

V. NUCLEAR MAGNETIC RESONANCE AND HYPERFINE STRUCTURE

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A. NUCLEAR ORIENTATION AND MAGNETIC MOMENT OF MERCURY 197

1. Nuclear Orientation by Optical Pumping

Optical pumping has been achieved for the first time in the vapor of the 65-hour mercury 197 radioisotope. Two per cent orientation was obtained which indicates a ground sublevel population ratio $m_{+1/2}:m_{-1/2} = 1.045$ (see Fig. V-1).

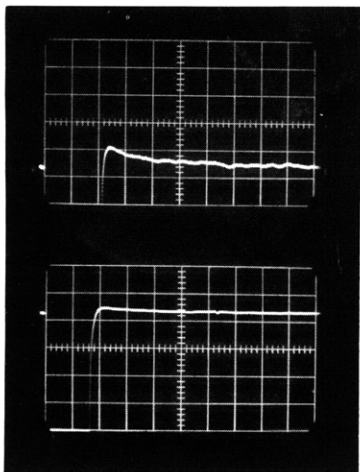


Fig. V-1. Optical pumping exponential in Hg^{197} vapor.

A 9/8-inch cubical cell containing the Hg^{197} vapor was illuminated with right circularly polarized σ^+ 2537 Å resonance radiation obtained by Zeeman-shifting the light from an Hg^{202} lamp with a 1350 gauss scanning field. The arrangement of the apparatus to detect optical pumping and measure the related time constants and the construction of the cell have been described in an earlier report (1). The cell was coated on the inside with G. E. Dri-Film (dimethyldichlorosilane) to reduce the rate of disorienting wall collisions, thereby increasing the relaxation time constant τ_R , and also increasing the amount of optical pumping.

2. Magnetic Moment of Hg^{197}

Resonance between the ground sublevels $m = \pm \frac{1}{2}$ has been observed at 356 kc while the cell containing the vapor was in a Helmholtz splitting field of 450 gauss. The width of the resonance was 500 cps, and a 7:1 signal-to-noise ratio was obtained.

The current in the Helmholtz splitting field coils was regulated to 1 part in 10^4 . After the Hg^{197} ground sublevel resonances were recorded, the cell was removed and a proton resonance probe inserted in the cell's place. The Helmholtz splitting field was then measured using a magnetometer from the Laboratory for Electronics, Inc. The average of 32 resonances gives

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$$\frac{\gamma_{\text{Hg}^{197}}}{\gamma_{\text{H}}} = 0.18585 (\pm 7)$$

The error quoted here is the probable error. If three times the standard deviations were used instead, the quoted error would be 0.00030.

The curves in Fig. V-1 indicate light intensity scattered at right angles by a cell containing Hg^{197} vapor. The lower curve shows the zero light level at the lower left. When the nylon shutter is suddenly removed, 2537 Å σ^+ light illuminates the cell, is absorbed by atoms in the $m = -\frac{1}{2}$ ground sublevel, and is re-emitted as σ^+ or π light. As atoms are pumped into the $m = +\frac{1}{2}$ ground sublevel, they can no longer absorb the σ^+ light and the scattered light decreases. The slight decrease of these curves indicates 2 per cent optical pumping. The upper curve is the optical pumping exponential of the lower curve magnified five times. The horizontal time scale is 1 sec/cm. The curves are slightly rounded because a 0.1- μfd capacitor has been placed across the 1 megohm input resistor of a Tektronix oscilloscope.

The nuclear spin of Hg^{197} is $1/2$ (2, 3). Hence, by taking $\mu_{\text{H}} = 2.79275 (\pm 3)$ nuclear magnetons (4), we obtain for the magnetic moment of mercury without diamagnetic correction

$$\mu_{\text{Hg}^{197}} = 0.5190 (\pm 2) \text{ nuclear magnetons}$$

The diamagnetic correction (5) would increase this value approximately 0.974 per cent.

Cagnac (6) was the first to succeed in optically pumping mercury vapor. Using his result for Hg^{199} , which also has a spin of $1/2$,

$$\frac{\gamma_{\text{Hg}^{199}}}{\gamma_{\text{H}}} = 0.1782706 (\pm 3)$$

we obtain for the ratio of the magnetic moment of Hg^{197} to Hg^{199} ,

$$\frac{\mu_{197}}{\mu_{199}} = 1.0425 (\pm 4)$$

The ratio is independent of the diamagnetic correction, which is the same for each isotope.

Stager (7) has measured the zero-field hyperfine-structure splittings of both isotopes. The ratio of his values of the interaction constants for the $^3\text{P}_1$ state is

$$\frac{A_{197}}{A_{199}} = 1.043284 (\pm 1)$$

Thus a hyperfine-structure anomaly is indicated. Work continues on the measurement

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of the Hg^{197} to Hg^{199} magnetic moment ratio, in order to improve the precision of the value of this anomaly.

3. Apparatus

In the five attempts to fill cells with Hg^{197} , no more than a few per cent of optical pumping of Hg^{197} vapor has been obtained. When the same cells are filled with Hg^{199} , either before or after they are filled with Hg^{197} , approximately 20 per cent of optical pumping of Hg^{199} results. Since the lamp intensity and the mean time to pump an atom, τ_P , remain about the same, it is indicated by an earlier report (8) that a 20 per cent

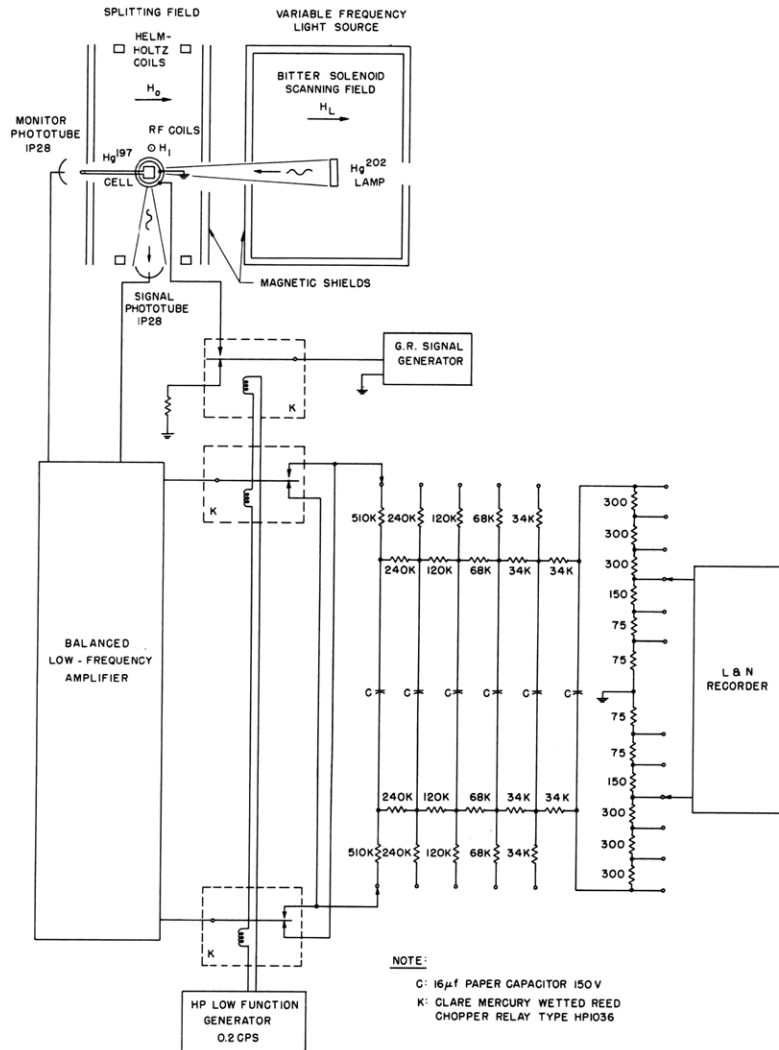


Fig. V-2. Top view of apparatus and block diagram of 0.2-cps lock-in detector.

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decrease in the mean time for an atom in the ground state to relax, τ_R , would account for this result. Further work is needed to verify this reduction in τ_R and determine its cause.

Since only a few per cent of optical pumping is obtainable in Hg^{197} vapor, some type of lock-in detector is necessary to obtain a reasonable signal-to-noise ratio for the ground sublevel resonance. The lock-in detectors in use in the Magnet Laboratory, M. I. T., called "diamods," operate at 30 cps. The mean pumping-time constant in mercury vapor, however, is approximately 2 seconds (1); therefore a much slower frequency lock-in detector is needed.

A block diagram of the lock-in detector constructed to meet this need is shown in Fig. V-2. It operates at 0.2 cps, although actually its frequency can be varied by changing the frequency of the Hewlett-Packard Low Function Generator. Signal-to-noise ratios as high as 14:1 have been obtained with this lock-in detector when only 2 per cent optical pumping of the vapor was available.

The lock-in detector works by turning the rf to the cell on and off at a 0.2-cps rate, while the light signal output from the cell is reversed from one side of a filter network to the other side at this same 0.2-cps rate. The result is that the only dc output from the filter network will be due to signals at this 0.2-cps rate.

The basic idea and part of the design of this lock-in detector is due to Henry R. Hirsch, whose aid I gratefully acknowledge.

W. T. Walter

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8. Ibid., see Eq. 7.

B. HYPERFINE STRUCTURE AND ISOTOPE SHIFT IN RADIO-CADMIUM

Observations have been made on the hyperfine structure of radioactive Cd isotopes obtained from deuteron bombardment of natural silver ($\text{Ag}^{107} \approx 51$ per cent,

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$\text{Ag}^{109} \approx 49$ per cent). From a study of the 3261 Å, 4678 Å, 4800 Å, and 5085 Å lines in the CdI spectrum we confirmed the spin assignment $I = 5/2$, and the A-value for the 3P_1 state in Cd^{109} (470 d) found by means of the double-resonance technique by McDermott and Novick (1). In addition, we measured the Cd^{109} - Cd^{113} isotope shift as +36 mK.

Radioactive-decay studies indicated the presence of Cd^{107} (5.7 hr). Since there was no spin and a factor value that was self-consistent for all the transitions with any of the rest of the lines observed, it is likely that Cd^{107} has the same spin as Cd^{109} , and a similar hyperfine structure. As the isotope shift for the addition of two neutrons is small here as compared with the linewidth, the Cd^{107} and Cd^{109} patterns would then almost coincide. It is expected that the use of a separated Ag^{107} isotope target, from which Cd^{107} will be produced, but not Cd^{109} , will allow a positive identification.

A value of $A = 407.4 \pm 3$ mK was measured for Cd^{113} in the 3S_1 state.

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C. A MERCURY ATOMIC-BEAM LIGHT SOURCE

In an experiment described in a previous report (1), the design of the atomic beam (2) called for a beam collimation ratio of 1:200; that is, for 1-inch mica beam slits separated by 5-mil stainless-steel spacers. The light output from this type of emission beam proved to be too small for our experiment. The short time (15 minutes) in which the slits of the beam would clog compounded the difficulty, and the original design had to be modified.

The new beam design, which is to be used in both the emission beam and the absorption beam, uses a 1:20 collimation ratio, and the mica slits are separated by 50-mil spacers. The emission beam has been operated at an oven temperature of approximately 90°C, and the mercury atoms were excited by photons from a water-cooled microwave discharge lamp filled with Hg^{202} . A typical value of the radiant energy re-emitted into a solid angle of 5×10^{-2} steradians was approximately 0.015 μw . The current from the photomultiplier detector produced by this light level was a factor of 15 above the dark current. The time in which the photomultiplier remained reasonably constant was at least 45 minutes. This is expected to provide a satisfactory emission beam.

I. G. McWilliams

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D. STUDIES OF ELECTRIC DISCHARGES IN MAGNETIC FIELDS AND IN LARGE VESSELS

The work reported on here represents some preliminary explorations of dc electric discharges in magnetic fields and in large vessels in which wall effects are minimized. Our purpose is to develop reliable techniques for further work and to indicate directions of promising research.

1. Techniques

The Langmuir probe has been our primary tool. In spite of its difficulties, it is still the only means of directly determining plasma potential, ion density, and electron-energy distribution at well-defined points in the discharge.

To overcome the problem of a changing work function of the probe, which gives spuriously non-Maxwellian energy distributions (1), an arrangement has been devised to clean the probe by electron bombardment immediately before reading the current. This is illustrated in Fig. V-3.

The current drawn by the probe is displayed on the y-axis of a Moseley Autograf x-y recorder. The voltage of the probe above a fixed base voltage is determined by the

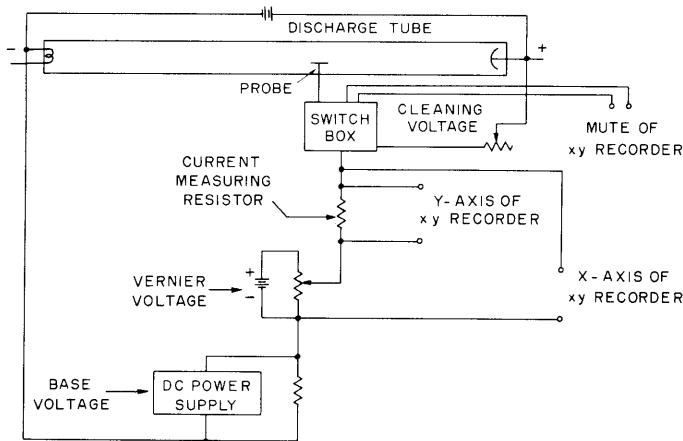


Fig. V-3. Block diagram of pulse-cleaning apparatus.

Vernier Helipot and battery and is displayed on the x-axis of the x-y recorder. In the switch box, the probe is connected alternately to the measuring circuit and to the cleaning voltage. The cleaning current is adjusted with a series resistor to heat the probe sufficiently to remove impurities. During the cleaning period the x-y recorder is muted to prevent it from returning to zero. The cleaning-recording cycle is controlled automatically by a timing motor and cams. The cycle is: 0.25 second record, and 0.75 second clean.

Studies with an oscilloscope camera show no appreciable change of work function over the 0.25-second reading period. Variations of several seconds amounted to changes in work function of 0.1 volt. These depended on the character of the discharge, but were in no case as fast as the cooling time of the probe.

The problems of current control and oscillations in the tube have also received some attention. Since the plasma potential of any point is dependent on tube current, any variation at the anode or cathode, or from external sources will disturb the probe measurements. Long-period changes cause obvious distortions of the current versus voltage curve. Higher frequencies will sweep the current taken by the probe rapidly up and down from the dc value determined by the steady probe potential. If the characteristic were straight, this would be no problem but since it is an exponential, it results in a shift of the average current taken by the probe and leads to false results. The most serious variations are anode oscillations and external changes.

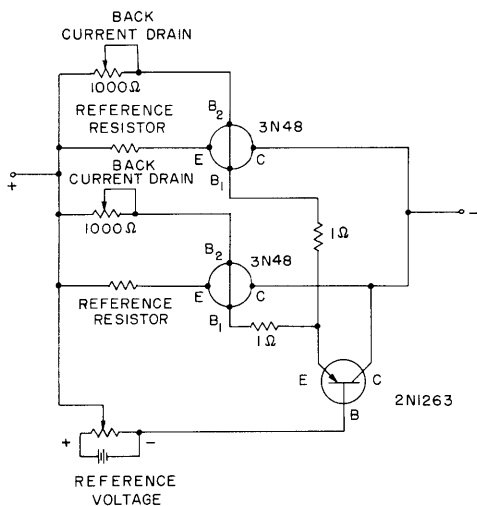


Fig. V-4. Circuit of transistor current regulator.

Current variations are controlled by a transistor current regulator in series with the ballast resistance and discharge tube. It is a modification of a circuit distributed by the Minneapolis Honeywell Corporation, and is shown in Fig. V-4. The current is regulated by two power tetrodes in parallel, controlled by comparing the voltage over

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series reference resistors with a battery voltage reference. The back current at high operating temperatures is drained from the B_2 connections. It can regulate currents of 0-10 amp, provided that the power dissipation does not greatly exceed 100 watts.

Current is regulated to approximately 1 per cent, or better, and most of the variation caused by anode oscillations of several kilocycles is eliminated. Anode oscillations are still a problem, however.

2. Work on Large-Diameter Tubes

The first attempt to determine the effect of removing the walls from the discharge axis was in a tube 6 inches in diameter, and 40 inches long. It is made of Pyrex with an oxide cathode and a stainless-steel hemispherical anode. Three probes intrude radially from the walls at intervals of 6 inches and 9 inches. They are movable radially by sliding magnetic slugs.

The probes are tungsten discs, 0.071 inch in diameter, and 0.002 inch thick. They are supported by tungsten wire, 0.003 inch in diameter. The support wire is shielded by, but does not touch, a Pyrex tube, 1 mm in diameter, which terminates 2 mm behind the probe face. They are oriented with the face parallel to the tube axis.

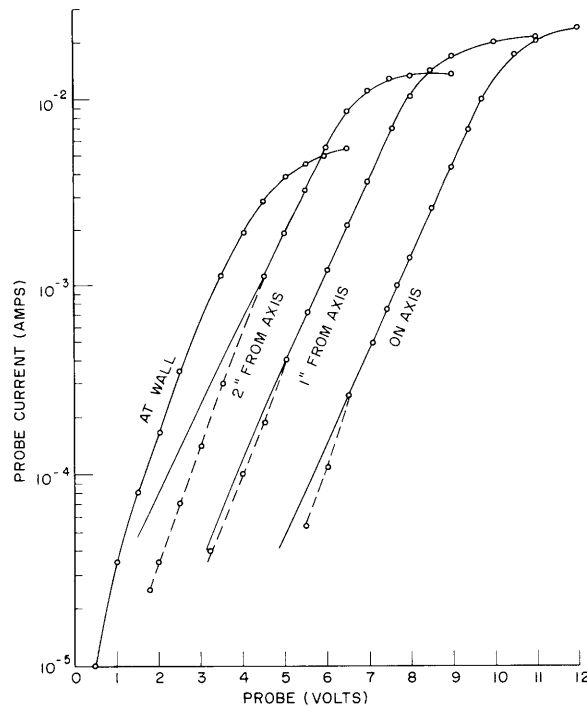


Fig. V-5. Log current versus voltage at four radial positions in the 6-inch tube.

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Although the results are preliminary, a sample of them is included here. The tube is filled with argon at a pressure 2 mm Hg and a few drops of liquid mercury at room temperature. The tube is carrying a 3-amp current. A semilogarithmic plot of current versus voltage is shown in Fig. V-5, for four radial positions at the center of the tube. The plasma potential has been arbitrarily chosen.

There is a deviation from a pure semilogarithmic dependence in each of the curves which indicates a shortage of high-energy electrons. This is especially noticeable near the walls. The temperature of the electrons on the axis is approximately 10,000°K.

Whether this loss of high-energy electrons is due to wall losses or to inelastic collisions is to be determined by a modification of the tube in the form of wall electrodes. By biasing these negatively, the electrons will be repelled. If the shortage is due to wall losses, the semilogarithmic plots should be linear to higher retarding potentials.

Further work also includes investigation of discharges in a 20-inch sphere that is now under construction.

3. Discharges in Magnetic Field

In order to determine the reliability of probe measurements in magnetic fields and to understand the dc discharge in moderate fields, a program of measurements has begun to determine variations of electron temperature, electron density, and electric field strength in nonuniform magnetic fields.

The configuration used, thus far, has been to place a discharge tube, 4 cm in diameter, and 2 meters long, in a solenoid that is 4 inches in diameter. The tube is moved along the axis of the solenoid and the various parameters measured as a function of position relative to the center of the solenoid. For example, position "-30" means that the probe is 30 cm from the center of the solenoid on the opposite side of the solenoid from the cathode. Position "0.0" means that the probe is at the center, and "+30" means that it is 30 cm from the center, with the cathode and probe on the same side of the solenoid.

A sample of the data gathered thus far is included. Although only rough results are available, the general form that was expected is discernible. Figure V-6 is a semilogarithmic plot of current versus probe voltage on the axis of the tube at 7 positions in the magnetic field, and in zero field. The tube is filled with argon to a pressure of 2 mm Hg and a few drops of liquid mercury. The probe is a tungsten disc, 0.071 inch in diameter, mounted on a tungsten wire, 0.003 inch in diameter. Two millimeters from the disc edge, the wire is shielded by a Pyrex tube. The probe plane is normal to the axis of the tube. The tube is carrying a current of 0.5 amp, and the magnet coils, 500 amp, or approximately 3000 gauss.

The probe characteristics are linear over an order of magnitude, or more, but the

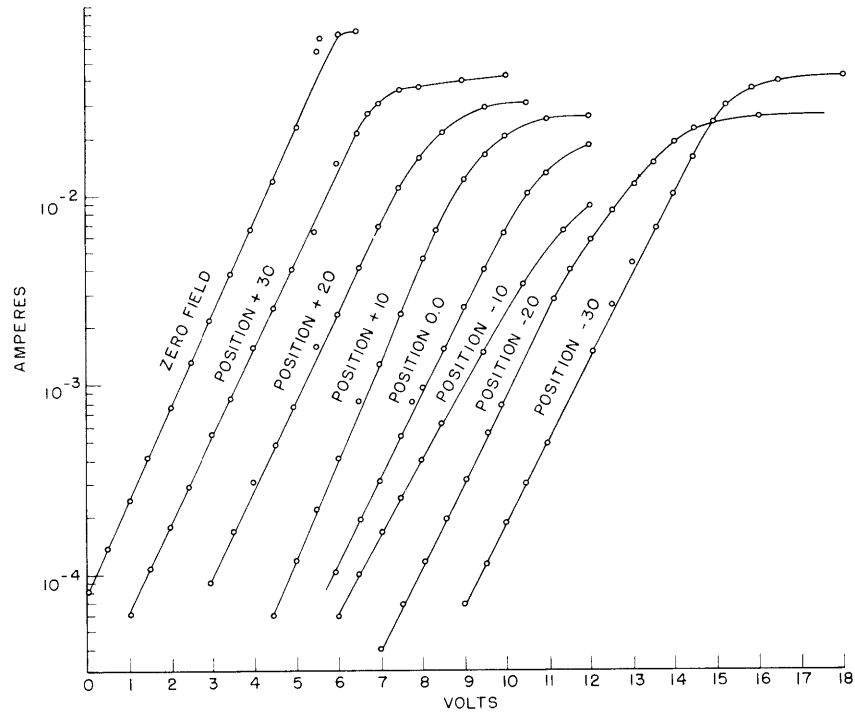


Fig. V-6. Log probe current versus probe voltage at 3000 gauss, and 0.5-amp tube current.

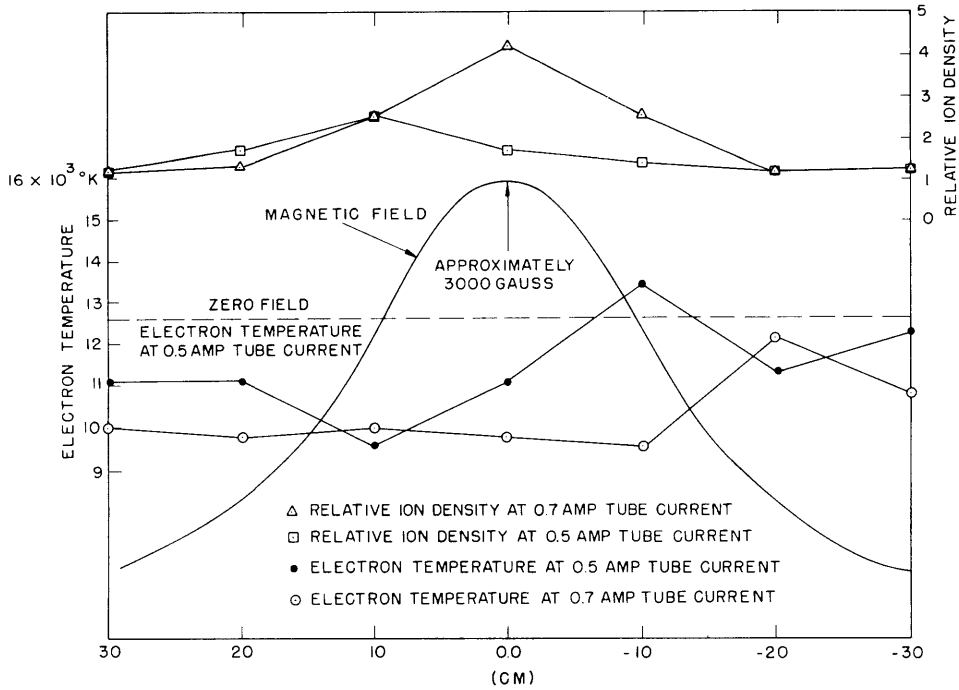


Fig. V-7. Electron temperature, magnetic field, and ion density as a function of positions in a solenoid.

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saturation electron current dips as the magnetic field increases. This is as expected from the work of Bohm and others (2). For this reason, ion currents must be used as an indication of ion density in the region of strong fields. In Fig. V-7 are plotted electron temperature, ion-electron density, and magnetic field as a function of tube position. The solenoid current is 500 amp, or approximately 3000 gauss. The tube current is 0.5 amp and 0.7 amp. Interpretation of these curves is incomplete, and is awaiting more precise data.

Future work will include final measurements in the nonuniform field with water-jacket temperature control, and work with a uniform-field solenoid.

T. Fohl, J. F. Waymouth, F. Bitter

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