COLUMBIA UNIVERSITY

DEPARTMENT OF PHYSICS

FIRST QUARTERLY PROGRESS REPORT

DECEMBER 16, 1962 THROUGH MARCH 15, 1963

U. S. ARMY ELECTRONICS RESEARCH AND DEVELOPMENT LABORATORY,
OFFICE OF NAVAL RESEARCH, AND AIR FORCE OFFICE OF SCIENTIFIC RESEARCH.

COLUMBIA RADIATION LABORATORY NEW YORK 27, NEW YORK

MARCH 15, 1963

CONTRACT: DA-36-039 SC 90789

COLUMBIA RADIATION LABORATORY

MARCH 15, 1963

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AD ________________ Accession No. ________________

Columbia Radiation Laboratory, Columbia University
538 West 120th Street, New York 27, New York

First Report on RESEARCH INVESTIGATION DIRECTED TOWARD EXTENDING THE USEFUL RANGE OF THE ELECTROMAGNETIC SPECTRUM

Report dated: March 15, 1963
vi + 54 pages, 13 figures

A detailed study has been made of the metastable lithium atom. The threshold energy (E_o), production cross section (σ), and lifetime (τ) are: $E_o = 56$ ev, $\sigma = 10^{-19}$ cm^2, and $\tau = 5 \pm 1$ μsec. These values are in reasonably good agreement with the theoretical calculations.

The fine structure splitting of the 3P term of the lithium atom has been determined by level crossing spectroscopy. The observed interval is 2880 Mc/sec and is about 12% smaller than the corresponding splitting. Precise knowledge of fine structure will provide a critical test of three electron wave functions.

The spin, magnetic moment and quadrupole moment of Cd^{113m} have been determined by optical double resonance. Computational techniques have been developed for the evaluation of fine structure corrections to the level crossing fields in (sp) configurations.

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An optical maser has been used for the precise determination of the frequency shifts of the light scattered by an acoustically excited liquid (Debye-Sears effect).

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1. The Physics of Matter at Electronically Generated Frequencies

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RESEARCH INVESTIGATION DIRECTED TOWARD EXTENDING THE USEFUL RANGE OF THE ELECTROMAGNETIC SPECTRUM

First Quarterly Progress Report
December 16, 1962 through March 15, 1963
CU-3-63 SC-90789 Physics

Object of the research:
Physical research in fields in which microwave frequency techniques are employed; the development of microwave electronic and circuit devices.

The research reported in this document was made possible through support extended Columbia Radiation Laboratory, Columbia University, jointly by the Department of the Army (Signal Corps), the Department of the Navy (Office of Naval Research), and the Department of the Air Force (Air Force Office of Scientific Research) under the Signal Corps Contract DA 36-039 SC-90789.

DA Task No. 3A99-20-001-09
NR 372-101

Prepared by R. Novick

COLUMBIA UNIVERSITY
Division of Government Aided Research
New York 27, N. Y.

March 15, 1963

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I. D. Abella and H. Z. Cummins, "Report on Quantum Electronics III Conference," Resonance Seminar, Department of Physics, Columbia University, New York, N. Y., March 15, 1963.

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L. Krisher, "Beam maser spectroscopy," University of Oklahoma, Norman, Oklahoma, January 3, 1963.

R. Novick and F. W. Byron, Jr., "Spins and moments of cadmium isotopes," Nuclear Seminar, Department of Physics, Columbia University, New York, N. Y., March 15, 1963.

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ABSTRACT

A detailed study has been made of the metastable lithium atom. The threshold energy (E_o), production cross section (σ), and lifetime (τ) are: $E_o = 56$ eV, $\sigma = 10^{-19}$ cm^2, and $\tau = 5 \pm 1$ μsec. These values are in reasonably good agreement with the theoretical calculations.

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I. ATOMIC PHYSICS

A. LIFETIME OF THE METASTABLE STATE OF SINGLY IONIZED HELIUM* (M. Lipeles, R. Novick, N. Tolk)

This is an experiment to measure the lifetime of the 2S metastable state of singly ionized helium by a time-of-flight method.

The apparatus consists of a 34-ft long, stainless steel, bakeable vacuum tube. The tube is divided into four separately pumped chambers by baffle plates with small diameter apertures through which the ion beam may pass. The first chamber contains the ion source through which helium gas is passed at a pressure of 2×10^{-5} Torr (air equivalent) and bombarded by 450 volt electrons to give a 1×10^{-8} A beam of helium ions of which about 1% are in the metastable state. The first intermediate chamber, primarily for vacuum separation, contains a microwave quenching cavity for modulating the metastable component of the beam and operates at a pressure of 5×10^{-7} Torr (air equivalent). The third chamber also serves as a vacuum separation chamber and operates at about 5×10^{-8} Torr (air equivalent). The fourth chamber is a 30-ft long drift tube containing a movable detector and operates at a pressure of 5×10^{-9} Torr (air equivalent). The beam is constrained to move down the axis of the drift chamber by an axial magnetic field which is started abruptly at the beginning of the drift chamber by a large Armco plate. A surface Auger detector is moved along the length of the 30-ft chamber and is contacted at twelve fixed points. The lifetime is determined by observing the decrease in the modulated metastable signal as a function of distance.

As a result of the development of the new ac electronics described in the previous report, the ac signal is stable to better than 1% for a constant dc beam. These conditions have permitted the careful measurement of the ratio of ac signal to dc signal under various conditions. We found that when the dc beam intensity was varied by changing the helium pressure in the source, the ratio of ac to dc remained constant to about 5%. For pressures above 1.8×10^{-5} Torr (air equivalent) in the source chamber the ratio of ac to dc began to drop. However, as a function of the axial magnetic field, the ratio varied by 10 to 15%. At station No. 1 without magnetic field the ratio varied by up to 50% as a function of lens deflection.

These variations in the ac-to-dc ratio made it impossible to make lifetime measurements, and in fact, for many conditions there was an appar-

ent increase in metastable signal with distance. These problems seemed to be associated with the collection efficiency for secondary electrons from our Auger detector. A study of the ac-to-dc ratio as a function of detector to ground potential reenforced this conclusion. Steps are therefore being taken to modify the detector in order to insure that all secondary electrons go rapidly to ground and do not return to the detecting surface.

An additional problem arose: for the conditions used previously it was no longer possible to obtain dc beams whose magnitude was independent of the axial magnetic field. Only when much larger values of the magnetic field were used to cancel the earth's field could we obtain regions of independence of dc beam and axial magnetic field. This poses a serious problem since we do not know what the beam trajectories are. Trajectories which carry the beam near to the walls of the chamber may introduce quenching and thus affect the ac-to-dc ratio. A continuous detector has been constructed and is being installed in the apparatus which will allow us to monitor the beam between stations and obtain more information about the trajectories. We are also seriously considering rewinding the axial magnetic field on a uniform vacuum chamber and using mu-metal shields to exclude external fields.

Program for the next interval: During the next quarter we will 1) study the beam trajectories in the present apparatus, 2) work on a design for a new drift tube, and 3) begin design of apparatus for simultaneous detection of the two-decay photons.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

B. OPTICAL DETECTION OF LEVEL CROSSINGS

1. Optical Detection of Level Crossings in the $(4s\,4p)^3P_1$ State of Zn^{67}*

(A. Landman, R. Novick)

The trial-and-error procedure mentioned in the last Quarterly Progress Report has proven successful in determining A, B, and g_J'. We used trial values for A, B, and g_J' and inserted the experimental values for the crossing fields to diagonalize the matrix and compare the eigenvalues of the

crossing states. The set which gave the best fit is as follows:

$$A = 609.086(8) \text{ Mc/sec} ,$$

$$B = -18.777(4) \text{ Mc/sec} ,$$

and

$$g_J' = 1.50100(3) .$$

This work has now been completed and is being prepared for publication. No further reports will be issued.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

2. Optical Detection of Level Crossings in the $^2P_{3/2}$ States of Na^{23} and Rb^{87}*
(R. J. Goshen, P. Thaddeus,† R. de Zafra)

Level crossings in the second excited state of Li^7 have been observed with the beam type apparatus previously described. We are able to obtain a sufficiently dense beam of alkali atoms without quenching our resonance radiation. The measurements on Na^{23} and Rb^{87} are planned at the conclusion of the Li work.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

†NASA Institute for Space Studies.

3. Level Crossing Experiments in the $^1P_1$ State of Cd*
(A. Landman, A. Lurio,† R. Novick)

A Cd^{113} cell has been made with the enriched sample received from England, and resonance scattering has been observed. We have also been able to make good circular polarizers with PVA (polyvinyl alcohol)

for the 2288 Å line, but we still lose a factor of ten in intensity with the Polacoat linear polarizers.

Program for the next interval: We plan to look for double resonance transitions during the next quarter.

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*This research was also supported by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-65.

†IBM Watson Laboratory.

4. Optical Detection of Level Crossings in the Stable Isotopes of Kr*
(D. Landman, R. Novick)

This project has been postponed because of a change of personnel.

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*This research was also supported by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-65.

C. COHERENCE TIME MEASUREMENTS

1. Detection of Level Crossings in Backscattering*
(R. J. Goshen, A. Landman, R. Novick)

No new measurements were made during the last quarter because much of the equipment and personnel time have been utilized for the Li 3P experiment. When the Li experiment is completed, backscattering in Cd will be continued with the addition of a new modulation scheme which will give increased sensitivity in obtaining lifetimes, including effects of coherence narrowing and collision broadening, from measured widths.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

2. High Field Measurements of the g Factors of the Alkali Earths by Double Resonance*
(R. Kohler, P. Thaddeus†)

Somewhat more accurate and reliable data than that given in the previous Quarterly Report were obtained through additional runs of the experiment. Various practical problems have prevented acquisition of completely reliable data on Cd. The nuclear resonance probe was continually heated and destroyed by the flames that warm the microwave cavity with its enclosed Cd sample. When this condition had been corrected through improvements in the construction of the probe and more judicious placement, it was found that the two available resonance cells had become defective. New resonance cells are currently being built.

Program for the next interval: It is expected that reliable data will be obtained and the g factor of Cd will be detemined to a few parts per million.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

†NASA Institute for Space Studies.

D. FINE STRUCTURE OF SINGLY IONIZED LITHIUM*

(P. Feldman, W. Kahan, R. Novick)

During most of the past quarter, work on this experiment was suspended while experimental runs on the metastable lithium atom (see I, E below, p. 8) were made. Towards the end of the quarter, construction and assembly of the apparatus described in the last report[1] were resumed and will continue throughout the next period.

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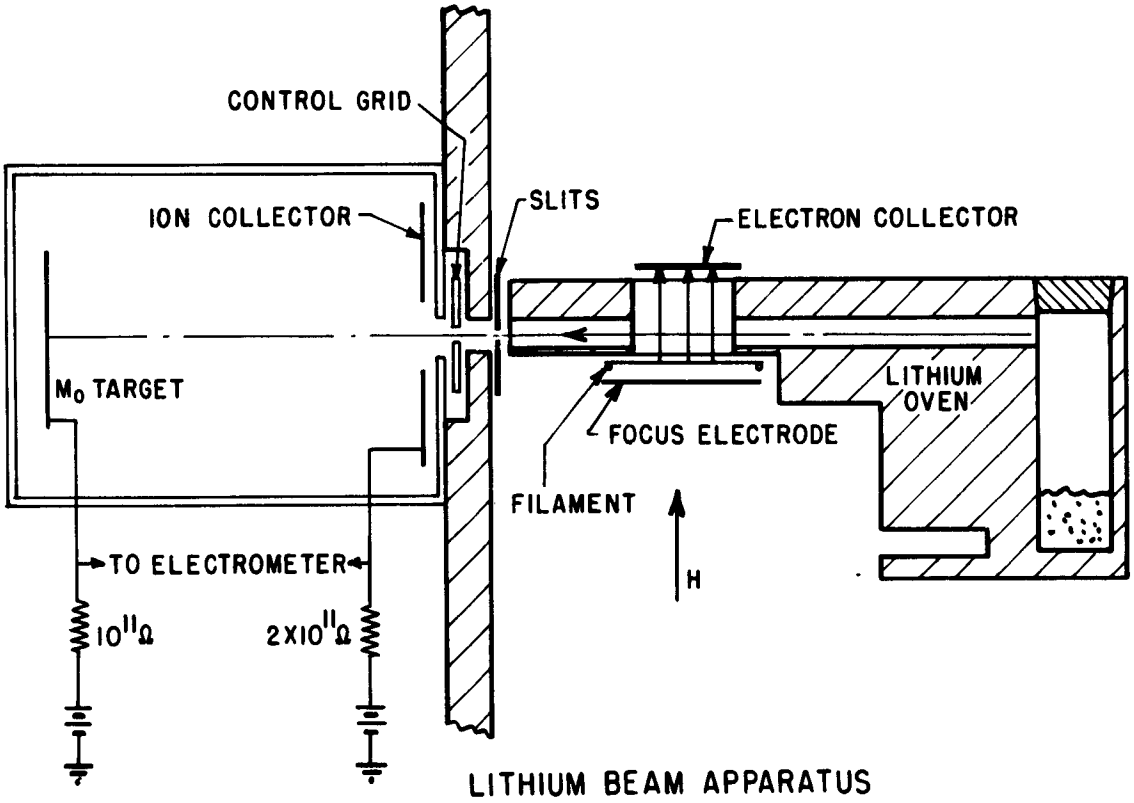
*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

(1) CRL Quarterly Report, December 15, 1962, p. 9.

E. THE METASTABLE LITHIUM ATOM*
(P. Feldman, R. Novick)

Preliminary evidence for the existence of the $(1s\,2s\,2p)\,^4P_{5/2}$ metastable state of lithium was reported in the previous Quarterly Report.[1] Many improvements in the experimental arrangement have enabled us to observe the structure of the excitation curve and to measure the lifetime and production cross sections for this state. These results are presented below, together with observations on other atoms and possible future applications of these atoms in the study of atomic and nuclear structure.

Fig. 1 shows the improved experimental arrangement. The major change is in the detector, which now consists of two plates. The plate nearer the source is cut so as not to intercept the beam. If we assume that lithium



LITHIUM BEAM APPARATUS

FIGURE 1. Lithium beam apparatus.

atoms in the metastable $(1s\,2s\,2p)\,^4P_{5/2}$ state decay to a ground state ion $(1s^2)\,^1S_0$ and a free electron, and if the detecting plate is biased so as to collect positive ions, then the ion current reaching the plate will be proportional to the number of metastable atoms reaching the entrance of the detector. The control grid is generally kept at some potential to prevent stray ions or ions resulting from the decay of metastable atoms before the detector from entering and being collected. We can also reverse the bias on the collector to detect electrons. The excitation curve taken in this way is the same as when ions are collected, but is smaller in magnitude because the electrons are emitted with 50 V energy (the ions come off at rest in the center of mass) and fewer are collected.

Fig. 2 is a detailed excitation curve taken with the ion collector. The sharp peak at 58 eV corresponds to the $(1s\,2s\,2p)\,^4P_{5/2}$ state, with threshold energy of 56 eV above the Li ground state. This result may be compared with Ta-You Wu's theoretical estimate[2] of 57.99 eV.

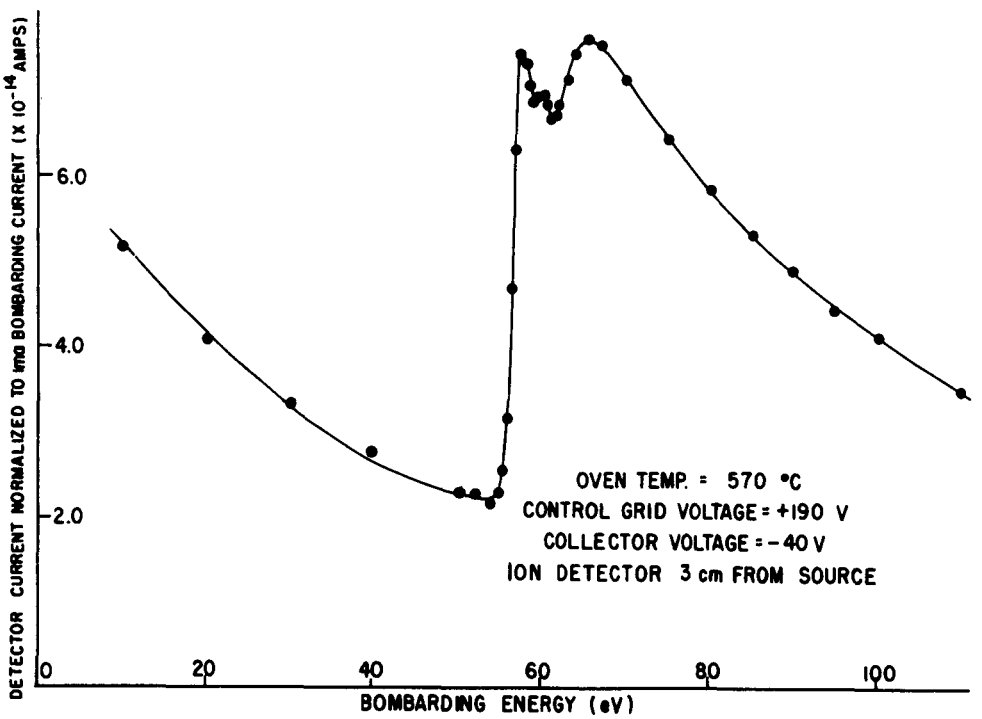


FIGURE 2. Number of ions collected per unit electron flux as a function of electron energy.

Another improvement was the suppression of parasitic oscillations in the 100 kc filament supply for the electron gun. This reduced the peak-to-peak spread in electron energy from 5 V to 1 V, and the improved energy resolution manifested itself in the appearance of a small peak at 60 eV. The other uncertainty in the energy measurements arises from contact potentials, limiting our values to no better than ± 1 V. The two smaller peaks in the excitation curve, at 60 and 65 eV, can probably be explained as other doubly excited metastable states, $(1s\,2p^2)\,^4P$ for the lower one, and $(1s\,2s\,ns)\,^4S$, $n \geq 3$, for the higher one, which decay through emission of electric dipole radiation to the lowest quartet level, $(1s\,2s\,2p)\,^4P_{5/2}$. However, there is no direct evidence to verify this, and the only supporting evidence is the presence of lines in the Li^+ spectrum[3] which do not fit the term system.[4]

The other detector is a molybdenum plate located 14 cm from the center of the source, sensitive to photons as well as metastable atoms. At 14 cm the metastable state we are looking at is hardly present and all that we see is attributed to photons from the decay of excited states of lithium atoms and ions in the detector region. Fig. 3 is an excitation curve taken with this detector. Note the threshold at 65 eV corresponding to the lowest excited states of the lithium ion.

The background in Fig. 2 has the same shape as the photon excitation curve below 55 eV and is presumably a photon effect, since it is not affected by the magnetic field. It is not linearly related to the lithium beam intensity and is somewhat dependent on the pressure in the system. Its two most striking features are its increase with time and its strong attenuation when the control grid is placed at some potential, either positive or negative with respect to ground. Although the exact nature of the background is still unknown, it does not hinder us from taking good data.

Lifetime

The lifetime of the $(1s\,2s\,2p)\,^4P_{5/2}$ state was measured in a time-of-flight experiment. The detector was made movable by means of a bellows assembly on the end plate of the vacuum system. The distance traveled by the beam was defined as the distance between the entrance pupil of the detector (right behind the control grid) and the center of the electron bombarder. This distance is variable over 1 inch. A fixed aperture, 0.090 in. x 0.025 in., is attached to the bulkhead separating source from detector chambers, and defines a beam which is smaller than the solid angle subtended by the entrance of the detector over a 1/2-in. length. With this geometry, the

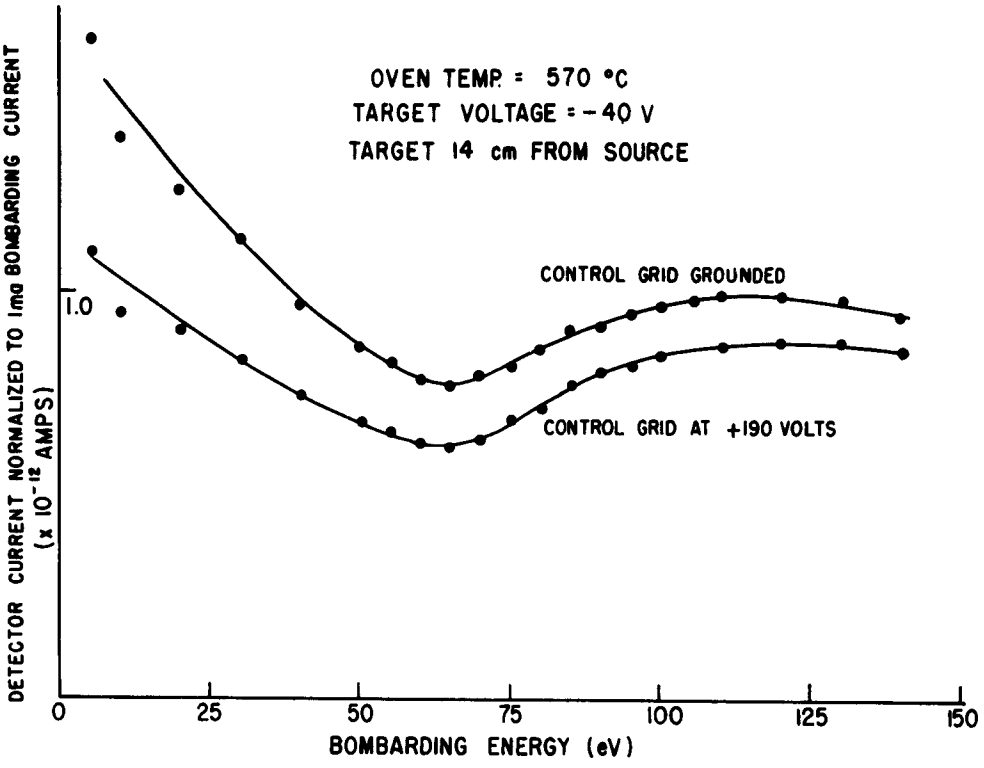


FIGURE 3. Number of photoelectrons collected per unit electron flux as a function of electron energy.

current at the ion detector does not have to be corrected for solid-angle effects. The metastable signal is measured by taking the difference between the observed current at maximum cross section and at threshold. Typical data are shown in the semilogarithmic plot of Fig. 4.

In reducing the data to determine the mean lifetime of the metastable state,[5] the Maxwellian velocity distribution of atoms in the beam and the finite length of the electron bombarder must be considered. If N_o is the number of metastable atoms per second excited at a point source, then the number remaining at a distance X from the source is given by:

$$N(X) = \frac{4 N_o}{\alpha^3 \sqrt{\pi}} \int_o^\infty v^2 \exp(-v^2/\alpha^2) \exp(-X/v\tau)\, dv \quad , \quad (1)$$

where τ = mean lifetime of atom,

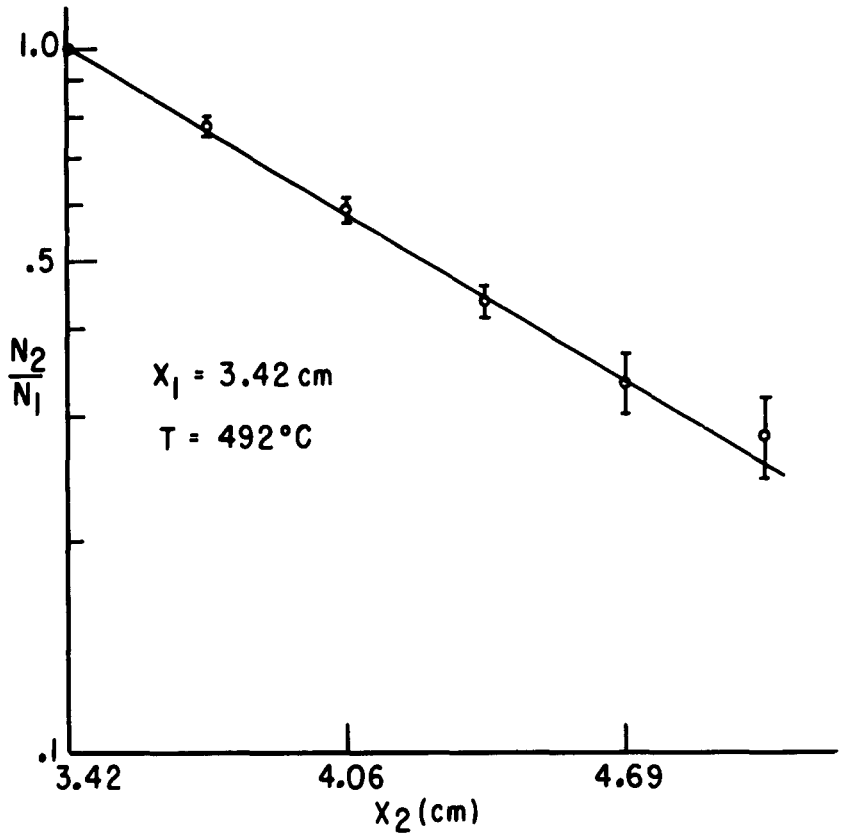


FIGURE 4. Relative ion signal as a function of distance.

and $\alpha = (2\,k\,T/m)^{1/2}$, the most probable velocity in the beam.

For a finite source of length ℓ centered at $X = 0$, equation (1) becomes:

$$N(X) = \frac{4\,N_o}{\alpha^3\sqrt{\pi}} \int_o^\infty \frac{v^3\tau}{\ell} \exp(-v^2/\alpha^2) \exp(-X/v\tau) \left[\exp(\ell/2v\tau) - \exp(-\ell/2v\tau)\right] dv \quad . \tag{2}$$

This integral may be evaluated numerically using a computer for different values of X, ℓ, and the parameter $a = X/\tau\alpha$. Fig. 5 shows the distance function $N(X)/N_o$ as a function of a, for $\ell = 0.95$ cm and $X = 3.1$ cm. The metastable signal is measured at two different points, X_1 and X_2, yielding currents I_1 and I_2. Now,

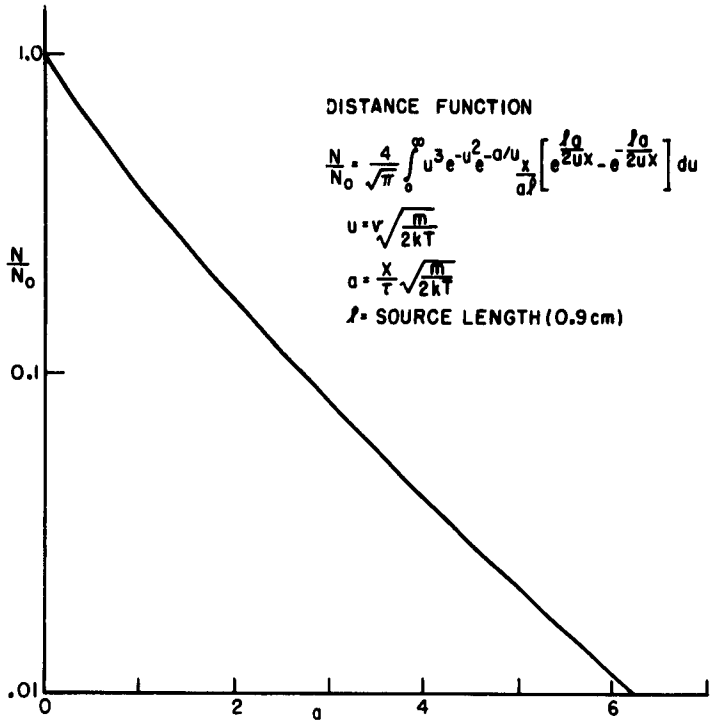


FIGURE 5. Distance function $N(X)/N_0$.

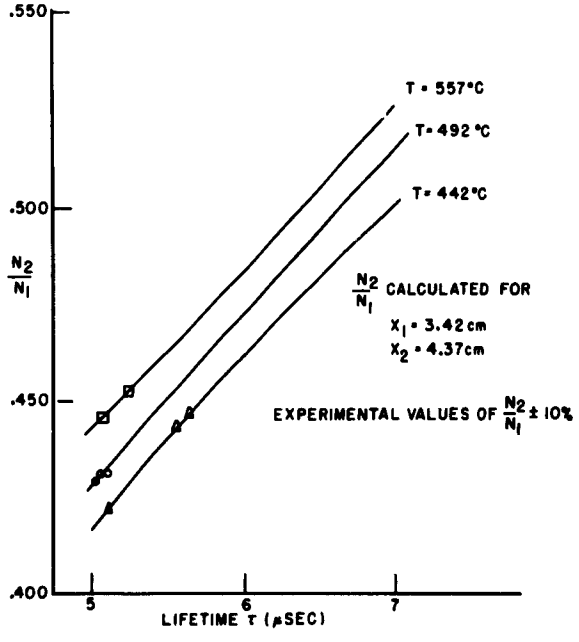


FIGURE 6. Graphical determination of lifetime τ from experimental data.

$$\frac{I_2}{I_1} = \frac{N_2 (X_2)}{N_1 (X_1)} = \frac{N_2/N_o}{N_1/N_o} \quad . \qquad (3)$$

Since we have no a priori way of knowing N_o, we must resort to graphical solution for τ. Knowing all distances and the oven temperature, we can calculate N_2/N_1 as a function of τ from the distance function, and the lifetime can be determined from the experimental values of N_2/N_1. This is done in Fig. 6 for three different oven temperatures. Data points are plotted directly on the graph and yield a lifetime $\tau \geq 5.1 \pm 1$ μsec.

Although no quenching effects were observed with the variation of pressure in the apparatus, pressure could not be sufficiently increased to observe the onset of any collision quenching; hence our result can only be looked upon as a lower limit, until further data are taken.

Cross Section

An order of magnitude measurement of the maximum value of the excitation cross section was made as follows: A surface ionization detector consisting of a 0.001-in. platinum-tungsten wire and suitable ion collector was used to determine the intensity of the neutral lithium beam, using the same geometry as before. The wire, an alloy of 92% Pt and 8% W, was heated until the number of lithium ions collected did not increase with increasing wire temperature. At this point (approximately 1700°K) the ionization efficiency of the wire for lithium is 20%.[6] The total beam intensity is obtained by measuring the intensity for three temperature values and the corresponding metastable intensity 3.4 cm from the source, if one assumes that the ion collection efficiency is 100%.

TABLE I. Total beam and metastable beam intensities.

T	$I_{neutral}$	$I_{metastable}$ (X = 3.4 cm)
440°C	5×10^{-7} A	2.3×10^{-14} A
490°C	2×10^{-6} A	8.4×10^{-14} A
555°C	5×10^{-6} A	2.7×10^{-13} A

All values ± 50%.

When the bombarding current and geometry are known, the cross section is obtained by using the distance function N_1/N_o to determine the number of metastable atoms in the source. The result is $\sigma \cong 10^{-19}$ cm^2.

Program for the next interval: The immediate program calls for a modification of the apparatus to include a microwave cavity for spectroscopy. This change should permit an exact identification of the state and measurements on the fine and hyperfine structures. We also plan to determine the nature of the differential metastability of the sublevels of the $^4P_{5/2}$, F = 4 state, and whether or not we can use this effect to produce polarized lithium ions. Autoionization has been observed in the heavier alkalis, K, Cs, and Rb, and there is the possibility that metastable autoionizing states exist in these elements as well as in Li. Potassium will be studied during the next quarter, using the same experimental arrangement.

As a check for systematic effects in the apparatus, cadmium was placed in the oven, and the experiment run in the usual manner. No unusual effects were observed, but a large signal was detected at the far molybdenum plate with thresholds at 22 and 70 eV. The known spectra of Cd I and Cd II do not indicate anything that might give the effect at 22 eV. However, similar effects were noticed in experiments on the total scattering of electrons in Cd vapor[7] performed over thirty years ago, with the appearance of thresholds at the same energies. This problem will also be investigated further during the next interval.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

(1) CRL Quarterly Report, December 15, 1962, p. 11.

(2) Ta-You Wu, Chin. J. Phys. 5, 150 (1944).

(3) Herzberg and Moore, Can. J. Phys. 37, 1293 (1959).

(4) Lee Bradley, private communication.

(5) W. Lichten, J. Chem. Phys. 26, 306 (1957).

(6) S. Datz and E. Taylor, J. Chem. Phys. 25, 389 (1956).

(7) R. Brode, Phys. Rev. 35, 504 (1930).

F. MEASUREMENT OF THE LIFETIMES OF THE $^1P_1$ AND $^3P_1$ EXCITED STATES OF GROUP II ELEMENTS*

(R. J. Goshen, A. Lurio,† R. de Zafra)

The results of the experiments on the $^1P_1$ states of Ca and Sr have been submitted for publication in the Physical Review. The measurement of τ for the $(4s\,4p)\,^1P_1$ state of zinc has been completed; the value is $(1.49 \pm 0.17) \times 10^{-9}$ sec.

Program for the next interval: A more elaborate apparatus capable of more precise measurements is being planned; it will be able to handle elements whose physical and chemical properties present severe difficulties. The study of the lifetime of the $^1P_1$ excited state of magnesium will be continued in the present apparatus.

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*This research was supported in part by the National Aeronautics and Space Administration under Grant No. NsG-360, and in part by the Office of Naval Research under Contract Nonr-266(45).

†IBM Watson Laboratory.

G. HYPERFINE STRUCTURE OF GROUP II A ISOTOPES*

(H. Bucka, R. J. Goshen, R. Novick, R. de Zafra)

Several resonance cells containing a 25% enriched sample of Ca^{43} were constructed and tested, but we failed to observe rf transitions in the $^3P_1$ excited state. We then decided to investigate the zero field level crossing (Hanle effect) involving the $^1P_1 \longrightarrow {}^1S_0$ main resonance line which would surely be observed if there were a Ca vapor pressure as low as 10^{-6} Torr. No such crossing was observed, and we are forced to conclude that something still is wrong either with the preparation or with the reduction of the Oak Ridge $CaCO_3$.

When we produced cells with stable Ca^{40} using the same chemistry (reduction with aluminum powder), fine crossing signals were easily obtained. We are unable to account for the unsatisfactory metallic yields from the Oak Ridge chemicals. Detailed discussions with Oak Ridge and spectroscopic studies of the samples have not helped us to understand the difficulty. We have recently tried to reduce reagent grade $CaCO_3$ using

titanium powder, and the results have been excellent. This technique will be attempted with the enriched isotope. Mischmetal will also be tried as a reducing agent.

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*This work was supported in part by the National Aeronautics and Space Administration under Grant No. NsG-360, and in part by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-65.

H. FINE AND HYPERFINE STRUCTURE OF THE 3P STATE OF Li^7*

(B. Budick, R. J. Goshen, A. Landman, R. Novick)

Both the zero field Hanle effect and the low field crossing have been observed in the 3^2P state.[1] Our magnet power supply which is intended to operate at high fields does not regulate well at zero field and so a study of the Hanle effect has been postponed. From the value of the crossing field (916 G) we have deduced a fine structure separation of 0.0961(5) cm^{-1}. The resonance signal is shown in Fig. 7. The peak-to-peak separation is 0.55 G.

Interestingly, the quoted splitting is 12% smaller than the doublet separation in the corresponding term in hydrogen. It should be compared with the measured fine structure in the 2P state which is 8% smaller than in the corresponding hydrogenic term.[2]

We are preparing to take precision data. This involves mapping our field carefully, replacing dc heaters with rf, recording proton and lithium resonances simultaneously, and investigating modulation effects. Our chief experimental difficulty is increasing our running time. The required beam intensity is such that collisions occur within the beam with appreciable scatter in the direction of our lenses.

Program for the next interval: A scheme to extend our running time, involving a "leaky cell" mentioned in the last report, is being studied. If it is successful, we hope to complete our measurement of the low field crossing, to measure a high field crossing that should also be observable, to repeat these experiments with Li^6, and to observe the 4P state.

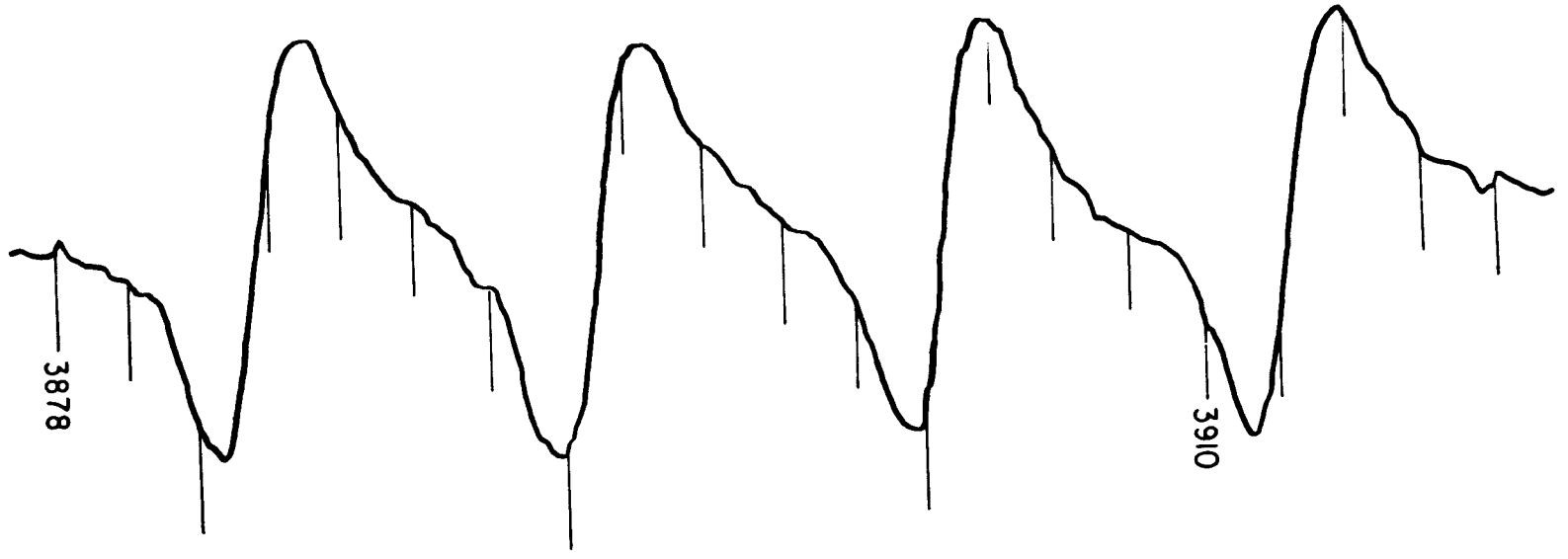

FIGURE 7. Low field level crossing.

*This work was supported in part by the National Aeronautics and Space Administration under Grant No. NsG-360.

(1) R. J. Goshen, H. Bucka, B. Budick, A. Landman, and R. Novick, Bull. Am. Phys. Soc. 8, 262 (1963); B. Budick, H. Bucka, R. J. Goshen, A. Landman, and R. Novick, ibid. 8, 352 (1963).

(2) Kenneth C. Brog, private communication.

I. SHARP FILTER FOR OPTICAL RESONANCE LINES BY USE OF THE FARADAY EFFECT*

(R. Kohler)

The optical system shown in the figure has been completed except for the construction of the Na cell. The system, including the magnet, is mounted permanently on its own optical bench, which in turn is to be mounted on the optical bench of the laboratory's Jarrell-Ash spectrometer.

The permanent magnet supplies a field of 3.4 kilogauss which calculations show is adequate to isolate either D line, or to transmit either fully with total exclusion of the other.

The purpose of the overall system shown in Fig. 8 is, on the one hand, to pass the light parallel to the magnetic field through 1/4 in. diam holes in the pole pieces, and on the other hand, to fill the optics of the spectrograph.

The Na cell is currently being constructed out of a special alkali resistant glass, Schott SM-157. This glass is expected to show no chemical attack at the required temperatures of about 230°C.

Program for the next interval: It is expected that during the next quarter, the system including the Na cell will have been completed, and a preliminary optical test of the filter will have been made.

*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

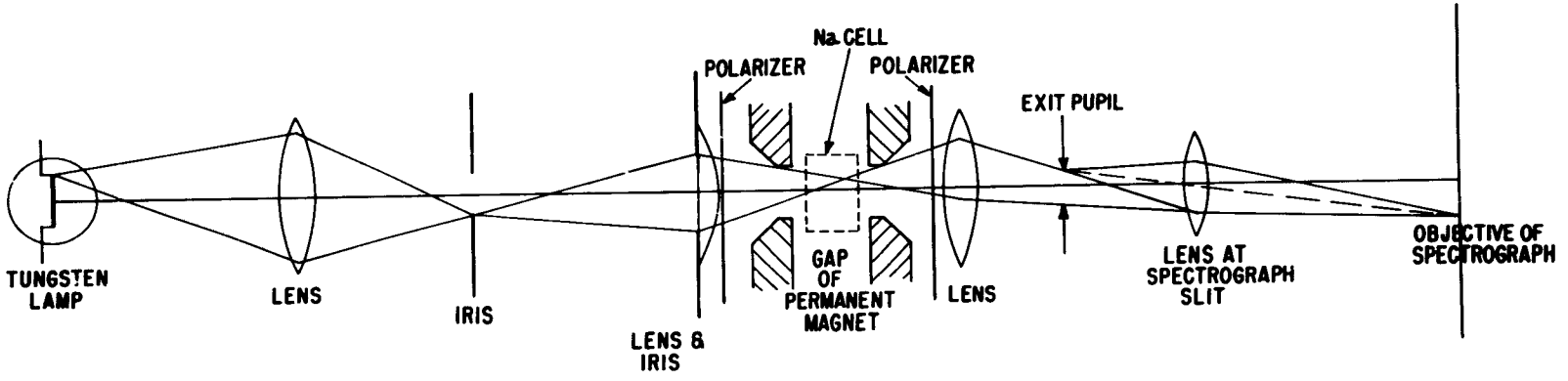

FIGURE 8. Optical system for the Faraday filter.

II. PROPERTIES OF RADIOACTIVE ATOMS

A. HYPERFINE STRUCTURE OF EXCITED STATES OF Na ISOTOPES*
(R. J. Goshen)

We still have not found windows for our resonance cell which are resistant to attack by alkali metals at high temperature and yet have acceptable transmission at 2853 Å. At 2853 Å the presence of impurities reduces the optical transmission coefficient of MgO to unusable or marginal values. We have continued to test MgO crystal and window samples for useful transmission at uv wavelengths in the hope that manufacturing processes would be improved, but thus far we have been unable to obtain an acceptable lot. We have therefore begun to investigate other materials which may meet our requirements in terms of their physical and chemical properties. BaF_2 and CaF_2 now appear to be very promising, and test cells are being constructed using such windows.

The double resonance spectrometer is in full operation, and the experiment will proceed as soon as satisfactory cell windows are obtained.

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*This research was supported by the Office of Naval Research Under Contract Nonr-266(45).

B. OPTICAL DOUBLE RESONANCE STUDIES OF RADIOACTIVE ATOMS*
(R. Novick, B. Perry, E. Saloman)

In the last quarter the spin and hyperfine interaction constants of the $(5s\,5p)^3P_1$ state of Cd^{113m} have been determined from intermediate field Zeeman effect measurements. The nuclear spin, magnetic dipole and electric quadrupole coupling constants are, respectively:

$$I = 11/2 \quad ,$$

$$A = -684.3(4)\ \text{Mc/sec} \quad ,$$

and

$$B = 174.4(13)\ \text{Mc/sec} \quad .$$

Neglecting nuclear structure and quadrupole antishielding corrections, the nuclear moments are:

$$\mu = -1.0861(6) \text{ nm} \quad ,$$

and

$$Q = -0.79(10) \text{ b} \quad .$$

A natural cadmium lamp was used to study the F = 11/2 state, and a Cd^{113} lamp for the F = 13/2 and F = 9/2 states. Individual $\Delta m_F = \pm 1$ transitions were observed in all three hyperfine states. Circular polarization measurements in the F = 13/2 state give the magnetic moment as negative.

The production of the Cd^{113m} sample has been discussed in previous reports.[1] Its extremely low radioactivity makes it difficult to estimate the actual amount of the sample. The F = 11/2 states are just about at the center of the natural cadmium lamp profile, and the resonances in this state, both for Cd^{113m} and for Cd^{115m}[2] isotopes, are of the same intensity. According to activity measurements, the Cd^{115m} cell had $1.5(7) \times 10^{11}$ atoms in the cell on September 4, 1962. From production calculations, and assuming 1% separation efficiency, one would have expected 5.2×10^{13} Cd^{115m} atoms on the foil; there were 3.6×10^{12}, and this quantity varied by 50% from foil to foil. Hence one would estimate 0.1(5)% for the isotope separation efficiency, and the expected yield with such an efficiency would be 6.4×10^{12} Cd^{113m} atoms. Thus only about 2 - 4% of the sample was distilled off the Pt foil in the cell filling procedure, compared with 80 - 90% of the radioactive sample when the target was silver.

A 10 mg sample of 99% Cd^{114} is being irradiated at the MTR to produce Cd^{115}. This is expected to produce an enrichment of 10^{-4} radioactive-to-stable sample, 0.04 radioactive-to-stable odd isotope.

Two proton bombardments on copper to produce 38 min Zn^{63} have been obtained. The dangerous radioactivity of this isotope makes the handling procedures extremely difficult. In both cases resonance cells were successfully filled, but lamp difficulties made the first run unsuccessful. Only about 10^{13} radioactive Zn atoms were distilled in the second run (10^{15} are necessary for the experiment). Future bombardments are planned.

Studies of suitable Zn resonance lamps have continued. The average lifetime of the Zn electrodeless discharge lamp is less than 10 hours, and its output is approximately 1.6 watts in the 3076 Å intercombination line, giving about 2.4×10^{15} photons/sec/cm^2 at the resonance cell. It is not ex-

pected that this intensity can be improved. The purpose of these studies is to manufacture a longer lived, more dependable lamp.

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*This research was also supported by the National Aeronautics and Space Administration under Grant No. NsG-360.

(1) CRL Quarterly Progress Report, June 15, 1962, p. 30.

(2) Ibid., September 15, 1962, p. 23.

C. HYPERFINE STRUCTURE OF Ca^{41} AND Ca^{45}*

(H. Bucka, R. J. Goshen, R. Novick, R. de Zafra)

The report of results on Ca^{41} and Ca^{45} is being transferred from this section and will be included in our comprehensive report on "The Hyperfine Structure of Group II A Isotopes," which is presented in section I, G above, p. 16.

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*This research was also supported in part by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-65.

D. OPTICAL DETECTION OF LEVEL CROSSINGS IN THE $(4s\,4p)^3P_1$ STATE OF Zn^{65}*

(A. Landman)

The trial-and-error procedure mentioned in the last Quarterly Progress Report has proven successful in determining A and B. We used trial values for A, B, and g_J' and inserted the experimental values for the crossing fields to diagonalize the matrix and compare the eigenvalues of the crossing states. The best values for A and B are as follows:

$$A = 535.172(8)\ \text{Mc/sec}$$

$$B = 2.865(8)\ \text{Mc/sec}$$

This work has now been completed and is being prepared for publication. No further reports will be issued.

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*This research was also supported in part by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-65.

III. PHYSICS OF MOLECULES

A. MASER BEAM SPECTROSCOPY*
(L. Krisher)

The beam maser spectrometer cavity has been changed over for the 0 ——— 1 transition of CH_3CN at about 18 400 Mc. An attempt to measure the hyperfine structure of this transition is in progress.

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*This research was also supported in part by the National Science Foundation under Grant No. NSF-G18811.

B. MICROWAVE ABSORPTION SPECTROSCOPY*
(L. Krisher)

Reports of results on this project are being transferred to section III, E, "High Temperature Microwave Spectroscopy" (see p. 30 below).

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*This research was also supported in part by the National Science Foundation under Grant No. NSF-G18811.

C. MOLECULAR BEAM VELOCITY SELECTOR*
(M. Hessel, P. Kusch)

The cause of the anomalous velocity distribution described in the last Quarterly Report[1] has been determined to be the residual magnetism in the deflecting magnets which preferentially deflects the low velocity atoms of K. Fig. 9 shows the measured velocity distribution (beam intensity vs reduced velocity of the molecule) for K with and without the deflecting magnets in the apparatus and for KCl with the deflecting magnets, compared with the theoretical distribution. The K (without deflecting magnets) and KCl velocity distributions agree with the theoretical distribution, except at low velocities. This slight deficiency of atoms on the low velocity side is probably caused by a velocity dependent scattering at the slits of the oven; for a further discussion of this point, see reference (2).

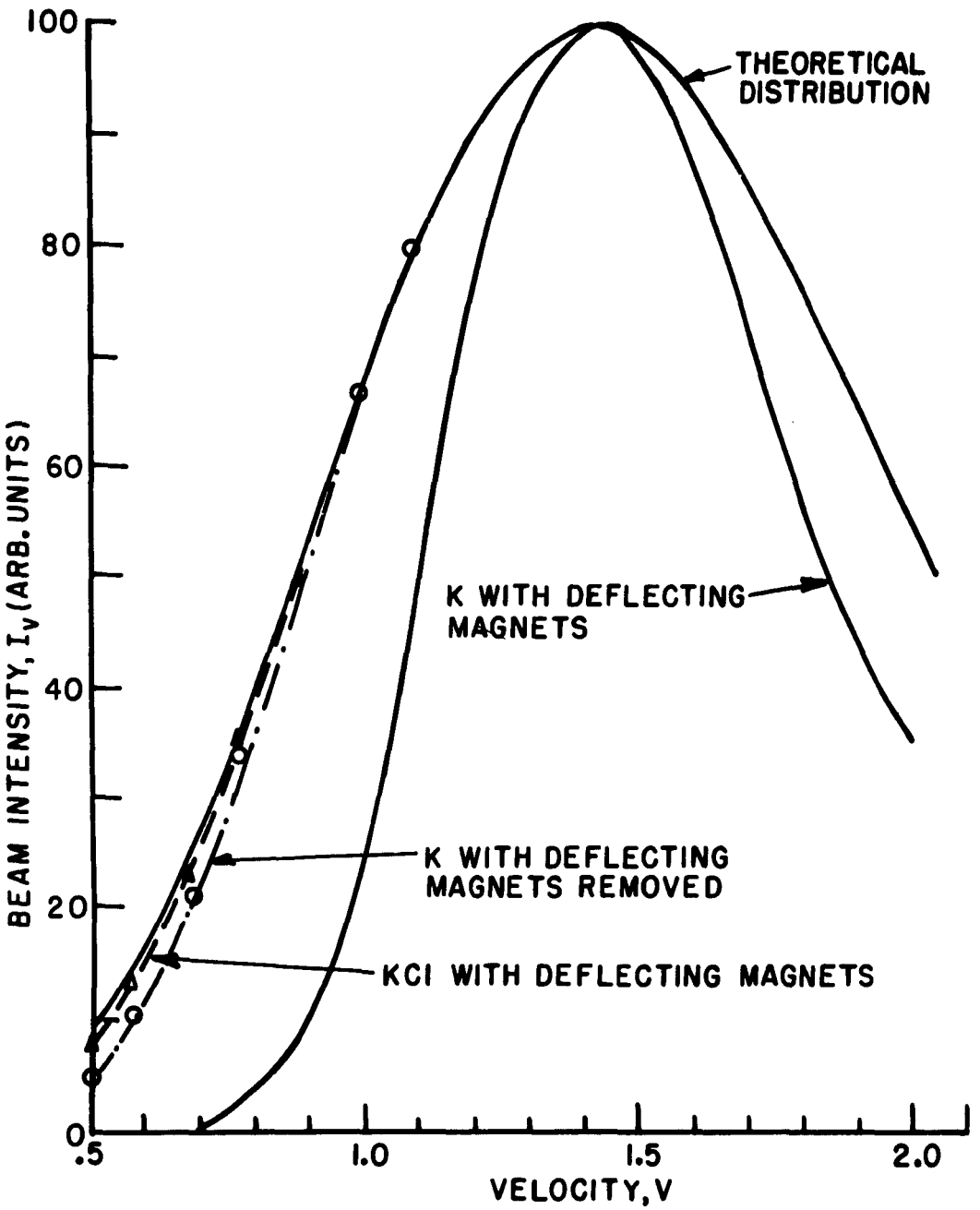

FIGURE 9. Velocity distribution (beam intensity vs reduced velocity of molecule).

KCL has a magnetic moment approximately 1/2000 that of K; therefore the deflecting magnets would not deflect the KCl molecule enough to produce a skewed velocity distribution. The residual magnetic field in the deflecting magnets was measured and found to be 750 gauss, large enough to give rise to the anomalous distribution.

Program for the next interval: We plan to perform the K-N_2 and KCl-N_2 scattering experiments described in previous reports.

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*This research was also supported by the Air Force Office of Scientific Research under Contract AF-49(638)-557.

(1) CRL Quarterly Progress Report, December 15, 1962, p. 33.

(2) R. C. Miller and P. Kusch, Phys. Rev. 99, 1314 (1955).

D. MOLECULAR BEAM ELECTRIC RESONANCE SPECTROSCOPY*
(P. Cahill, L. P. Gold)

The object of this program[1] is the measurement of the microwave and rf spectra of simple molecules by the molecular beam electric resonance method.

The initial experiment planned for this apparatus - the measurement of the rotational spectrum of lithium chloride - has been performed during the past quarter in a high temperature microwave absorption spectrometer as described in section III, E. A study is currently being made of the possibility of state selection in beams of simple polyatomic molecules, e.g., sodium hydroxide. A computer program[2] is being used to calculate the Stark effect of the many rotational levels which would be present at suitable beam temperatures.

Construction of the internal components of the spectrometer is almost complete, and their assembly is in progress. The apparatus will employ electric quadrupole A and B fields for state selection;[3] each will be 10 cm long. The beam will be ionized on a tungsten surface ionization detection filament which will serve as the source of a 60° mass spectrometer. The ions will be drawn out at an angle of 60° from the beam; the ion gun design is a

modified version of one described by Trischka.[4] Mass analysis will be accomplished by a permanent magnet capable of producing a field of over 5 kG in a 1/4-in. gap. The output ion beam of the mass spectrometer will be detected by a Bendix model M-306 electron multiplier. These components are currently being assembled in the beam can. The C field is still under construction and will be described in a future report.

A modulator and phase-sensitive detector have been constructed during the past quarter and are now being tested. Power supplies for the mass spectrometer and beam detector are under construction.

The klystron phase-locking circuit described in the previous report has been modified by replacing the 10 Mc internal reference frequency in the Gertsch FM-4 with a variable-frequency oscillator. When the oscillator sweeps over a range of about 1.5 Mc around 10 Mc, a K-band klystron locked to the Gertsch may be swept over a range of about 50 Mc with a stability of 500 cycles/sec or better depending on the stability of the variable oscillator used.

In order to maintain constant power output from a reflex klystron, a transistorized power stabilizer has been constructed and tested. A fraction of the klystron power is crystal detected, and changes in this crystal current are fed back to a Gyraline variable attenuator by use of a transistor circuit. Variation of the current through the Gyraline produces a rotation of the microwave electric field vector in the waveguide, and hence the microwave power is changed. The four transistor stabilization circuit, shown in Fig. 10, consists of a balancing bridge and two stages of amplification. Measurements of the operating system were made in K-band with a Raytheon 2K33 klystron and a calibrated microwave power attenuator; power stabilization to better than 1%, as monitored by reading a crystal current of 50 μA with a 1N26 crystal, was obtained for an 8 dB change in klystron power.

Program for the next interval: Construction and testing of the spectrometer will continue. Calculations on possible molecules to be studied will continue, and experimental studies will begin.

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*This research was also supported in part by the Air Force Office of Scientific Research under Contract AF 49(638)-557, and in part by the Office of Naval Research under Contract Nonr-266(45).

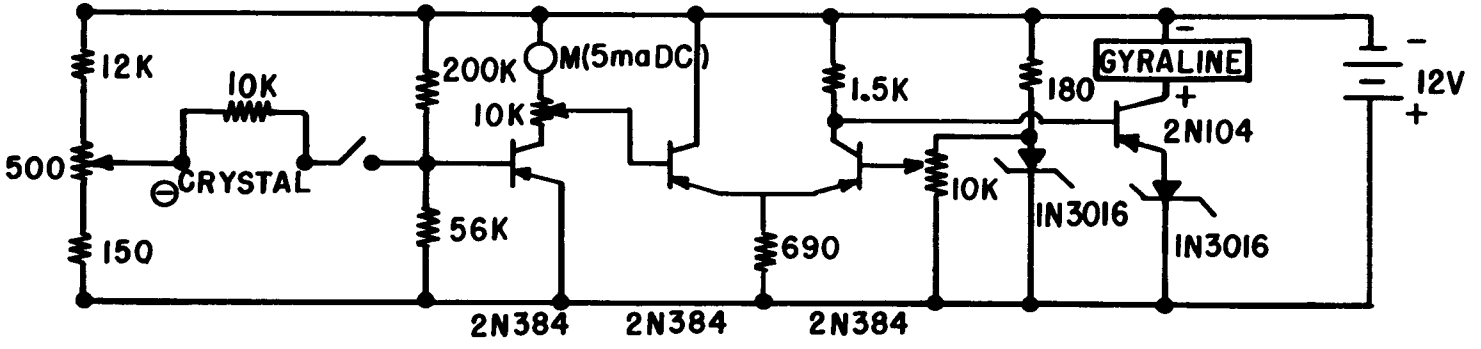

FIGURE 10. Klystron power stabilizer circuit.

(1) CRL Quarterly Progress Report, March 15, 1962, p. 45.

(2) R. Beaudet, Ph.D. Thesis, Department of Chemistry, Harvard University, 1961.

(3) H. G. Bennewitz, W. Paul, and C. Schlier, Z. Physik 141, 6 (1955).

(4) R. Braunstein and J. W. Trischka, Phys. Rev. 98, 1092 (1955).

E. HIGH TEMPERATURE MICROWAVE SPECTROSCOPY*

(P. Cahill, P. Gold, L. Krisher)

This is the first report on a new project to study the microwave absorption spectra of simple molecules in the vapor phase for cases where high temperatures are required to attain sufficient vapor pressure. We have constructed a high-temperature microwave spectrometer of new design and have used it to measure the rotational spectrum of lithium chloride.

Several high-temperature microwave spectrometers have been described previously.[1-6] The most successful of these[6] was constructed in this laboratory by Townes and his colleagues in 1954 and used to measure the microwave spectrum of many of the alkali halides;[4] this instrument could achieve a maximum temperature of 930°C.

The present high temperature spectrometer consists of nickel waveguide 38 1/2 in. long, with 80 mil wall thickness, inner dimensions 1.099 in. by 1.333 in., with a nickel septum 22 in. long supported inside and electrically insulated from the waveguide by eight Alsimag 222 insulators, as shown in Fig. 11. Both ends of the nickel waveguide extend beyond the furnace and are water cooled by use of copper coils. The Stark septum is located entirely in the hot region of the furnace, and electrical connection to the septum is made by a 1/16-in. strip of nickel which is connected to an Advac seal in the cold section at one end of the guide. Tapers to X-band or K-band are attached to the nickel waveguide by O-ring vacuum seals, and mica windows on the other ends of the tapers complete the vacuum system. The waveguide has been heated to 1000°C, and the water cooling has been sufficient to maintain the ends of the guide at room temperature. Otherwise, the spectrometer is a conventional 100 Kc Stark modulation system with phase

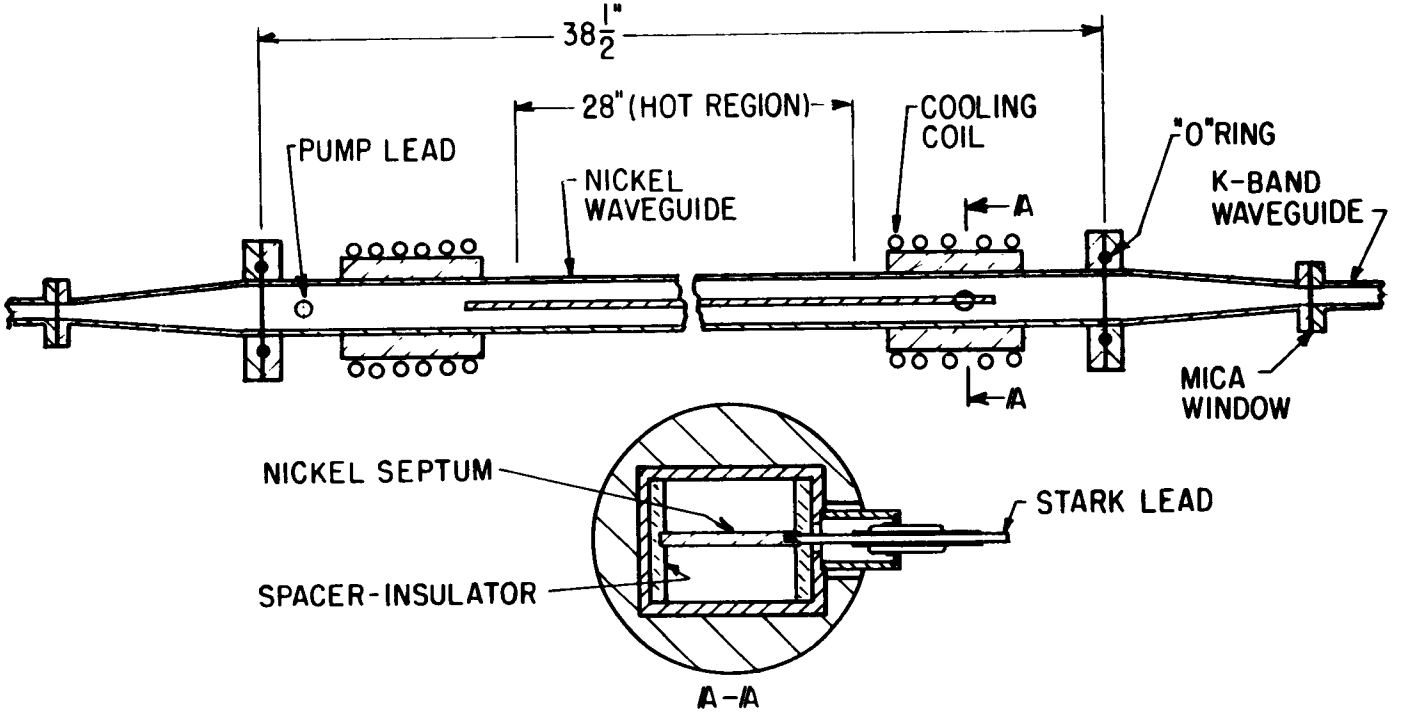

FIGURE 11. High temperature microwave cell.

TABLE II. Observed frequencies and molecular constants of lithium chloride.

Vibrational State	Li^7Cl^{35} (Mc)	Li^7Cl^{37} (Mc)
0	42 122.1 ± 0.2	41 743.1
1	41 646.6	41 274.0
2	41 175.9	
Y_{01}	21 181.1	20 989.9
D_e ($-Y_{02}$)	0.103 ± 0.001	(0.101 ± 0.001)[a]
Y_{11}	240.2 ± 0.2	236.9 ± 0.2
Y_{21}	1.2 ± 0.1	(1.2 ± 0.1)[a]
r_e = 2.02067 ± 0.00006 Å[b]		

a) Calculated from corresponding Li^7Cl^{35} constant.

b) r_e calculated from the relationship,

$$B_e = \hbar^2/2Mr_e^2 \quad ,$$

with $\hbar = 6.62517 \pm 0.00023 \times 10^{-27}$ erg-sec,

and the unit of atomic mass $= 6.02486 \pm 0.00016 \times 10^{23}\ g^{-1}$.

sensitive detection and oscilloscope presentation.

This technique provides a valuable complement to the molecular beam electric resonance method of studying molecular spectra.[7] The latter method provides much higher resolution and permits work at higher temperatures. However, the nature of the state selection and detection techniques limits to a great extent the types of molecules which may be studied in molecular beams; a much wider range of problems are accessible to the absorption method. Also, for many cases, the absorption spectrometer may provide a more convenient method of search for spectral lines which may then be studied in higher resolution in a molecular beam.

The $J = 0$ to $J = 1$ transitions for the three lowest vibrational states of Li^7Cl^{35} and the two lowest vibrational states of Li^7Cl^{37} have been observed near 42 kMc at 800°C. The observed frequencies are given in Table II along with the calculated molecular constants. The observed frequencies have been analyzed by the theory of Dunham[8] and, using previously measured values of ω_e and $\omega_e x_e$,[9] the first four potential energy coefficients in the Dunham expression for the potential energy were obtained. Microwave power at 42 kMc was obtained by frequency doubling the output of a Raytheon QK306 klystron. Frequency measurements were made with markers from a Gertsch FM4 locked to a Hewlett-Packard model 540B transfer oscillator, which was continuously counted to one part in 10^7. Oscilloscope presentation was used, and line widths of 1 to 2 Mc were observed for lithium chloride in the presence of up to 1 Torr of N_2 as a buffer gas. The quadrupole coupling constant, eqQ, for chlorine is - 3.1 Mc in lithium chloride;[10] therefore, due to the present line widths, no chlorine quadrupole structure was observed. The work on lithium chloride was done simultaneously and independently by Dr. David Lide at the National Bureau of Standards, and a joint publication is currently being prepared.

Program for the next interval: The program for the next interval will consist of the construction of another high temperature microwave cell with a high temperature value for admitting sample to the cell. The search for microwave absorption due to $BaCl_2$ and KCN will continue.

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*This work was also supported by the Air Force Office of Scientific Research under Contract AF 49(638)-557, the Office of Naval Research under Contract Nonr-266(45), and the National Science Foundation under Grant No. NSF-G18811.

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(2) H. Fitzky, Z. Physik 151, 351 (1958).

(3) P. A. Tate and M. W. P. Strandberg, J. Chem. Phys. 22, 1380 (1954).

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(5) J. Rusk and W. Gordy, Phys. Rev. 127, 817 (1962).

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(10) D. T. F. Marple and J. W. Trischka, Phys. Rev. 103, 597 (1956).

IV. SOLID STATE PHYSICS

A. ENDOR AND OPTICAL STUDY OF COLOR CENTERS*

(I. Bass, R. Gazzinelli, R. Marzke, R. Mieher)

1. Electron Nuclear Double Resonance of Silver Doped Alkali Halides

In the last quarter new features were introduced in the ENDOR spectrometer in such a way that the sample can be irradiated in the spectrometer at low temperatures by x rays.

A study of silver doped alkali halides was started. We were able to irradiate the doped crystals at liquid nitrogen temperature and run the ESR spectra while keeping the samples at the same temperature. We observed the lines due to V_k centers (Cl_2^- molecule), the lines due to one electron trapped in a substitutional silver ion (Ag^o), and the lines due to one hole trapped in a substitutional silver ion (Ag^{++}), as reported by Delbecq, et al.[1] A search for ENDOR lines in these three centers was unsuccessful. Saturation measurements showed that the spin lattice relaxation time (T_1) was too short at 77°K.

A new cryostat for the spectrometer which permits cooling the sample to liquid hydrogen or liquid helium temperatures was designed, and is being built.

Program for the next interval: When the new cryostat is completed, we plan to search for the ENDOR lines of the V_k, Ag^o, and Ag^{++} centers.

2. Double Nuclear Magnetic Resonance

Since the last Quarterly Report several improvements have been made in the experimental apparatus. A detailed description of the equipment will be given in a later report.

With the new apparatus double nuclear resonance effects have been seen in NaCl, KBr, and LiCl. The procedure consists in observing saturation of the resonance of one nucleus, e.g., Na in NaCl, while another nucleus, e.g., Cl, is irradiated at its resonant frequency. Experiments are now in progress to determine the sensitivity of the method in detecting small

numbers of spins present in the crystal as impurities, and in observing quadrupole splittings -- unobservable directly -- of the nuclear resonance due to lattice defects.

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*This research was also supported by the National Science Foundation under Grant No. NSF-GP 53.

B. ADIABATIC DEMAGNETIZATION IN THE ROTATING FRAME*
(S. Hartmann)

In the past quarter a cw nuclear magnetic resonance apparatus was built and a power amplifier for pulsed nmr applications was almost completed. The fabrication of general and specialized electronic apparatus for work on this project is continuing.

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*This research was also supported by the National Science Foundation under Grant No. NSF-GP 370.

V. OPTICAL AND MICROWAVE MASERS

A. INFRARED AND OPTICAL MASERS

1. Optical Maser Spectroscopy*
(H. Z. Cummins, N. Knable, L. Gampel, Y. Yeh)

a) Debye-Sears Effect

The optical maser spectrometer described in our preceding report was completed and operated successfully. Despite the complexity of the optical system, alignment was achieved rather easily because the maser beam itself is an ideal alignment source.

We have employed the apparatus to measure the frequency shifts in the Debye-Sears effect with both traveling and standing ultrasonic waves, and in Bragg scattering measurements with high frequency waves. In all three experiments, the frequency shifts measured were found to agree with the theoretical predictions to within the experimental error of less than one part per million. These experiments all employed water in the scattering cell, and in all cases signal power was high since the driven ultrasonic waves have large scattering coefficients.

b) Brillouin Scattering

After completion of the Debye-Sears and Bragg measurements, the driven ultrasonic cell was used to determine the sensitivity of the spectrometer. It was found that the sensitivity is approximately five orders of magnitude lower than the theoretical value for optical heterodyning. With the present sensitivity, Brillouin scattering from a homogeneous liquid would not be observable. We are currently studying the individual components of the spectrometer, and will rebuild it to increase the sensitivity. We are also investigating liquid mixtures which exhibit a critical mixing temperature for which the Brillouin scattering is very large. It appears that spectroscopy of these systems may be possible even with the limited sensitivity of the present equipment.

Program for the next interval: We will first attempt to observe Brillouin scattering from the binary system aniline-cyclohexane which exhibits critical mixing (and opalescence) at approximately 45°C.

We are currently making and will continue a series of power and response measurements in an effort to increase the heterodyning efficiency of the spectrometer.

A new 6328 Å He-Ne maser will be constructed and operated with various mirror configurations designed to increase the single-mode power output.

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*This research was also supported jointly by the Army Research Office under Grant No. DA-ARO(D)-31-124-G380 and the National Science Foundation under Grant No. NSF GP-438.

2. Ruby Maser
(I. D. Abella, S. Hartmann, N. Kumit)

The construction of the "pulsed reflector"[1] laser which was mentioned in the last progress report has begun. The present arrangement consists of a 90° ruby rod, terminated at one end with a corner prism, and pumped by a helical flash tube. Interposed between the ruby and an external 99% reflecting mirror are a mica quarter-wave plate and a Kerr cell, oriented with their fast or slow axes at 45° to the optic axis of the ruby. With no voltage across the Kerr cell, light leaving the ruby rod as an ordinary ray reenters it as an extraordinary ray, having passed twice through the mica quarter-wave plate. This effectively spoils the Q of the laser since a) the extraordinary ray is not amplified appreciably,[2,3] and b) upon reflection from the corner prism the path of the extraordinary ray is not parallel to its incoming path because of the bi-refringence of the ruby. The divergence of the incoming and outgoing rays is sufficient to cause them to be lost from the optical cavity in a few passes.

When the Kerr cell is pulsed, the polarization is restored to its original direction, and oscillation occurs. Since the population inversion can be built up to a high level, the gain is large, and a very brief high intensity pulse is generated. It was found that at room temperature the longest pulse which we could apply to the Kerr cell with the pulse-forming networks we had at hand, 50 nsec, was not of sufficient duration to allow the oscillation to build up to the point where it could be observed. At close to liquid nitrogen temperature, "giant" pulses of peak intensity, roughly 1000

times larger than a normal laser spike, were observed coming approximately 25 nsec after the Kerr cell was pulsed. Pulses of half-width as narrow as 15 nsec have been observed. A typical pulse is shown in Fig. 12a. Here the pulse is instrumentally broadened because the phototube is being operated at a low voltage, thus producing a slow rise time. The wiggles on the baseline are caused by rf pickup from the Kerr cell, which has been fired twice to indicate the baseline when there is no giant pulse. This picture is shown in order to compare the pulse with normal laser output, which is shown in Fig. 12b. Here laser action is taking place on the 8% reflectivity of the front face

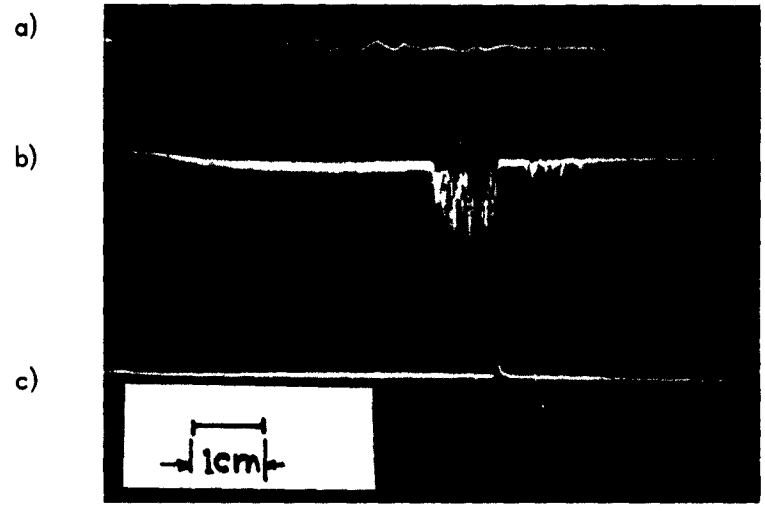

FIGURE 12. Laser output.

a) Upper trace: 100 nsec/cm, 0.5 V/cm; 7102 photomultiplier terminated in 50 ohms, with 900 V on anode.

b) Middle trace: 100 μsec/cm, 0.01 V/cm; photomultiplier unchanged except 1200 V on anode.

c) Lower trace: Kerr cell sync out, 100 μsec/cm.

of the ruby rod. When the Kerr cell is pulsed (see marker in Fig. 12c), the rod is seen to stop lasing for about 50 μsec, indicating that the giant pulse (which is too large and fast to be seen in this picture) has decreased the population inversion well below the threshold for oscillation on the 8% Fresnel reflection. Lasing starts again when the population difference has been restored by the pumping light. The pumping threshold using the external mirror is however only about 40 joules less than the 800-joule threshold using the front of the rod. This fact and the data of Fig. 12 indicate an inversion excess of approximately 5%.

Program for the next interval: We will investigate the dynamics of the buildup of the giant pulse in the hope of obtaining shorter pulses of higher peak power. A new laser head employing a liquid nitrogen dewar is being designed which will keep the temperature constant. The next report will contain a description of the experiments to be performed using the Q-switched laser.

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(1) F. J. McClung and R. W. Hellwarth, Bull. Am. Phys. Soc. 6, 414 (1961).

(2) I. D. Abella and H. Z. Cummins, J. Appl. Phys. 32, 1177 (1961).

(3) D. F. Nelson and R. J. Collins, Advances in Quantum Electronics, J. R. Singer, ed. (Columbia University Press, 1961), p. 79.

B. SENSITIVITY OF MICROWAVE SPECTROMETERS USING MASER TECHNIQUES*

(H. Lecar)

Work on this project has been completed, and a paper is being prepared for publication. A final report on the project will appear in the next Quarterly Report.

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*This research was also supported by the National Science Foundation under Grant No. NSF-G18811.

C. RUBIDIUM MASER

(P. Davidovits, N. Knable)

In order to confirm the value for the spin-spin relaxation cross section quoted in the last Quarterly Report, rubidium vapor pressure measurements were made on the cell. The density was determined by a measurement of the absorption of white light by the $S_{1/2}$, F = 1 $\longrightarrow$ $P_{3/2}$ 7800 Å resonance line, using a high resolution spectrometer. Knowing the f value for this transition, we computed the density from the absorption, assuming a Doppler-broadened line shape. The computed densities agreed within the limits of experimental accuracy with those taken from vapor pressure charts of Honig.[1]

A copper-plated stainless steel cavity designed for the TE_{011} mode has been constructed. The electrical properties of the cavity are satisfactory. Initially it was hoped that vacuum tight window joints would be obtained by using glass on copper O-ring seals, but this approach has not been successful since the vacuum could not be retained on temperature recycling. Similar difficulties were encountered with aluminum and gold O-rings. After repeated failure of the O-ring seals, this approach was abandoned.

At present experiments are being conducted with epoxy resin window seals. We are also investigating the possibility of making housekeeper-type window seals.

Program for the next interval: During the next quarter work will continue on the vacuum tight cavity.

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(1) R. E. Honig, "Vapor pressure data for the more common elements," RCA Review 18, No. 2, 199 (June, 1957).

VI. RADIOASTRONOMY

A. THE 10-CENTIMETER MASER FOR RADIOASTRONOMY
(W. K. Rose)

Polarization measurements such as those previously reported may be used to provide an upper limit on the number of electrons in intergalactic space. If the Faraday rotation takes place in intergalactic space (not in the source or in our galaxy), we may also obtain an estimate of the scale of the inhomogeneities. Radiation from distant galaxies will be depolarized by inhomogeneities in the intergalactic magnetic field and electron density that exist across the source as seen by the observer. To estimate the amount of depolarization we assume that space is divided into independent regions such that $\nabla H \times L = H$ (or $\nabla N \times L = N$, if $\nabla N > \nabla H$) where H is the component of the magnetic field in the direction of the observer, N is the number of electrons per cubic centimeter, and L = the characteristic length of the region. In addition, we assume that L is much smaller than the distance, D = n L, to the source. These assumptions indicate that the difference in the amount of Faraday rotation in intergalactic space for radiation originating from different parts of the source is

$$\Delta\psi \text{ (radians)} = \frac{10^6 N (\nabla H) (S/2) (D/n^{1/2})}{\omega^2} = \frac{5 \times 10^5 NHS (D/L)^{1/2}}{\omega^2} \quad (1)$$

where S is the diameter of the source in cm. The depolarization which takes place because of differences in the amount of Faraday rotation across a region of length S/2 is approximately

$$P(\nu) = P_o \frac{\sin (10^6 HNS/\omega^2)}{10^6 HNS/\omega^2} = P_o \frac{\sin 2x}{2x} \quad (2)$$

where $P(\nu)$ = the degree of polarization at frequency ν and P_o = the degree of polarization at frequencies such that x is small. Therefore, the depolarization which results from n regions of average length S/2 is obtained by substituting $\Delta\psi$ in equation (1) for x in equation (2).

By measuring the degree of polarization and the position angle of the maximum intensity, we can obtain an upper limit for the number of electrons/cc in intergalactic space (we assume $H = 10^{-7}$ gauss in intergalactic space) and, if most of the Faraday rotation takes place in intergalactic

space, we can estimate the scale of the inhomogeneity of H (or N). We have used the recent 21-cm measurements of the California Institute of Technology and our own at 9.4 cm to arrive at the following estimates by means of equations (1) and (2) and the expression for the Faraday rotation of the position angle of the intensity maximum, which is

$$\psi_{21\ cm} - \psi_{9.4\ cm} = 10^6\, NHD \left(\frac{1}{\omega^2_{21\ cm}} - \frac{1}{\omega^2_{9.4\ cm}} \right) / n^{1/2} \quad . \qquad (3)$$

TABLE III. Electrons N/cc in intergalactic space.

Source	Electrons N/cc in intergalactic space
Hercules A	$\leq 8 \times 10^{-5}$
3C433	$\leq 4 \times 10^{-5}$
3C295	$\leq 4 \times 10^{-5}$

B. M-BAND RADIOTELESCOPE*

(W. Kahan)

Because weather conditions have been unfavorable, no experimental work has been undertaken during the past quarter. There are no plans at present to resume measurements of telluric O_2 lines.

Calculations are in progress to compute the atmospheric microwave absorption in the mm band caused by ozone in the upper atmosphere, to determine whether ozone absorption of solar mm wave radiation can be detected with a radiotelescope. The results of these calculations will be presented in a forthcoming progress report.

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*This research was also supported by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-50.

C. MODELS OF PLANETARY ATMOSPHERES

(W. Ho, R. Osborn, P. Thaddeus†)

Data are being taken on the absorption of microwave radiation (20 kMc) by various gases and mixtures of gases at pressures from 0 to 20 atmospheres and at temperatures up to 100°C. Results of this work will be reported as soon as the data are complete.

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†NASA Institute for Space Studies.

VII. CRYOGENICS

A. HIGH FREQUENCY PROPERTIES OF SUPERCONDUCTORS*
(S. Zemon)

During the last quarter extensive data were taken on the same pure zinc cavity. Measurements were made at eighteen frequencies between 48 and 82 kMc and at temperatures from about 0.28°K to 0.85°K. For detection purposes we used a PRD bolometer from 50 to 75 kMc and a TRG bolometer above 75 kMc in conjunction with the Hewlett-Packard standing-wave amplifier.

The data have not yet been evaluated, but it was noted that the mode curve distortion due to waveguide VSWR was successfully removed by the placing of the directional coupler in the cryostat very close to the cavity.

Program for the next interval: The most recent data will be analyzed and evaluated, and a paper will be written.

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*This research was also supported by the National Science Foundation under Grant No. NSF-G17080.

B. RADIATION PRESSURE OF SECOND SOUND IN LIQUID HELIUM II*
(C. Metz)

Calculations were completed during the last quarter, and the writing of the thesis was begun.

Program for the next interval: The thesis will be finished during the next quarter.

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*This research was also supported by the National Science Foundation under Grant No. NSF-G17080.

C. ELECTRONIC AND LATTICE HEAT CAPACITIES OF SUPERCONDUCTORS*

(H. Leupold)

The modifications of equipment proposed in the previous report have been made, and heat capacity measurements of the Nb crystal are about to begin. It is hoped that these measurements will extend down to about 0.4°K. Final processing of data already obtained was begun during the same period.

Program for the next interval: All measurements on the Nb crystal will be completed, and the doctoral thesis will be written.

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*This research was also supported by the National Science Foundation under Grant No. NSF-G17080.

VIII. MAGNETRONS AND SPECIAL DEVICES

A. UNIVERSAL RESONANCE LAMP*

(B. Budick, R. J. Goshen, A. Lurio,† R. de Zafra)

No further experimental work is planned on the flow lamp. Previous results will be summarized in a paper which will appear in the Review of Scientific Instruments.

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*This work was supported in part by the Air Force Office of Scientific Research under Grant No. AF-AFOSR-62-65.

†IBM Watson Laboratory.

B. ULTRAVIOLET POLARIZERS

(R. J. Goshen, R. Novick, M. Mandelkern)

We have investigated clear polyvinyl alcohol (PVA)[1] for use as retardation plates in the far ultraviolet. The transmittance of several PVA samples is shown in Fig. 13. As is well known, this material becomes birefringent when stretched, and it is quite easy to produce a 1/4 λ retardation at any wavelength in the region of interest.

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(1) Supplied by American Cyanamid Co.

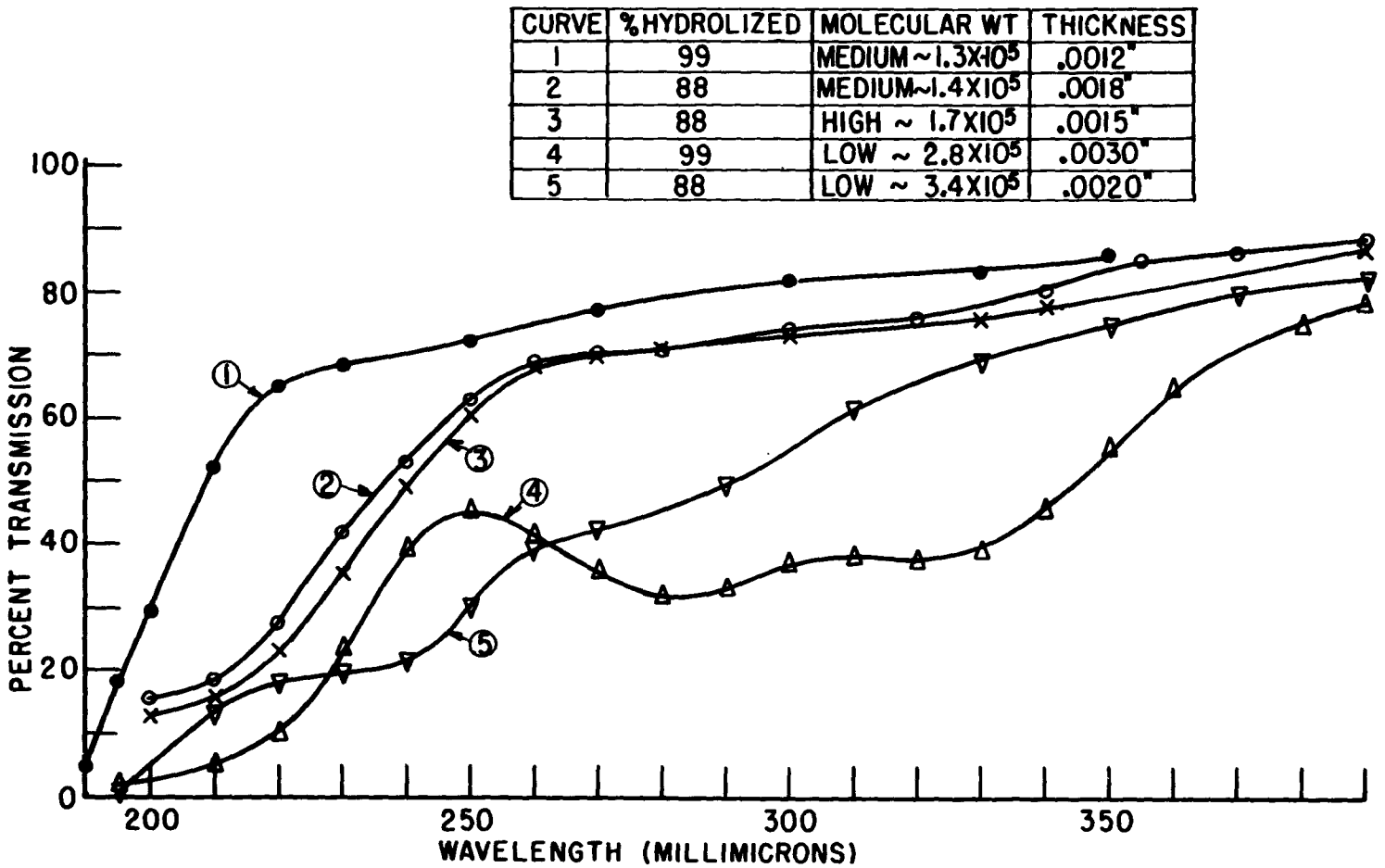

FIGURE 13. Transmittance of polyvinyl alcohol in the far ultraviolet.

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Columbia Radiation Laboratory, Columbia University
538 West 120th Street, New York 27, New York

First Report on RESEARCH INVESTIGATION DIRECTED TOWARD EXTENDING THE USEFUL RANGE OF THE ELECTROMAGNETIC SPECTRUM

Report dated: March 15, 1963
vi + 54 pages, 13 figures

A detailed study has been made of the metastable lithium atom. The threshold energy (E_o), production cross section (σ), and lifetime (τ) are: E_o = 56 ev, $\sigma = 10^{-19}$ cm^2, and $\tau = 5 \pm 1$ μsec. These values are in reasonably good agreement with the theoretical calculations.

The fine structure splitting of the 3^2P term of the lithium atom has been determined by level crossing spectroscopy. The observed interval is 2880 Mc/sec and is about 12% smaller than the corresponding splitting. Precise knowledge of fine structure will provide a critical test of these electron wave functions.

The spin, magnetic moment and quadrupole moment of Cd^{113m} have been determined by optical double resonance. Computational techniques have been developed for the evaluation of fine structure corrections to the level crossing fields in (sp) configurations.

A new electric resonance molecular beam apparatus has been constructed and will be used for the study of molecular structure. A new high temperature microwave absorption spectrometer has been constructed and used for the determination of the rotational structure of LiCl. This spectrometer is unique in that it employs a nitrogen buffer gas to reduce the rate of contamination of the microwave windows and Stark plate insulators.

An optical maser has been used for the precise determination of the frequency shifts of the light scattered by an acoustically excited liquid (Debye-Sears effect).

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2. Contract DA 36-039 SC-90789

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