V. NUCLEAR MAGNETIC RESONANCE AND HYPERFINE STRUCTURE

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A. HYPERFINE STRUCTURE AND ISOTOPE SHIFTS IN Hg^{195}, Hg^{195*}, AND Hg^{194}

Successful light sources of Hg^{194}, Hg^{195}, and Hg^{195*} have been prepared as described in Quarterly Progress Report No. 64 (page 40). Hyperfine-structure spectra were obtained in the $2537\,\text{Å}$, $4047\,\text{Å}$, and $4358\,\text{Å}$ lines. We obtain the following preliminary results:

$$I(Hg^{195}) = 1/2$$

$$I(Hg^{195*}) = (13/2,\ 11/2)$$

$$\mu(Hg^{195}) = 0.54 \pm 0.02 \text{ nm}$$

For $I = 13/2$:

$$\mu(Hg^{195*}) = -1.05 \pm 0.02 \text{ nm}$$

$$Q(Hg^{195*}) = (1.6\pm1.0) \times 10^{-24} \text{ cm}^2$$

Isotope shifts:

$$Hg^{194} - Hg^{198} = 0.302 \pm 0.018 \text{ cm}^{-1}$$

$$Hg^{195*} - Hg^{198} = 0.221 \pm 0.020 \text{ cm}^{-1}$$

Further analysis of recent data is in progress. This is expected to yield a definite result for the spin of Hg^{195*} (which we expect to be that of the $i_{13/2}$ neutron on the basis of the shell model) and more accurate values for the isotope and isomeric shifts.

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B. THE MAGNETIC MOMENT OF MERCURY 197 BY MEANS OF OPTICAL PUMPING

The use of optical pumping to orient nuclei and thereby enable ground-state nuclear magnetic-resonance experiments to be performed in dilute vapors has been described in previous reports,[1-3] particularly for mercury. The precision of the measurement of the magnetic moment of the 65-hour radioisotope Hg^{197} has recently been improved by

making the following changes. (a) The cell containing Hg^{199}, which had been used before as a calibration standard was opened and refilled with both Hg^{197} and Hg^{199}. This cell had shown the largest amount of optical pumping of the seven cells tested, despite the fact that its walls had not been coated with G.E. Dri-Film. (b) The cell was placed in a larger splitting field (1200 gauss, instead of 450 gauss). (c) The stray magnetic field at the position of the cell, which is influenced by the scanning field at the lamp, was reduced. We discovered that the major contribution to this leakage field was produced by current in the bus bars on the ceiling of the Magnet Laboratory, which are used to supply the scanning magnet, a Bitter solenoid. Thirty-five feet of 1.875-inch diameter "kickless welding cable" (2500-amp capacity) was purchased from Mackworth G. Rees, 1573 East Forest Avenue, Detroit, Michigan. This cable contains 6 conductors hexagonally spaced about a fluted center. Three conductors are tied in parallel to carry current to the scanning magnet, while the other three in parallel form the return circuit. Hose connections at either end of the cable allow water-cooling of the six conductors. The scanning magnet has been connected to the bus bars in the motor generator room by means of this kickless welding cable. This arrangement reduced the leakage field by more than a factor of 10, so that when the scanning magnet is changed from Hg^{197} to Hg^{199} optical-pumping light the leakage field changes by less than 0.005 gauss.

With these changes, resonances 25 cps wide were observed at 933 kc and 859 kc. The measured ratio was $\dfrac{\mu_{197}}{\mu_{199}}$ = 1.042479 (±15). Comparison of the measured ratio with the ratio of Stager's values[4] of the interaction constants for the $^3P_1$ state, A_{197}/A_{199} = 1.043284 (±5), indicates a hyperfine-structure anomaly of 0.772 (±16) parts in 1000.

Using Cagnac's Hg^{199} result,[5] γ_{199}/γ_H = 0.1782706 (±3), we obtain

$$\frac{\gamma_{197}}{\gamma_H} = 0.1858434 \ (\pm 27)$$

and

$$\mu_{197} = 0.519014 \ (\pm 10) \ \mu_N$$

without diamagnetic correction. In addition, comparing the Hg^{199} resonance with the proton resonance, we obtain γ_{199}/γ_H = 0.178273 (±5), which is in agreement with Cagnac's result within our error limit. The errors quoted are three times the standard deviation.

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References

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5. B. Cagnac, Ann. phys. 6, 467 (1961).

C. D-C DISCHARGE IN THE LARGE SPHERICAL LAMP

In Quarterly Progress Report No. 64 (pages 40-42), a spherical lamp that is provided with movable anode, cathode, and Langmuir probes was described. It was stated that by operating the tube with the anode and cathode close together, a point source of ions and electrons could be approximated. Since then, measurements have been made which indicate that the discharge has the expected form.

In our model of the cathode region we consider that secondary electrons in the cathode glow form a dense, spherically symmetric cloud about the cathode spot. These, together with positive ions, diffuse outward because of the density gradient. For a certain distance the electron diffusion current is sufficient to carry the tube current, and there is no accelerating electric field. In fact, the field is negative over part of the region because of the ambipolar field. In this region (Faraday dark space) the electrons are relatively cool and do not excite the atoms.

When the diffusion current density becomes less than that required to maintain the tube current, the electric field becomes accelerating and the electrons are heated. These hotter electrons excite and ionize atoms, and the glow of the positive column is observed.

The factor determining the length of the dark space is the diffusion rate of the electrons. The diffusion rate Γ is given by

$$\vec{\Gamma} = -D_e \vec{\nabla} n \quad \text{where} \quad D_e = \frac{V^2}{3\nu_m}, \tag{1}$$

where D_e is the diffusion coefficient; V, the electron velocity; and n, the electron density. As ∇n diminishes, the diffusion current must eventually become inadequate, and a positive column forms. The distance from the cathode at which the column forms depends on the inverse of the pressure through the collision frequency, ν_m. If there are walls nearby, as in a cylindrical lamp, wall recombination will provide an additional loss of carriers, and the dark space will be still smaller.

When the anode is near the cathode, and the walls far away, the diffusion current will be symmetric about the cathode, and the current density will be inversely proportional to the square of the radial distance from the cathode. If the anode is close enough to intercept enough current to carry the tube current, no accelerating field develops and
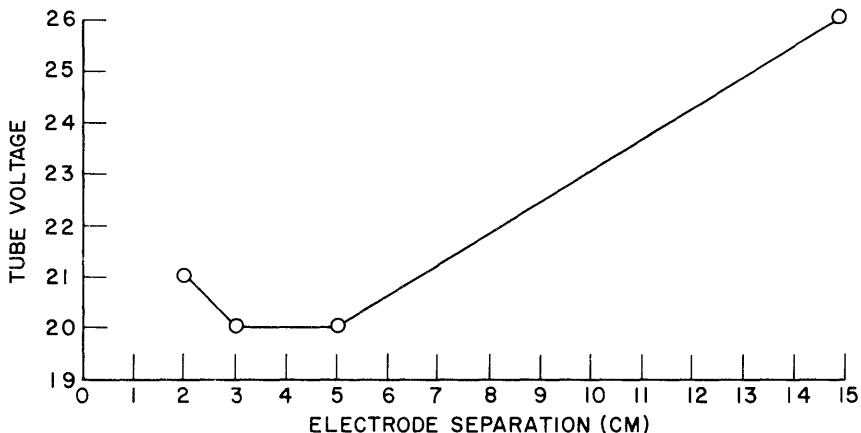
Fig. V-1. Voltage drop across tube as a function of electrode separation. (Current, 2 amps; argon pressure, 2 mm Hg; mercury vapor at room temperature; anode in dark space until separation is ~15 cm.)

the Faraday dark space envelops the anode.

The characteristics of a discharge operating in this mode are that all ionization and heating of electrons occurs in the immediate region of the cathode, and the ions and electrons diffuse radially. The only electric field that is external to the cathode region is the ambipolar field, and it is also radially directed.

These features seem to be found in our discharge. As we showed in the previous report, the distance between the cathode and the edge of the positive column increases with decreasing pressures. The dark space is also larger than that usually found in cylindrical tubes at these pressures. A typical curve of tube voltage as a function of electrode separation is shown in Fig. V-1. We note that the voltage drop decreases with increasing distance over a portion of the curve. This indicates that a negative electric field exists.

Probe measurements, taken with the pulse-heated apparatus described in Quarterly Progress Report No. 62 (pages 110-115), indicate that the electron temperature and density are spherically symmetric about the cathode, to at least 4 cm from the cathode spot. The only variation is in the immediate region of the cathode support. Similarly, the potential seems to be a function of the radius only. The electron temperature varies from ~6000°K near the cathode to ~3500°K near the wall. The electron density varies from ~ $5 \times 10^{11}/cm^3$ near the cathode to ~ $5 \times 10^9/cm^3$ near the wall. The potential near the wall is ~2 volts lower than that near the cathode.

For ions and electrons diffusing outward from a central source of constant supply, the flow obeys the equation

$$\text{div } \vec{\Gamma} = 0 \tag{2}$$

when there is no recombination in the volume of the tube. For spherical symmetry,

$$\Gamma = -\frac{Z_o}{r^2},$$ (3)

where Z_o is the rate of production inside the cathode region.

However, from Eqs. 1 and 2, we get Laplace's equation

$$\vec{\nabla} \cdot \vec{\Gamma} = \nabla^2 (Dn) = 0$$ (4)

where D is the ambipolar diffusion coefficient. This has a solution of the form

$$\Omega = \frac{C_o}{r} + C_1 \qquad \Omega = Dn.$$ (5)

Using the boundary conditions $\Omega = 0$ at $r = r_{wall}$ and $\Omega = \Omega_o$ at $r = r_{source}$, we get

$$C_o = \Omega_o \left(\frac{r_s r_w}{r_w - r_s} \right) \qquad C_1 = - \frac{\Omega_o r_s}{r_w - r_s}$$

and

$$\Omega = \Omega_o \frac{r_s}{r_w - r_s} \left(\frac{r_w}{r} - 1 \right).$$ (6)

Variations from this law will indicate the presence of recombination in the volume of the tube.

Also, the fact that the electron temperature is a function of radius should allow an investigation of energy transfer in the electron gas.

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