aspects of the Faraday accelerator, particularly those connected with boundary layer and electrode effects. The first two, relating to accelerator experiments and heat transfer gage development, are mainly experimental, while the latter two, which are concerned with the theory of a homopolar device and general transport theory, are entirely theoretical.

II. Shock Tube Accelerator Experiments

The shock tube experiments summarized in the preceding semi-annual report showed that the Faraday accelerator would not produce velocities higher than the "ionization velocity" (i.e., the velocity for which the kinetic energy of an atom equals its ionization energy) even when driven at high power levels[1]. While we recognized that this poor performance was a result of current flowing through the low magnetic field region of the accelerator, we suspected that the current path may be partly determined by the timing of the current pulse with respect to the onset of gas flow through the accelerator from the "reservoir" behind the reflected shock front. We have therefore begun a systematic study of the effect of timing upon accelerator performance, with no significant results to be reported at this date.

We have decided to conduct tests on the heat transfer to the walls, including the electrodes, by the methods discussed in section III below, in a channel having an axially uniform magnetic field. This is the configuration of our previous experiments[2], for which the overall performance was in fair agreement with the theory. Consequently, a constant B-field accelerator section is being designed, which will contain provisions for inserting heat transfer gages.

We are also not certain whether the flow meter readings are a reliable indication of the flow velocity downstream of the accelerator. We are therefore also conducting measurements of the shock speed downstream of the accelerator in order to check the flow meter.

III. Heat Transfer Gage Development

We have begun development of two new types of heat transfer gages, both based on the principle of measuring the temperature rise of a film exposed to a plasma by infrared emission[3]. The first gage is designed for a response time of one-tenth microsecond and is to be used to measure rapidly changing heat transfer, such as occurs in magnetically driven shock tubes. The second gage is designed to measure the heat transfer to an electrode in our Faraday accelerator experiment over a period of 100 microseconds. These gages are therefore quite different in design.

Both gages will be used with a mercury-doped germanium detector (Texas Instruments Model No. GHC-8103) which has a rise time of 0.1 microsecond and is sensitive in the infrared wave length range from 6 to 16 microns, having its peak sensitivity at about 10 microns, which is also the black-body peak for a 300°K source. This detector represents a considerable improvement in response time and signal-to-noise ratio over others we have previously used[3].

The fast-response gage is a typical "thin" gage, having a 5000 Å thick layer of carbon on either a As_2S_3 or TlBr crystal, overcoated with a 1000 Å layer of Al. The As_2S_3 crystal has about the least thermal conductance of any material which is transparent in the 6 to 16 micron range, in which the detector is sensitive. As a result, the temperature rise of the gage is faster and greater than that possible with other materials, such as sapphire. This fast-response gage acts on a different principle than that proposed by Camac and Feinberg[4], who use a high conductivity crystal to produce a rapid response, but which gives a small signal.

The second gage is a typical "thick" calorimeter gage, consisting of a 5000 Å layer of carbon overcoated with a 10 micron layer of Al, both layers being applied to a As_2S_3 or TlBr crystal. In this case, the thick Al layer absorbs and integrates the heat delivered to the gage, the crystal being an effective insulator for the 100 μsec test time. The gage is installed in an electrode, collecting a current proportional to its area. The thickness of the Al layer is determined by the requirement that the resistive heating of the gage caused by any current it collects must be less than the heat absorbed from the plasma.

Both gages are in the process of being vacuum-coated prior to testing. Since we have not used either material previously, we expect some difficulties in developing the proper coating procedures.

IV. Homopolar Accelerator Theory

While it is not known at present whether the "ionization velocity" is a significant limit in the Faraday experiment mentioned above, this characteristic velocity has been found empirically to be pertinent in several other experiments, such as the homopolar discharge[5,6], the Hall current arc[7], the ionizing wave[8], and even low speed discharges. In the case of the homopolar discharge, there are significant measurements which show that the bulk of the gas rotates with a velocity about equal to the ionization velocity[6]. We have decided to study this case in some detail, because there are some pertinent experimental results[6,9] and because we believe that the behavior of this device can be explained quantitatively on the basis of boundary layer effects.

The most thorough study of this experiment is that of S. C. Lin[10], who treated the flow as a homogeneous one, that is, as a free-molecule flow. The bulk of the experiments, however, were carried out at high enough pressures that all the significant mean free paths are less than the size of the apparatus. Fig. 1 shows the mean free paths for a hydrogen plasma plotted as a function of degree of ionization, assuming that the random velocity of the heavy particles is about equal to the ionization velocity. Since the experiments were conducted at pressures above 10 microns with electrode spacings of about ten centimeters, it can be seen that the flow is at least transitional, and probably even continuum.

An order of magnitude analysis of the Hartmann boundary layers on the insulating faces of the discharge chamber shows that the joule heating of the ions in this layer could be conducted to the interior of the chamber, as well as to the wall, and thus maintain the ionization of the rotating plasma, which tends to disappear due to diffusion to the wall and radiative recombination. The electrons act as the medium for transmitting the thermal energy of the ions to the atoms which are thereby ionized.

We have formulated the Hartmann boundary layer equations for this case, for which the magnetic field effects on transport properties are essential, in the form of the Grad moment equations in the transport limit. Although these equations are only as accurate as the first approximation of the Chapman Enskog method which gives the transport coefficients, it should be accurate enough for our purposes, especially since the plasma density is so low that slip boundary conditions will be required. The form of the Grad equations are especially convenient for treating this three component, two-temperature plasma. We are presently studying approximate solutions of these equations.

V. Transport Effects in Boundary Layers

We have been studying a method of solving boundary layer equations for a partially ionized gas which is somewhat different from the traditional approach. The standard method consists in solving the equations for conservation of mass for each species, total momentum and total energy, the appropriate transport coefficients being calculated from the multicomponent formulae given, for example, by Hirschfelder, Curtiss and Bird.[11] The latter calculation is by no means simple, and there has been extensive recent discussion[12,13] concerning the level of approximation required in the usual Chapman-Enskog expansion. Furthermore, the possibility of temperature non-equilibrium between electrons and heavy particles introduces additional complications which have not yet been treated explicitly in the literature. We have therefore considered working directly with the moment integrals of the Boltzmann equation in the numerical integration scheme of the usual type for a boundary-layer problem, i.e., a system of first order equations for the fluxes and scalar variables. In this scheme, the transport coefficients are not calculated directly, but may be found subsequent to the boundary layer solution. Furthermore, the use of several temperatures for different species is very simply taken care of, and the level of expansion in Sonine polynomials may be taken differently for each species. It would also appear that molecular effects, such as the Eucken correction, could be added in a simple manner.

At the present time it is not clear whether this method would reduce the amount of time required for a machine solution to a given boundary layer problem. It appears to us that the formulation of the problem by the new method is simpler and more flexible than by the traditional approach, which should ultimately result in a saving of programming time and perhaps also computer time.

VI. Acknowledgment

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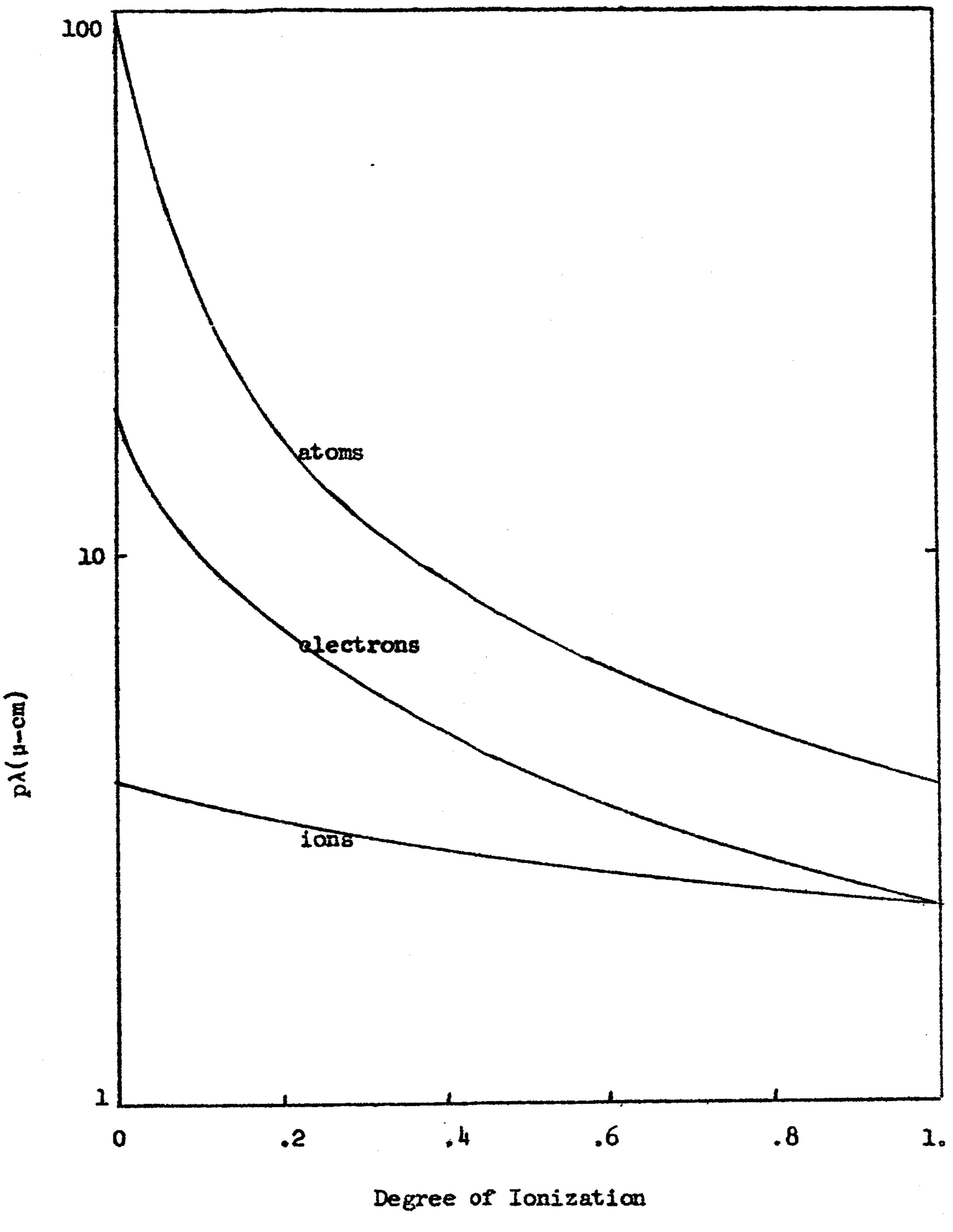

Fig. 1. Atom, electron and ion mean free path in a homopolar experiment. Vertical scale is the product of initial pressure (microns Hg) and mean free path (cm).