II. Microwave Physics

A. Radio Frequency Spectra

1. Oxygen Absorption Spectra at 5 mm.

Staff: Mr. J. B. Ingersoll
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Problem: Van Vleck has pointed out the presence of absorption of electromagnetic waves in oxygen due to magnetic coupling of the molecular rotational and spin system. Measurements by Beringer showed that this was indeed the case, and the absolute value of the attenuation was measured.

The present work hopes to refine the preliminary measurements of Beringer to reveal the fine structure of this line (the composite absorption of a number of sharp lines which overlap at atmospheric pressure due to pressure broadening) at low pressures, and to assign absolute frequencies (for secondary frequency standards) to the individual components. Studies of line breadth as a function of pressure will be made to assist in formulating pressure broadening theory.

Method: The method of measurement is quite simple. Five millimeter r.f. from a single source is divided between two almost equal lengths of waveguide. At the output end they are added in phase opposition and hence cancel each other, thus with one arm evacuated there is no output from the receiver which those arms feed. The evacuated arm is then filled with oxygen and the absorption, or unbalanced power, is read on the receiver output.

Components developed: For measurements at low pressures (narrow absorption lines) extremely good frequency stability in the signal source is necessary. So a Pound type of r.f. stabilizer has been made at 1 cm. At present Neher A5022 (high voltage) local oscillators working at about 1 cm. are used. Attempts are being made to have some 2K-33"s satisfactorily modified by Raytheon to extend the available frequency range.

A silicon crystal frequency multiplier is used to obtain about 25 μwatts of 5 mm r.f. The receiver is a superhetrodyne with a harmonic mixer using a second stabilized A5022. The receiver sensitivity is thought to be about 115 db below one watt, with a 4 mc/s wide i.f.

Magic tees for 5 mm. have been made for dividing and recombining the signals in the comparison waveguide arms.

Plumbing for 1 cm. work is made by scaling the waveguide and all dimensions from the existing 1.25 cm. components.

Results: Measurements have been made from about 5.40 to 5.[illegible] [illegible], but the line predicted in this region has not been found.

The measured absorption is self-consistent and checks well with Beringer's results.

Preliminary indications in this region indicate that off-resonance absorption follows a less than linear law.

The original method of taking data and changing frequency has proved to give results too slowly. The plumbing has been rearranged and redesigned in part to allow for more rapid measurements. It is thought that accurate data must be taken at the rate of one point an hour to make the measurements practical. This will include, of course, retuning and readjusting time.

It should be noted that since the coupling is relatively weak (compared with electric coupling) this absorption is spectroscopically very weak, even though in terms of radio and radar ranges, or in terms of db/km it is quite large. Therefore extreme care and sensitivity must be used to insure relevancy of the data taken and to guard against spurious results.

2. Caesium Hyperfine Structure

Staff: Dr. A. Roberts
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The object of the experiment is to detect and study the absorption of microwave radiation in transitions between hyperfine structure states in caesium vapor.

Caesium vapor is introduced into a resonant cavity which controls the frequency of a stabilized microwave oscillator. If absorption takes place in the caesium vapor, it is expected that a change of the resonant frequency will occur. To detect this change the oscillator is heterodyned against another oscillator at a slightly different frequency and the beat note detected with a radio receiver. The currently proposed procedure is to modulate the caesium absorption by varying its resonance frequency by means of an a.c. magnetic field, and to detect the frequency modulation.

Stabilized oscillators have been set up and are operating. The receiver has been prepared. Helmholz coils for producing the external magnetic field have been built. A resonant cavity suitable for containing caesium vapor is in process of construction. Temperature control equipment for the resonant cavity and the caesium reservoir is being constructed. A lock in amplifier for [illegible]

[illegible]

9.200 megacycles gives a deflection [illegible]

is about equal to the background.

3. Molecular Beams

Staff: Prof. J. R. Zacharias
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Mr. D. Nagle

A laboratory is being constructed for research in radio frequency spectroscopy of atomic and molecular beams. It is proposed to study several current problems which involve measurement of nuclear moments, spin, and hyperfine structure $\Delta\nu$. Facilities are being provided so that several molecular beam apparatuses may be operated at once.

The first experiment planned is to measure the nuclear spin and magnetic moment and the hyperfine structure separation of Na^{22}. Three year Na^{22} may be produced by the Mg ($d\alpha$) reaction, and decays by positron emission to Ne^{22}, whose spin is known to be zero. It appears that, using most of the conventional methods of the magnetic resonance method for atoms, an apparatus can be built with a deflection sensitivity of .06 Bohr magnetrons which will require 100 microcuries of Na^{22} for three hours operation. This represents about four hours bombardment time for the cyclotron, and hence it would appear that a number of runs can be made. Indeed Dr. E. Clarke of the cyclotron group has informed us that he has recently produced about 1.5 millicuries, which will be available for such experiments.

Construction work now in progress includes the outfitting of a room to house a 28 v, 3000 ampere hour storage battery, and another to house charging generators and mechanical vacuum pumps. Plumbing parts for the fore-vacuum lines are being assembled and tested. Several circuits have been built for pressure measurements, and one is now in use for testing of vacuum parts. The shop is now fabricating magnet cores, coil forms, and various vacuum parts.

The details of the main envelope are now being finished by the drafting room, and this job can soon begin in the shop. Detectors of several types are being developed, and the associated amplifier circuits are under study. The work on the r.f. equipment has been deferred, since it is felt that it presents no particular difficulty.

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[illegible]

Staff. Prof. W. P. Allis
Prof. S. C. Brown
Prof. A. F. Kip
Mr. M. A. Herlin
Mr. C. W. Zabel

The following is a brief account of the work which has been done on gas discharge problems since the Basic Research Group was organized. The goal of the group working on discharge problems is first, to study the fundamental properties of electrical discharges in gases which are excited by microwave power, and second, to add to the present knowledge of direct current and low frequency alternating current discharges by means of some of the techniques which have been developed in the Radiation Laboratory during the war.

In order to fill in certain gaps in the data taken by the group working on T-R boxes during the war, and in order to familiarize ourselves with the fundamental techniques of microwave measurements, the first project started consisted of measurements of power transmitted through a T-R box under various conditions. A pulsed 10 cm. power source was set up along with appropriate measuring and monitoring devices. A variety of gases were used in the T-R box, and in some cases water vapor was added, since the presence of water vapor is of considerable importance in producing rapid recovery time in the T-R box. The relative powers in the "spike" at the beginning of a power pulse through the T-R box and the "flat", or equilibrium power, during the major part of a power pulse were observed as a function of pressure and gas filling. The results of these measurements will be included in the report of Radiation Laboratory Group 53.2.

Since it was felt that new methods would be desirable in order to investigate most efficiently the fundamentals of the microwave discharge, as soon as the work on T-R boxes was well started, most of the data taking was turned over to technicians and plans were begun for the investigation of discharges by other techniques.

An electrodeless discharge produced at microwave frequencies in a resonant cavity has been studied. The cavity used is cylindrical and oscillates in the $TM_{0,1}$ mode in which the electric field is parallel to the axis and maximum along the axis. The discharge takes place in a cylindrical glass tube coaxial with the cavity. The tube diameter is limited to the region of nearly uniform field near the axis of the cavity. The cavity and discharge are excited with a tunable continuous wave 3000 megacycle magnetron. The input admittance of the cavity is measured as a function of power by standing wave technique. The complex conductivity of the discharge is determined as a function of power from the measured and computed constants of the cavity. The complex conductivity as a function of power gives the voltage and current characteristic of the discharge. Voltage and complex current characteristics have been studied as a function of cavity dimensions, tube dimensions, and pressure. A brief report of preliminary results will be given at the meetings of the Physical Society in April (M.A. Herlin and S. C. Brown).

A second apparatus is just being completed which will be used for measurements of the behavior of electrons in a microwave electrodeless discharge at power levels below that necessary for the existence of a self-maintained discharge. Electrons will be supplied by an external source and measurement of the change in Q and resonant frequency will be made as in the case of the experiments described above. However, instead of making measurements by means of the reflected power from the resonant cavity, the power transmitted through the cavity will be measured. A null method will be used which compares the power through two branches of the line from the power source. Through one branch the power passes through known attenuators and through the other it passes through the cavity, thus allowing measurement of characteristics of the discharge within the cavity. The null measurements are achieved by rectifying the power through both branches with crystals and comparing the signals from the crystals on a null galvanometer. The attenuation required to maintain balance of the two signals is measured in such circumstances that the required information on changes in Q and resonant frequency is obtained. Construction and preliminary calibration tests have been made on this apparatus and it is expected that measurements will soon be possible.

The theoretical aspects of the study of the fundamental processes which occur in microwave discharges have also progressed rather well. The problem has been formulated and the large amount of computing necessary to carry out the numerical integrations is well underway. The few checks that have so far been possible between the experiment and the theory have been encouraging. A third part of the gas discharge program which is well under way is to be used to investigate certain properties of the d.c. discharge in a Geiger-Muller counter by means of microwave techniques. A Geiger-Muller counter has been constructed which can act as a resonant cavity at 3 cm. wavelength. A scaling amplifier has also been built to feed voltage pulses proportional to the motion of the positive ion space charge sheath into both the video amplifier and the sweep trigger of an oscilloscope. Another oscilloscope, phased with the first, is fed by a 3 cm. radar receiver measuring the attenuation of a signal in the counter. This latter oscilloscope will measure the number of electrons present in the counter discharge as a function of time. By this means, the positive ions and the electrons in the discharge may be measured separately and at the same time, on two oscilloscopes.

About 3 months time has been spent by one of the members of the group in rebuilding the high speed oscilloscope belonging to the Laboratory for Insulation Research. This device is now in its final stages of reconstruction and should be operating soon to measure the build-up time of high power microwave discharges.

2. Microwave Spark Breakdown

Staff: Dr. D. Q. Posin

An abstract has been sent to the Physical Society for the April meeting in Cambridge. The title of the abstract is "Electrical Breakdown in Air at Microwave Frequencies", in which the effect on breakdown field strength of pressure, gap width, pulse width, and repetition rate are discussed.

Initial ionization and breakdown field strength: Using a capsule of Co^* on the outside of the waveguide at various heights above a breakdown gap, a curve has been obtained giving breakdown power as a function of height of capsule. The problem remains of interpreting Co^* distance from the breakdown gap as a measure of initial intensity of ionization. The resulting curves show a nearly linear relationship between the breakdown power and the height of the capsule.

II. C. Low Temperature Research

Staff: Prof. J. C. Slater
Prof. F. Bitter
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Prof. L. Tisza
Dr. J. R. Feldmeier
Dr. W. E. Henry
Mr. J. B. Garrison
Mr. E. Maxwell

(1) Purpose and Scope of Investigations

The purpose of this project is to investigate the properties of matter or temperatures near absolute zero with initial emphasis on superconductivity at microwave frequencies. (Among possible applications of this work would be the use of high Q resonators for constructing high stability oscillators, etc.)

The execution of this project was made possible by the construction of a helium liquifier at M. I. T. Initial designs were made by Professor Collins of the Mechanical Engineering Department and later development was carried out by him in cooperation with Professors Bitter and Squire of the Physics Department.

The microwave measurements program in the Electronics Laboratory has been carried on by Messrs. Garrison, Maxwell and Dr. Henry under the direction of Professor Slater.

(2) Program

The program as originally set up calls for the following lines of development:

(a) Conductivities of various metallic conductors and superconductors are to be investigated at microwave frequencies by resonant cavity techniques. Measurements are to be made over a range of temperatures extending from room temperature down to liquid helium temperature. Part of this problem is the development of special apparatus and techniques for measuring high Q's with precision, including the design of an improved spectrum analyzer.

(b) Temperature control and measurement technqiues are to be developed for the purpose of stabilizing the helium refrigerator temperature at any desired level in the operating range of 2 - 300°K.

(c) Measurement of nuclear magnetic moments at low temperatures in the presence of high magnetic fields.

(3) Progress to Date

(a) Microwave Measurements

Of the program outlined in (2), only parts (a) and (b) have been worked on experimentally as of this writing. Measuring equipment has been set up for measurement of Q's at x band. Although techniques are constantly being improved it is believed that present methods are adequate for moderately precise measurement of Q's up to 50,000. The present method is essentially a refinement of the conventional scheme of measuring input impedances over the range of frequencies contained in the band width of the resonator. It is realized that this method may be inadequate for Q's higher than about 50,000 and attention is being given to other schemes as well.

Preliminary measurements have been made on an OFHC copper resonator at temperatures ranging from that of liquid nitrogen to boiling water. The increase in Q for decreasing temperature was not as large as would be predicted on the basis of the increase in d. c. conductivity. This discrepancy is probably due to surface roughness effects.

A technique of casting resonant cavities in highly polished molds is currently under investigation. This approach is being used to circumvent some of the difficulties involved in obtaining high polishes on the interior surfaces of resonant cavities. This method appears to be especially promising for lead cavities in view of the difficulty of machining and polishing very ductile metals.

The first investigations of superconductivity will be made with a lead cavity to be constructed by the method just described.

(b) The problem of temperature control and measurement has been attacked by Dr. Henry, using a refined resistance thermometric technique. The development of the necessary electronic circuits is in progress.

(c) Helium Refrigerator.

Helium was successfully liquified by Profs. Collins, Bitter, and Squire early in February. After some preliminary tests at M. I. T., the refrigerator was moved to its permanent location in Bldg. 20 and is now being set up.

(d) Nuclear Moments.

Manpower for experimental work has only recently become available for item C of the program outlined in (2). This work is proceeding under the direction of Prof. Bitter with Messrs. Poss and Alpert assisting.

II. D. Ferromagnetism at Microwave Frequencies.

Staff: Dr. C. Kittel

There is at present no reliable information on what happens to the permeability of ferromagnetic materials such as iron and nickel at microwave frequencies. It is known that up to at least 200 megacycles these materials exhibit their normal permeability (100) as determined from measurements at low frequencies such as 60 cycles alternating current. It is also known from the old measurements of Hagen and Rubens on infrared reflection coefficients of metallic surfaces that the permeability of iron and nickel is substantially unity at 10^{12} cycles/sec. The intermediate region wherein the transition in permeability occurs has only been explored with the primitive microwave techniques available in 1935.

It is planned in this laboratory to investigate this problem using modern microwave transmitters. A survey indicates that the expected effects of the "magnetic spectrum" are easily within the scope of present-day teqhniques. It seems likely that the measurements will consist in measuring the frequency response of a coaxial resonant cavity; the central conductor of the coax will be a fine wire of the specimen under investigation.

A theoretical analysis of the behavior to be expected has made considerable progress on the basis of the relation between eddy current skin depth and the size of the elementary ferromagnetic domains. Work on the theory will continue.

This problem offers promise of supplying a valuable tool for the exploration of domain structure in ferromagnetic materials.