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COLUMBIA UNIVERSITY

DEPARTMENT OF PHYSICS

CONTRACT AT-30-1-Gen-72

NUCLEAR PHYSICS RESEARCH AT COLUMBIA UNIVERSITY

John R. Dunning
Scientific Director

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Columbia University
in the City of New York
[NEW YORK 27, N. Y.]
DEPARTMENT OF PHYSICS

March 20, 1950

Mr. W. E. Kelley, Manager of Operations
New York Operations Office
United States Atomic Energy Commission
Post Office Box 30, Ansonia Station
New York 23, New York

Dear Mr. Kelley:

Herewith are transmitted to you five copies of "Nuclear Research at Columbia University, 1949-1950" by Professor J. R. Dunning, which report on the present status and proposed future direction of the Nuclear Research Program at Columbia University, under Government Contract AT-30-1-Gen-72, with the Atomic Energy Commission.

It is our opinion that this work has already been very productive, but that a vast amount of work yet remains to be done in carrying forward those fields of research in which we have been working during the past two years. Instruments and techniques already developed here have brought forth excellent results, and will help materially with the quantitative accumulation of data in nuclear investigations both at Columbia and at other installations. However, because so much work yet remains to be done in the categories outlined herein, we have not increased the scope of this proposed program at the present time.

Columbia University is not relying fully on the Atomic Energy Commission for full support of its work. Contributions to the program from University and other funds are comparable. However, the University can, by no means, proceed at a level desirable for this important field of research with only its own resources. Insofar as it is able, Columbia University is supporting the program through such direct costs as cyclotron operation time not charged to the contract, time of staff members not directly charged to the contract, overhead in excess of the 35% allotted by the contract. The University is

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also contributing most of the capital equipment, such as the cyclotron, beta-ray spectrometers, neutron velocity spectrometer systems, timing systems, air conditioning, general radiation detection equipment, and a large fraction of general laboratory equipment and apparatus. At the present time, the University is rebuilding its own neutron velocity spectrometer, and constructing another for the Brookhaven Laboratories, the result of which should be a very efficient and coordinated program of neutron velocity spectrometer studies in this area.

Another important feature of the research program of the University has always been, and continues to be, the training of badly needed personnel in the nuclear physics field. Columbia now has approximately 250 graduate students in Physics, many of whom are on the general staff of this contract, undertaking investigations under the scope of the contract in fulfillment of their Doctoral requirements.

It should be noted that the proposal requests an additional appropriation of approximately $20,000. The burden of directing closely the research for the program has fallen, for the most part, on four members of the senior staff. The limit of human endurance forbids that this burden be carried by such a small group indefinitely. The additional appropriation is, therefore, to be used in carrying on the task of developing a mature, experienced supervisory staff, the new members of which are being brought up from within the organization, itself. Although young scientists of supervisory capabilities are developed here principally for the research field as a whole, some of these scientists are, and will be, retained at the University for purposes of developing continuously a supervisory staff for this contract. Compensation paid to these men, of necessity must approach what their talents would command outside the University.

This proposal is sent with the hope that the continuation of this work may be approved by the Atomic Energy Commission and an appropriate settlement negotiated. We believe the research contract in this proposal comes in the Unclassified Areas of research as defined in Sections 1-175, 1-502, 1-508, 1-520 and 1-521 of Bulletin NY-62 Appendix A, and therefore propose that a supplement be written under provision of Bulletin NY-63.

Very truly yours,

George B. Pegram
Chairman

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CONTRACT PROPOSAL

CONTRACT AT-30-1-GEN-72

COLUMBIA UNIVERSITY

A. SUMMARY OF RESEARCH PROGRAM

I. NEUTRON VELOCITY SPECTROMETER TRANSMISSION MEASUREMENTS

The survey of all available elements and isotopes with the neutron velocity spectrometer is continuing. Thus far, 48 elements have been investigated and more than 100 resonance levels observed. The velocity spectrometer has recently been completely rebuilt in order to make more efficient use of cyclotron time. Methods of analyzing the data to obtain more information about the resonance levels are being investigated. The range of nuclear forces is being determined by measuring the cross section of parahydrogen at liquid hydrogen temperature. The paramagnetic scattering of neutrons, which has definitely been established in this laboratory, is being investigated further in several different ways. The effects of the state of a material and change of state of a material on the neutron cross section is being studied. The method of directly measuring the energy dependence of the neutron capture cross section of a substance by detecting the immediate gamma-rays emitted is being investigated.

II. NEUTRON SCATTERING MEASUREMENTS

The apparatus for studying the scattering of slow neutrons has operated successfully. The background has been reduced to such a degree that the resolution of the velocity spectrometer and intensity considerations alone determined at what energy the apparatus can be used. The scattering of the 4.8 ev resonance in gold is being studied in detail to calibrate the

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apparatus. A method has been devised to measure the ratio of the scattering cross section to the total cross section without thick or thin sample corrections. These calibration runs can be used to measure the scattering characteristics of all levels thus far observed with the neutron velocity spectrometer. The system for measuring the neutrons scattered in the forward direction by paramagnetic salts has been operated successfully.

III. ANALYTICAL STUDIES AND CRYSTAL GROWING

The exact chemical composition and, occasionally, the isotopic composition of the samples under investigation are required in many of the experiments carried out in the laboratory. The analytical laboratory of the Department of Chemistry is available for all types of purity analysis and research. It is used extensively for the preparation and analysis of neutron velocity spectrometer samples, beta-ray spectrometer samples, and so forth. A new program on the analytical application of neutron transmission techniques to analytical problems has been undertaken. This was suggested by the difficulties encountered in the analysis of samples for the neutron velocity spectrometer and has proved useful in the determination of hafnium in zirconium. Research has started on the preparation of a series of iron crystals for studying paramagnetic scattering of neutrons in these salts. These experiments should lead to a better understanding of the theory of magnetism.

IV. SPECIAL MATERIALS INVESTIGATION

Tests on the neutron properties of a wide variety of specific materials have been requested for use in the design and construction of nuclear reactors, health monitoring equipment, protective clothing, and so forth. These tests proved very valuable in the past and should prove more valuable in the future as nuclear technology expands. The facilities of this laboratory have been called upon by the New York Operations Office and various contractors of the Atomic Energy Commission for special measurements, for which they are particularly well adapted. The experience of various members of this

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laboratory has assisted on specific problems on many occasions in the past and an experienced staff is available for consultation.

V. INSTRUMENT DEVELOPMENT

The electronic instrument development laboratory at Columbia is primarily interested in developing instruments for use in specific experiments. However, many of the instruments developed for particular purposes find wide application in other fields. During the past year, the following instruments have been developed: a scaling unit with an 0.05 microsecond resolving time, a regulated scintillation counter power supply, a pulse height analyzer, a standard pulser, a 7.5 Mc bandwidth amplifier using Philips EFP60 tubes, a stabilized coincidence circuit and a delayed incident circuit to measure time in units of 10^{-9} seconds.

VI. LIGHT PARTICLE INVESTIGATIONS

The situation in the field of beta-ray spectroscopy has changed recently from one of complete confusion to one in which the simplest applications of the theory are in complete agreement with experiment. Further development of the field must wait on the performance of experiments which will decide which of the possible theoretical possibilities or combinations of possibilities are applicable to beta disintegration. The beta-ray spectroscopic group at Columbia has played a major role in bringing about the present situation. Using the helical focusing beta-ray spectrometer, which has the largest transmission for a specified resolution, the experimental data on allowed spectra has been shown to be in good agreement with the theory. Forbidden spectra have been and are being investigated to determine the type or types of interaction to be used. The nuclear level structure of various materials is being investigated by beta-gamma coincidence techniques. A portable semi-circular focusing beta-ray spectrometer has been used to investigate the superallowed transitions of the Wigner series to determine the matrix elements in very light nuclei. Beta-gamma

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and gamma-gamma angular correlation measurements are being made in order to assign uniquely the spin and parity in each level. The characteristics of nuclear isomers are being studied using delay line coincidence techniques. The apparatus for measuring the angular distribution between beta particles and the ion recoils of $helium^6$ has been completed and the experiment to determine the properties of the neutrino is under way. The system for measuring short half-lives by cyclotron modulation techniques is operating successfully and a systematic survey of materials which have radioactive half lives in this time range is under way.

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COLUMBIA UNIVERSITY

B. RESEARCH PROGRAM

I. NEUTRON VELOCITY SPECTROMETER TRANSMISSION MEASUREMENTS

A. Neutron Interaction with Elements and Isotopes

W. W. Havens, Jr., L. J. Rainwater, M. Levin

The Columbia University velocity spectrometer has been used to investigate all available elements and isotopes. Up to the present time 48 elements have been investigated and more than 100 neutron resonance levels observed. In the inital broad survey the primary emphasis was on locating neutron resonances. The determination of the nuclear constants from the data available was secondary. For accurate location of the energy of the level a thick sample is desired. But for accurate determination of the nuclear constants associated with a level a relatively thin sample should be used. Therefore, a compromise sample thickness was usually chosen for the initial experiments. In this manner the positions of the neutron resonances were able to be located with a fair degree of accuracy, and some information about the resonance level constants was obtained.

The results already accumulated indicate that many of the neutron resonance levels should be reinvestigated with the best resolution available, using several different sample thicknesses. In order to obtain sufficient statistical accuracy with the best resolution now available it takes about ten hours of cyclotron running time for one setting of the velocity spectrometer. Except in the very highest energy region, at least two settings are usually required to plot a resonance level. Thus approximately twenty hours are required per resonance per sample thickness. Since an investigation of at least two different sample thicknesses would be required for each resonance, the task of properly reinvestigating all the resonance levels already known is extremely large. At least 4,000 hours of cyclotron running time would be necessary. Therefore, only the most interesting cases have been reinvestigated.

During the past year new data have been obtained on aluminum, beryllium, graphite, chromium, cobalt, copper, iron, nickel, ruthenium, thallium, zinc, rhenium, gallium, sodium, and bromine. 10 M97

Most of these data represent reinvestigation of old samples in the highest energy region with better resolution than heretofore obtainable.

In order to make an appreciable dent in the mountain of velocity selector data that can and should be accumulated for the purpose of formulating a resonable theory of the neutron capture process, the Columbia University neutron velocity spectrometer has been completely rebuilt. A duplicate set of timing circuits is being built here for use with the Brookhaven 60" cyclotron under a subcontract with that laboratory. The new velocity selectors will have 32 detector pulses on each of two channels. The cyclotron and detector modulation pulses can be varied from 0.5 to 1024 microseconds, and the repeat times can be varied from 256 to 32,768 microseconds. If all design improvements are actually realized in practice, the new system should be about six times as efficient as the old. Improved neutron detectors are also being studied which should give another factor of six improvement leading to a large overall increase in efficiency.

The new timing system is being installed at the present time. It is hoped that with the increased efficiency of the system more time will be available for the study of neutron resonance levels.

The Columbia and Brookhaven programs will be well coordinated to avoid unnecessary duplication of effort.

B. Analysis of Neutron Resonance Levels

E. Melkonian, W. W. Havens, Jr.

A great deal of time and effort has been spent in accumulating the vast amount of data with the Columbia University neutron velocity spectrometer. However, relatively little effort has been spent in investigating new methods of analysis of this data. Most of the data has been analyzed by the method introduced by Havens and Rainwater (Phys. Rev., 70, 154 (1946)), which involves tedious numerical integration.

Analytical methods of applying the appropriate resolution function of the apparatus to the Breit-Wigner formula are being investigated. We propose to form a computing group to investigate the various methods of analyzing the velocity selector neutron resonance

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data and applying this analysis to a large number of the neutron resonance levels that have already been discovered.

C. Precise Determination of the Parahydrogen Cross Section - E. Melkonian

Determination of the range of nuclear forces required that two quantities be obtained experimentally, as both the singlet and triplet scattering amplitudes must be known. As was pointed out in a Letter to the Editor in The Physical Review (Phys. Rev., 69, 236, 1946), the experimental quantities that can be used best to determine the scattering amplitude are the free neutron cross section and the scattering cross section of parahydrogen at very low temperatures.

The free proton cross section has previously been measured in this laboratory to better than 0.5% (Phys. Rev., 76, 1750-1759, 1949). Therefore the value of the parahydrogen cross section must be determined to find the range of nuclear forces.

At the present time the design of the experimental apparatus for the measurement of the parahydrogen cross section at liquid hydrogen temperature has been completed and the construction begun.

The system for studying the preparation and analysis of the parahydrogen has been assembled and is just getting under way.

It is expected that preliminary results will be obtained on this experiment by July 1, 1950, and should be completed within the next year.

D. Paramagnetic Scattering of Neutrons - I. W. Ruderman

The paramagnetic scattering of neutrons has now definitely been established in these laboratories (Phys. Rev., 76, 11, 1572-84, 1949). This work is being continued by four different methods of approach. 1) The paramagnetic scattering cross section of manganous salts is being studied as a function of the temperature of the material; 2) other salts with high paramagnetic susceptibilities such as iron salts are being investigated; 3) other paramagnetic substances such as O_2 will be studied;

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and 4) the neutrons paramagnetically scattered through small angles will be measured as a function of the neutron wave length.

In method (1) a sample holder has already been built for use at liquid nitrogen and liquid hydrogen temperatures. The paramagnetic scattering cross section of crystals of manganous sulfide will be determined first. Perliminary work has been done on the preparation of crystalline MnS.

In method (2), crystals of salts of a series of iron compounds will be investigated. Research on the preparation of crystals of this material has been started.

In method (3), the cross sections of O_2 as a function of temperature will be measured. The apparatus that is being constructed for the parahydrogen experiment will be ideally suited for these measurements. Oxygen has a very peculiar magnetic behavior at very low temperature in that it obeys the Curie law down to a temperature of about -183° C. and then becomes almost ferromagnetic.

Method (4) will be discussed under Neutron Scattering Measurements.

E. The Diffraction of Neutrons by Amorphous Quartz - I. W. Ruderman

Slow neutron transmission data for fused quartz from 0 to 6.4 A is now complete. These data reveal numerous diffraction peaks. The theoretical significance of these results is being studied.

F. Effect of Change of State on Neutron Cross Section - E. Melkonian

Neutrons absorbed by cadmium have been used by many investigators to study materials in various states. For example, Rossel, et al, have studied N_2 as a gas, a liquid, and a solid in two phases. Neutron spectroscopy may yield additional information on this subject. The study of water and ice has been contemplated here; in most cases the techniques are available for making these measurements. For example, considerable

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work has been done at low temperatures ("cold neutron" source, p-H_2 setup, and so forth) so that the design of a sample holder for some low temperatures should not be too difficult.

G. Capture Cross Sections by Neutron-Gamma Reactions - E. Meservey.

In general when neutrons are captured by nuclei, several gamma-rays are emitted immediately. The number of gammas emitted by a given sample should be proportional to the number of neutrons captured, and it is therefore hoped that, by counting the number of gammas, a direct measure can be obtained of the cross sections of nuclei for radiative capture. When used in conjunction with the neutron velocity selector, the method can be used to determine radiative capture cross sections as a function of neutron energy in the thermal and resonance regions.

The main effort thus far has been expended in reducing background gamma radiation. Various collimation systems and shielding materials have been tried, and the ratio of desired counts to background counts has been improved by a factor of about 20. (This ratio is now between 3 and 4 at the indium resonance.) Considerably more improvement is needed in order to make the method useful when capture cross sections are small compared with scattering cross sections.

Detection of the gamma-rays has been accomplished by using an anthracene crystal and photomultiplier tube (1P21). In the immediate future it is planned to explore the possibilities of using two such set-ups in a coincidence arrangement. A relatively high coincidence rate can be expected if the neutron absorbing sample is placed between the two crystals, since this arrangement takes advantage of the fact that on the average several gammas are emitted for each neutron captured.

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II. NEUTRON SCATTERING CROSS SECTION AS A FUNCTION OF THE TIME OF FLIGHT OF THE INCIDENT NEUTRON

A. Neutron Scattering Measurements - J. Tittman, C. Sheer, W. W. Havens, Jr., L. J. Rainwater

A complete investigation of the slow neutron scattering cross section of nuclei as a function of the energy of the incident neutron is recognized as one method of obtaining detailed knowledge of the properties of the nucleus. The difficulties encountered in performing these experiments have been so great, however, that relatively little data have been obtained. Because of the increasing importance of this information, to supplement the data already accumulated on the "resonances" observed in neutron transmission measurements, an apparatus has been constructed which will show how far the techniques of the modulated cyclotron velocity spectrometer can be carried in investigating neutron scattering cross sections.

On the basis of data taken with the original scattering plus collimating system, the experimental apparatus was completely rebuilt. For energies up to about 10 electron volts the background is now approximately equal to the counting rate which would be due to scattering from a graphite target of 98% transmission. At higher energies, 10 to 1,000 electron volts, the background has been reduced by a factor varying between 5 and 10, thus extending the region in which the apparatus can be used to several thousand electron volts. The remaining limitation is imposed solely by the resolution of the neutron velocity selector. Some improvements will be made, however, in order to reduce the running time necessary to take data for a specified statistical accuracy.

The distribution of beam intensity in the plane perpendicular to the beam, at the position of the target, has been measured, with the result that the beam is of approximately constant intensity over an area 3" x 3". The intensity drops to about 70% of maximum at a distance of 1.8" from the axial line, and to 1% of maximum at 7" from the axial line.

The apparatus has been used to investigate gold with high resolution in the energy region between 0.7 and 250 electron volts. The results verify qualitatively the predictions of the Breit-Wigner theory (or the Feshbach, Peaselee, Weisskopf theory) in that the ratio of the scattering

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from gold to that from a thin carbon target shows a pronounced peak in the vicinity of the 4.8 electron volt resonance and a distinct dip on the low energy side of this resonance (around 3 - 3.5 electron volts) with a recovery towards lower energies. Unresolved levels have also been detected in the region between 100 and 1000 electron volts. The investigation of gold is being continued for the purpose of building up higher statistical accuracy.

Analysis of data -- a method for the analysis of the data has been developed so that a curve of σ_s vs. E for gold may be obtained in a reasonable time. A method for the evaluation of that fraction of the background counting rate which disappears when a thick target is in position has been developed. This method utilizes the pure boron^{10} recently received from Oak Ridge.

The method of analysis of the data is essentially the measurement of the ratio of the counting rate of gold to that of a reference carbon target as a function of energy.. The functional relationship is such that it depends only on σ_s/σ_t and geometry when the target transmission $<<1$. A standard target of B_2O_3, of the same size and shape, has been cast and is being ground to size. Since σ_s/σ_t is known for this sample, it will then be standardized against the carbon target. Then N/N_o can be plotted vs. σ_s/σ_t and σ_s/σ_t determined for the gold. Extremely thin (0.1 and 0.5 mil) gold targets have been prepared and σ_t will be measured more accurately than has been done previously by the usual transmission experiment techniques. In this manner measured values of σ_s as well as σ_t will be available.

Gold is an extremely favorable sample to investigate because it has only one isotope and a neutron resonance at an energy low enough for the resolution of the apparatus to be fairly good. This investigation should furnish sufficient data to enable one to determine the capabilities and limitations of the method. After these calibration measurements have been made, the apparatus can be used to investigate the resonant scattering cross section of a large number of the levels discoverd in the transmission measurements.

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B. Paramagnetic Neutron Scattering Experiment
P. J. Bendt

The neutrons scattered in the forward direction by paramagnetic salts are being investigated by actual detection of the neutrons scattered by the sample. The experiment will measure the paramagnetic scattering cross section as a function of neutron wave length, and by a choice of samples will show how this quantity is affected by coupling between the paramagnetic ions. Two rings of BF_3 counter tubes are used, one ring of eight tubes, and a second ring of ten tubes. Neutrons detected by the two rings will travel different path lengths, and be counted on different neutron velocity spectrometer channels. For neutron wave lengths of 2 to 3 angstroms, where the angular form factor is important, only the ring subtending the smaller scattering angle will be used; at longer wave lengths, both rings will be used to improve intensity.

The apparatus for this experiment has been completed, and some preliminary data obtained. These preliminary data are very encouraging and indicate that this experiment should be completed within the next year.

III. ANALYTICAL STUDIES AND CRYSTAL GROWING

A. Analytical Laboratories - T. I. Taylor, I. W. Ruderman, R. A. Anderson, J. Durbin, R. Cram

It is essential that the exact chemical composition and sometimes the isotopic abundances in the samples under investigation with the neutron velocity spectrometer be known; otherwise interpretation of the data is impossible. The facilities of the analytical chemical laboratory include mass spectrometer, emission spectrograph, flame photometers, photo-electric calorimeters, photo-fluorimeters, ultra-violet spectrometer, electrolysis equipment, polarographic analysis equipment, polarizing microscopes and X-ray diffraction apparatus, all of which facilitate the determination of the chemical and isotopic composition of the samples. The analytical requirements of nuclear physics experiments are specialized, however, since information which is usually unimportant in ordinary chemical analysis is extremely important in special experiments. This is due to the fact that the nuclear absorption properties vary so markedly

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from isotope to isotope and that the changes are extremely large. Also, it is not usually weight percentage that the physicist is interested in, but nuclear percentage. This usually makes the analysis of each sample a special standardization problem, even though all the usual analytical chemical facilities are available.

The problem of sample purity on neutron velocity spectrometer investigations has been particularly emphasised recently because of the anomolous level observed at 2300 electron volts in aluminum.

Because of the possibility of wide fluctuations in the level strengths, it is impossible to associate a transmission dip in the high energy region with the principal element of the sample, and, therefore, much more care must be given to preparing extremely pure samples.

B. Application of Neutron Transmission Techniques to Analytical Problems - R. A. Anderson, T. I. Taylor, W. W. Havens, Jr.

The difficulties encountered in the chemical analysis of samples being investigated with the neutron velocity spectrometer led to the idea that the neutron properties of material could be employed as a useful analytical tool. Reexamination of old data and some auxiliary chemical tests on samples already investigated showed the method to be fairly sensitive in some cases. The method is sensitive for detecting such impurities as rhodium in platinum, tantalum in columbium, indium in tin, manganese in aluminum, hafnium in zirconium, hydrogen content of samples, mixtures of rare earths; on further investigations other special applications will undoubtedly be found. Three papers on the general aspects of neutron spectroscopy as applied to chemical analysis have been published in Nucleonics (Vol. 5, December, 1949; Vol. 6, February, 1950; and Vol. 6, April, 1950). Specific applications of the interaction of neutrons in chemical analysis are being studied for quantitative analysis.

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C. Crystal Growing for Paramagnetic Neutron Scattering Experiment - T.I. Taylor, I.W. Ruderman

Since the paramagnetic scattering of neutrons has been firmly established, experiments investigating the properties of this phenomenon should be continued. Crystals are necessary for these investigations because it is impossible to interpret the data when the diffraction and interference effects in microcrystalline media are present. When crystals of sufficient size are used and the neutron wavelength is longer than twice the cut-off wave length, the Bragg relationship is no longer fulfilled and the effective scattering cross section theoretically should be almost zero. Since the capture cross section is easily established and the wavelength dependence known, the paramagnetic cross section in crystals of sufficient size can be determined.

Further paramagnetic scattering investigations of iron and manganous salts which have high paramagnetic susceptibilities require that crystals of these materials be grown. Other crystals and samples of interest which will aid in understanding the interactions of neutrons also will be prepared.

D. Radiochemical Laboratories - I.W. Ruderman, E. Marder, A. Lenz, J. Stark

Because a large number of the problems encountered in research in nuclear physics are chemical by nature, a semi-service chemical laboratory has been instituted to help with the physical research. This laboratory primarily prepares samples for the neutron velocity spectrometer, separates radioactive elements for the beta-ray spectroscopic group and prepares the sources for the beta-ray spectrometer.

This laboratory has not only proved very valuable in helping with the overall research program, but has also contributed substantially to the fundamental research.

The specific activity of radio-bromine samples produced by a Szilard-Chalmers reaction has been increased considerably. The boron loading of plates for neutron detection has been considerably improved and the neutron fluxes of the cyclotron have now been calibrated. 19 m 47

At present the laboratory, in addition to the preparation of sources for the beta-ray spectroscopic group and samples for the neutron velocity spectrometer, is investigating the possibility of increasing the specific activity of As^{76} by using the Szilard-Chalmers reaction in various organic compounds of arsenic. The production of Br^{82} has been further increased.

It is difficult to predict the future program of this laboratory, as it depends on the chemical problems met in other researches. However, the contribution of this laboratory to the efficient progress of the overall research program shows that its formation was well justified.

IV. INVESTIGATION OF SPECIAL MATERIALS

T. I. Taylor, M. Levin, W. W. Havens, Jr., L. J. Rainwater

The facilities of this laboratory are called upon by the Atomic Energy Commission and contractors of the Atomic Energy Commission for special measurements for which this laboratory is particularly well adapted. This is especially important in the investigation of contractors' materials for nuclear energy devices. These special materials can be investigated with the neutron velocity spectrometer in the energy range from 0.001 to over 10,000 electron volts at the present time. These types of tests have been performed for the Carbide and Carbon Chemical Corporation and the General Electric Company. Tests on such construction materials as beryllium, zirconium, titanium and vanadium have been performed in the past. The information supplied on these materials as a function of the energy of the incident neutrons is of value in the design of pile structural material and moderator reflector systems. During the past year the fact that a hafnium impurity was the neutron absorber in a zirconium sample was demonstrated in this laboratory. Hafnium spectrographic analysis techniques have been investigated by the analytical laboratory, and the analyses of several samples determined.

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V. ELECTRONIC INSTRUMENT DEVELOPMENT

The electronic instrument development laboratory at Columbia is primarily interested in developing instruments for use in specific experiments. However, many of the instruments developed for a particular purpose find wide application in other fields. During the past year the following instruments have been developed in this laboratory.

A. High Speed Scaling Unit - V. Fitch, S. Lipman

A scale-of-four circuits with a resolution of about 0.05 microseconds has been developed. A number of these units have been placed in operation and function well in routine operations. (R.S.I., Vol. 20, No. 12, 942-944, Dec. 1949.)

B. Regulated Scintillation Counter Power Supply
V. Fitch, S. Lipman

Since a change of 1% in voltage on an electron multiplier will change the scintillation counting rate by 12 - 15%, a well regulated high voltage supply is needed. A supply which will provide 20 ma with an output impedance of 2 ohms and will change by about 2 volts in 1000 for a 30 volt change in input voltage has been developed.

C. A Pulse Height Analyzer - V. Fitch, S. Lipman

A two channel pulse-height selector has been designed and a final model constructed. The channel widths are established by a series of biased diodes. The intrinsic shortcoming of diodes when utilized in this fashion, i.e., capacitative feedthrough, has beeneliminated by a capacitance neutralization scheme. Extensive checks on the diodes used, type 6AL5, show them to be entirely satisfactory for the purpose when properly matched. The circuit includes a linear amplifier, gain 1000, which has a built-in delay line shaper. The output of the amplifier is fed to the biased diodes and then to coincidence and anti-coincidence circuits which allow the pulse to be recorded in the proper channel.

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Two channel widths, 2 and 10 volts, are available. The two channels may be used to examine pulses over a 100 volt range in amplitude. The circuit recovers rapidly, being capable of recording two pulses separated by 0.5 microseconds.

Extension to n-channels is readily accomplished. Each additional channel requires 3 tubes exclusive of the scaling circuits.

Preliminary use of the device indicates satisfactory performance.

D. A Standard Pulser - V. Fitch, S. Lipman

A new precision step-function pulser has been designed. This circuit will deliver both plus and minus pulses with a rise time of 2×10^{-8} seconds. The output wave form rises sharply, stays constant for 10 microseconds, and then decays to zero in about 5 microseconds. The old pulser has been rewired to incorporate the new circuit.

E. Wide Band Amplifiers - V. Fitch, S. Lipman, L. J. Rainwater

Delay line coupled amplifiers have been designed and constructed for oscillographic use. Two amplifier units are used to drive the oscilloscope deflecting plates push-pull. The overall gain is approximately 16 with bandwidth about 75 Mc.

A general purpose stabilized amplifier was designed and constructed primarily for use with scintillation detectors. The maximum gain is 250 and the minimum rise time is 2×10^{-8} seconds.

The secondary emission tubes, Philips type EFP60, have been incorporated into feedback amplifier loops and work satisfactorily. Loop gains of 50 are obtained with minimum rise times of 10^{-8} seconds.

F. Stabilized Coincidence Circuit - O. Martinson, C. Sheer

A coincidence circuit of greater stability than was available in a commercial unit has been designed and constructed. The

specific application was in the study of beta-gamma correlations from Na^{22} by the coincidence method (Wu and Shakmov) in which the Atomic Instrument Company model 204A amplifiers were originally used. Since the rise time of these amplifiers was of the order of 0.2×10^{-6} seconds, the output pulses were used to drive a blocking oscillator in order to generate a sharper pulse to feed to a coincidence circuit. Although this arrangement worked satisfactorily when pulses of uniform height were fed into the amplifiers, when pulses of random height distribution were used, such as obtained from a scintillation counter, a "jitter" was obtained in the output pulses of the blocking oscillator which effectively reduced the coincidence resolution. This jitter was due to the fact that pulses of random height after passing through a discriminator emerge with a random initial slope. Since the exact instant at which the blocking oscillator is triggered depends upon when the pulse reaches the triggering level, there will be a random time elapsing between the start of the pulse and the instant at which the blocking oscillator fires.

In order to eliminate this difficulty, a circuit was designed which delays the input pulse by means of a delay line and then gates the delayed pulse at a specific time when all pulses have risen to the required level. In this manner all pulses, regardless of their initial height, are fed to the blocking oscillator with the proper triggering amplitude at the same time relative to the start of the pulses, thus eliminating the jitter.

This circuit operated successfully and gave a coincidence resolution of 2.5×10^{-8} seconds when used with the Atomic Instrument Company amplifiers. Subsequently amplifiers having a shorter rise time were built to replace the latter so that at present the coincidence resolution of the apparatus is down to 10^{-8} seconds with input pulses of random height.

G. Delayed Coincidence Apparatus - P. Isaacs, C. Sheer

A variable mercury delay line for equalizing and controlling the propagation time in various channels of a coincidence system has been constructed.

The primary detector will be a scintillation counter using either anthracene or stilbene as a phosphor, which will give a rise time of the

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order of 10^{-9} seconds. The pulse from the counter is amplified in a tuned amplifier resulting in a modulated chain of waves. The wave chain goes to the mercury delay line. The difference in delay between corresponding points on two different chains can be controlled to within 0.002 microseconds. It may be possible to achieve even shorter resolving time by using a selector circuit to select one of the positive half-cycles of the wave, although this has not as yet been tried. The coincidence circuit will use the same linear properties of dividers and it is hoped to attain a resolving time of about twice the pulse width of 0.06 microseconds.

The chief advantages of the mercury delay line over other types of delaying circuits is that it is possible to obtain continuously variable delay time without alternation of wave form. The accuracy of adjustment is, then, the only limitation on the resolution and in this case is about 10^{-9} seconds or approximately ten times the resolution of other coincidence circuits. It also has the definite advantage of a large bandwidth and is very compact and convenient to use.

This delayed coincidence system was originally designed to measure the delayed beta-gamma coincidence to determine the half-lives of metastable states.

The circuit can also be used in time-of-flight measurements in conjunction with a magnetic field to differentiate between mesons and protons. It can also be used as a mass spectrometer and to measure the energy of the recoil nucleus in the neutrino experiment.

VI. LIGHT PARTICLE INVESTIGATION

A. Helical Focusing Beta-Ray Spectrometer - C. S. Wu, L. Lidofsky, L. Feldman, P. A. Macklin

During this past year several of the discrepancies between the theory of beta-disintegration and the experimental results obtained by many investigators have been resolved. The beta-spectroscopy group at Columbia University has played a major role in the resolution of these discrepancies.

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1. Allowed Spectra: The outstanding cases of the deviation of the experimental data from theoretical prediction, that of "allowed spectra" in the low energy region, were resolved in the Columbia laboratories using the helical focusing beta-ray spectrometer for investigating copper^{64} and sulfur^{35}. Since the simplest applications of the theory are now clarified, it is possible to investigate more complex phenomena in order to determine the type of interaction to be used in beta-disintegration theory.

2. Forbidden Spectra: The highly forbidden spectra such as chlorine^{36} and beryllium^{10} have been investigated with the high transmission spectrometer. At present the most crucial and interesting case of potassium^{40} is being investigated with improved conditions. This spectrometer will be used almost completely in the near future for the investigation of forbidden spectra.

One of the next isotopes to be investigated will be tecnetium^{99}. According to nuclear shell structure analysis, the spin of $_{43}Tc^{99}$ is 9/2 with even parity. The product nucleus $_{44}Ru^{99}$ probably has a spin 3/2 and even parity. With a spin change of three units and no parity change, the transition is most probably second forbidden and should yield a unique forbidden spectrum. The transition of A^{41} to the ground state of K^{41} is another transition which should have a forbidden spectrum on the basis of shell structure analysis. When sufficient data are accumulated on the various types of forbidden spectra, it should be possible to determine uniquely which type, or combination of types, of the five possible interactions is responsible for the beta-disintegration.

3. Beta-Gamma Coincidence with Beta-Ray Spectrometer:

If, in a beta disintegration, the product nucleus is left in an excited state, the excited state immediately goes to the ground level by emitting one or several gamma-rays. By investigating the compton- or photo-electrons ejected by the gamma-rays in a spectrometer, the energies of these gamma-rays can be determined. However, in order to ascertain the energy levels and disintegration schemes, a mere knowledge of the energies of the radiations alone is often found to be insufficient. It is usually also necessary to determine which radiations are emitted in successive and which in alternate process. This correlation of the various radiations is best studied by the method of coincidence counting, in conjunction with a beta-ray spectrometer. The applicability of the technique

is limited by the over-all detection efficiency of the instruments used and by the resolving time of the coincidence amplifiers. For this reason, the high transmission magnetic solenoidal spectrometer is particularly well suited for coincidence studies. A systematic study has been launched in investigating the problem of piping light through lucite rods and shielding electron photo-multiplier tubes from stray magnetic fields. The results of these investigations should have general usefulness as well.

B. Portable Semicircular Focusing Beta-Ray Spectrometer - H. Brown.

A semicircular focusing beta-ray spectrometer was constructed for the purpose of measuring the spectra of radioactive gases. Since one of the main difficulties encountered in beta-ray spectroscopy was the finite thickness of the source and source backing material, it was thought that the investigation of radioactive gases might avoid this difficulty. This spectrometer has operated successfully by pumping gases through probes bombarded with deuterons in the cyclotron. The half-lives of oxygen^{15}, fluorine^{17}, and neon^{23} have been investigated with this system preliminary to determining the beta-ray spectrum. The beta-ray spectra of oxygen^{15}, argon^{41}, and helium^{6} have already been investigated with this spectrometer.

Although it is not possible to measure the beta-ray spectrum in the very low energy region with this spectrometer, by confining the investigation to spectra of endpoint energy greater than 1 million electron volts, not only can the endpoints be obtained but a decision can be reached on whether the spectra are of the allowed shape or not (3/4 of the spectrum is sufficient for this purpose).

A determination of the half-life of a beta-emitter and the endpoint of the spectra enables one to calculate the "ft" value of the beta-emitter. This quantity is closely associated with the coupling constant of the interaction. In particular, the "ft" value of helium^{6} has been found to be the lowest so far measured.

In the future this spectrometer will be used to investigate the Wigner series of "super allowed transitions." These are transitions in which the nuclear wave functions of the disintegrating nucleus and the resultant nucleus are so alike that the matrix element involved is approximately one. Most of the so-called "mirror image" nuclei are

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the emitters and products of this series. The beta-activities of these nuclei are generally short-lived but fortunately some of these could be made into gases for circulating purposes. The accurate determination of the half-life and upper energy limit of these mirror nuclei may shed some light on the further understanding of the theory of beta-decay.

C. Beta-Gamma and Gamma-Gamma Angular Correlation Measurements - I. Shaknov, C. S. Wu

Even if the disintegration scheme of a beta-emitter is known, the assignment of spin and parity of each level is still lacking. The only methods which may yield some further information on the assignment of the spin and parity of each individual level are the investigation of the angular correlation between gamma-gamma and beta-gamma radiations. In order to carry out these investigations, the scintillation counters, fast pulse amplifiers, fast coincidence analyzer and pulse height analyzer have been designed, developed and built in this laboratory. A systematic survey of the known beta-gamma and gamma-gamma angular correlations should prove to be important for the theory of beta-decay.

D. Nuclear Iosmerism - L. J. Lidofsky, C. S. Wu, P. A. Macklin

There is another group of particularly interesting phenomena known as isomers. According to the theory of isomerism, the half-life of the metastable state is determined by the spin-change involved and the energy available. The half-lives of isomers so far determined experimentally vary from 10^{-8} seconds to a few hours or days. The technique used in determining half-lives greater than a few seconds is to follow the decay of the isomer. For those in the microsecond region or less, the method of delayed coincidence has been very successful, but not for a longer delayed period. This laboratory has developed a mercury line delay device. Initial test of this device has shown great promise in providing delay between two pulses as much as 20 microseconds. This device is going to be used in the investigation of isomerism as soon as the assembly is completed.

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E. Investigation of Beta-Ray Spectra below Ten Thousand Electron Volts - C.S. Wu, W.W. Havens, Jr.

To investigate beta, gamma or X-rays of very low energy, the most appropriate method is probably to introduce the radioactive gas directly into a proportional counter, and then analyze the pulse heights. In fact, a surprising amount of soft gamma-rays of a few thousand electron volts have been observed recently. In order to extend the range of our investigation to the lowest energy possible, the proportional counter method of investigating low energy beta, gamma, and X-rays has been contemplated. The first radioactivity which will be examined in the proportional counter to ascertain whether or not there are any soft gamma-rays of a few thousand electron volts in association with its beta-decay will be that of chlorine^{36}. The importance of this investigation is stated in the review article of "The Recent Investigations on the Shape of Beta-Spectra."

F. Neutrino Investigations - B.M. Rustad, S. Ruby, E.T. Booth, Jr.

The existence and the properties of the neutrino still remain a fundamental question. Several systems of increasing degrees of refinement involving the measurement of direction and energy of the emitted electron and the positive ion recoil have been designed using electron multipliers coincident with Geiger counters as detectors. A system for transferring radioactive gases to a distant apparatus has been completed. The intensity obtainable is very satisfactory. A permanent helium^{6} generator has been installed in the cyclotron room. Absorption experiments on the radiation from helium^{6} have been made which show that a gamma ray is not emitted in disintegration. The isotope is therefore a very suitable material for the neutrino experiment.

The complete equipment to measure the angular distribution between beta particles and ion recoils in helium^{6} is being assembled and tested. This apparatus includes a large vacuum envelope with associated pressure measuring equipment, special positive particle detecting coincidence circuit, well-regulated 10,000 volt high voltage supply for vacuum envelope (each having its own pressure measuring equipment), Geiger counter, amplifier and scaling circuit for determining energy of beta particles. All the components of this apparatus are being tested before final assembly, which is expected in the near future.

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G. Modulated Cyclotron Technique Applied to Short-Lived Radioactive Disintegration - R. Ashapa, G. Grimm

A 1000 cycle oscillator has been constructed as the fundamental time control for use with the velocity selector timing circuits. The arc and detector pulses can be varied from 5 milli-seconds to 1 second and the duty cycle from 80 milli-seconds to 16 seconds. By varying the pulse width of the "arc on time" and the "detector sensitive time," neutron induced beta-ray activities of half-lives from a few milli-seconds to the order of several seconds can be determined with ease. The most serious difficulties encountered in this investigation, such as high background counts inside the cyclotron enclosure and the short radioactivities induced in the shielding and counter itself, have been improved or eliminated. Trial runs have been carried out on a sample of beryllium of less than 1 gram. The true counts due to the short-life activities of helium^6 are greater than the background counts, and the half-life determined is 0.827 seconds which is in good agreement with previous values from other laboratories. The immediate projects of this group are to determine precisely the short half-life of boron^{12} (~0.022 to 0.027 seconds) from N^{15} (n, α) B^{12} and to scan any possible short activities from light elements which had escaped the ordinary method of detection. It is needless to say that this method should be most useful for investigating delayed neutron activities from fission and the short periods of beta-activities from fission. This method of investigation should also prove useful in connection with the high-energy accelerator, as the lifetime of a highly excited beta-active nucleus could be extremely short, according to the possible ft values.

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C. PROPOSED BUDGET

Proposed Projects

I. Neutron Velocity Spectrometer Transmission Measurements

II. Neutron Scattering Measurements

III. Analytical Studies and Crystal Growing

IV. Special Materials Investigations

V. Instrument Development

VI. Light Particle Investigations. 30.M97

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SALARIES AND WAGES

Project	Senior Scientists	Junior Scientists	Electronic Technicians	Cyclotron Group	Machine Shop	Drafting	Chemical Labs.	Administrative Staff	Totals
I	7,000	9,500	3,300	4,000	1,000	750	1,000	2,100	28,650.00
II	3,200	4,250	3,000	3,000	500	750	1,000	2,100	17,800.00
III	2,300	2,400	1,540	-----	500	300	5,500	2,100	14,640.00
IV	4,000	4,000	8,100	-----	1,800	750	610	2,100	21,360.00
V	6,250.	9,500	3,500	1,000	1,840	750	3,000	2,100	27,940.00
VI	3,200.01	2,320.53	1,500	1,000	1,000	500	2,500	2,100	14,120.54
TOTALS	25,950.01	31,970.53	20,940.00	9,000.00	6,640.00	3,800.00	13,610.00	12,600.00	124,510.54

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Project	Cyclotron	Consultants	Supplies Materials Services	Telephone Telegraph Postage	Travel	Insurance	Totals	Salaries and Wages	Aggregate Totals
I	15,000	---	8,550	400	500	250	24,700	28,650.00	53,350.00
II	10,000	---	13,000	400	500	250	24,150	17,800.00	41,950.00
III	1,500	---	6,450	400	---	250	8,600	14,640.00	23,240.00
IV	1,500	7,500	15,000	400	1,000	250	25,650	21,360.00	47,010.00
V	2,000	---	12,500	400	500	250	15,650	27,940.00	43,590.00
VI	10,000	---	8,500	400	500	250	19,650	14,120.54	33,770.54
TOTALS	40,000	7,500	64,000	2,400	3,000	1,500	118,400	124,510.54	242,910.54

Overhead at 35% of salaries	43,578.69
Salary adjustments at 10% of salaries	12,500.00
GRAND TOTAL	298,989.23

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PROPOSED BUDGET

	Number of Personnel	Average % Full Time	Estimated Cost
Senior Scientific Staff	11	94	25,950.51
Junior Scientific Staff	14	63	31,970.53
Administrative Staff	6	100	12,600.00
Chemistry Laboratory	5	100	13,610.00
Electronic Technicians	7	100	20,940.00
Cyclotron Group	6	70	9,000.00
Machine Shop	2	100	6,640.00
Drafting	2	100	3,800.00
			124,510.54
	Salary adjustments		12,500.00
			137,010.54
	Overhead at 35% of salaries		43,578.69
			180,589.23
Cyclotron, 1600 hours at $ 25/hour			40,000.00
Consultants			7,500.00
Supplies, materials, services			64,000.00
Telephone, telegraph, postage			2,400.00
Travel			3,000.00
Insurance			1,500.00
			298,989.23

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Comments on Specific Items in Proposed Budget

I

An increase of approximately $20,000 in salaries and salary adjustments is reflected almost entirely in reorganization of the Senior Scientific Staff. Up to this time, the duties of directing closely the research program under the contract have fallen on four staff members. This huge burden cannot be carried by these four scientists indefinitely. The development of Junior Staff members has progressed in an admirable fashion. Several of these, now considered experienced and capable physicists, in some cases have been, and in other cases will be, advanced to the Senior Scientific level. They must receive compensation for their services at least to an extent where their salaries under the contract approach the amounts they can command outside the organization. This move is obviously necessary to hold the staff intact.

In general, such an arrangement will enable this laboratory to carry out more efficiently pure research by assuring adequate supervision of all research personnel.

II

The figure, $64,000, for Supplies, Materials and Services is based on previous experience. In the past, expenses for materials and supplies have been approximately half the payroll. It is impossible to anticipate future expenditures in detail. Commercial scientific equipment is, to a great extent, behind our own instrument developments. In the cases where commercial equipment for our requirements does not exist, we must design and build our own. Consequently, much of the outlay is for such items as resistors, tubes, transformers, wire, glass, and so forth. Occasionally, commercial equipment meets our needs. For example, a Tektronix oscilloscope with an extremely high resolution time, now in development, will cost approximately $4,000. An instrument of this type is necessary for us to keep abreast with the field. However, such an item is the exception rather than the rule. Our own developments have consistently been ahead of the commercial field. We can only base our requirements on past needs related to other budget expenditures.

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Distribution of Assignments - Senior Scientific Staff

	I	II	III	IV	V	VI	S.M.
Havens	x	x	x	x	x	x	x
Rainwater	x	x	x	x	x	x	x
Taylor			x	x			
Wu				x	x	x	x
Morrissey						x	
Sheer	x	x			x		
Brown	x				x	x	x
Melkonian	x					x	x
Ruderman			x	x		x	x
Rudin					x	x	

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University Contributions -- Calendar Year 1949

1. 1650 hours of cyclotron time (3500 hours used on A.E.C. work, 1950 hours charged) at $25/hour..... 41,250.00

2. Salaries of personnel exclusively on Contract program: 2 full time employees, 8 part-time, employed during various stages of the program.....13,500.00

3. Overhead at 68.5% of salaries (33.5% over the 35% allowed on Gen 72 Contract).....41,711.03

4. Equipment, supplies, materials purchased; repairs and replacement on capital equipment. Items include laboratory and office furniture (e.g. chemistry laboratory bench at $1050); replacement parts on cyclotron (e.g. 2 tubes at $1070 each); detection apparatus (e.g. scalar at $850); fitting of a complete photographic darkroom, complete with baths, enlargers, sinks, light-proof doors and windows, etc., ($4250).
Above are examples of capital expenses. Minor expenditures which account for the larger fraction of the outlay are too numerous to mention here.....45,000.00

5 Free tuition for Contract employees on subjects pertaining to their phases of Contract work. Each full time employee is allowed 6 points (at $20 per point) per semester. This is taken as an added incentive to acquire satisfactory personnel 3,500.00

TOTAL 144,961.03

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NOTE: Added to these must be included many intangible outlays other than the direct monetary expenditures listed above, which the University makes available through the very nature of its composition:

(1) Time contributed by scientists, graduate students, technicians over and above time paid for from Contract or Department payroll. Experience has shown that the Senior Staff is not bound to a forty hour work week. Similarly, graduate students preparing Ph.D. theses on work of Contract scope must do so on their own time. Generally, the very nature of many types of research makes necessary long intervals of uninterrupted study and work extending far beyond a normal eight-hour day. There is no monetary compensation for these situations, but they are of extreme importance to the progress of the program.

(2) The services, consultations, and advice of members of the University Scientific Staff outside the Contract are available and used any time it becomes necessary. The consulting services of Professor I.I. Rabi, for example, were used extensively during the past year without compensation.

(3) University services, not covered by the general overhead allotment, are used as necessity dictates. The electron microscope, various spectrographic services, laboratories, and shops are open for use of Contract scientists and technicians at all times.

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D. LIST OF REPORTS

D. LIST OF REPORTS

Serial Number	Title	Author
CUD 19	Beta Spectrum of A^{41}	H. Brown, V. Perez-Mendez
CUD 20	Beta-Ray Spectra of Cu^{64} and Ratio of N+/N-	C. S. Wu, R. D. Albert
CUD 21	"P" Report for October, November, and December, 1948	J. R. Dunning
CUD 22	A Precise Determination of the Slow Neutron Cross Section of the Free Proton	E. Melkonian
CUD 23	Slow Neutron Velocity Spectrometer Studies of O_2, N_2, A, H_2, H_2O, and Seven Hydrocarbons	E. Melkonian
CUD 24	A Precise Determination of the Slow Neutron Cross Section of the Free Proton and Slow Neutron Velocity Spectrometer Studies of O_2, N_2, A, H_2, H_2O, and Seven Hydrocarbons	E. Melkonian
CUD 25	Determination of the Phase of Neutrons and of Incoherent Scattering Cross Sections	I. W. Ruderman, P. J. Bendt.
CUD 26	Scattering of Slow Neutrons by Para-magnetic Crystals	I. W. Ruderman
CUD 27	The Beta Spectrum of Chlorine^{36}	C. S. Wu, L. Feldman
CUD 28	Beta Spectrum of Yttrium^{91}	C. S. Wu, L. Feldman
CUD 29	Radioactivity of Chlorine ^{36}	C. S. Wu, C. H. Townes L. Feldman

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Serial Number	Title	Author
CUD 30	On the Spin and Beta-Spectrum of Chlorine^{36}	C.S. Wu, C.H. Townes
CUD 31	Interpretation of Beta Sources from Thick Sources	L. Feldman, C.S. Wu
CUD 32	Beta Spectrum of Beryllium^{10}	C.S. Wu, L. Feldman
CUD 33	Beta Spectrum of Oxygen^{15}	V. Perez-Mendez, H. Brown
CUD 34	"P" Report for January, February, and March, 1949	J. R. Dunning
CUD 35	High Resolution Scale-of-Four	V. Fitch
CUD 36	"P" Report for April, May, and June, 1949	J. R. Dunning
CUD 37	2 ev Neutron Resonance Absorption in U235 and 5 ev Neutron Resonances in U234	W.W. Havens, Jr., L.J. Rainwater, E. Melkonian
CUD 38	Beta-Spectra from Gaseous Sources	H. Brown, V. Perez-Mendez
CUD 39	A New Method for Determining the Phase with which Slow Neutrons Are Scattered by Nuclei	P.J. Bendt, I.W. Ruderman
CUD 40	Beta-Spectrum of Praseodymium^{143}	L. Feldman, L. Lidofsky P. Macklin, C.S. Wu
CUD 41	Beta-Spectrum of $_{61}Pm^{147}$	L. Lidofsky, P. Macklin, C.S. Wu
CUD 42	Experimental Verification of Angular Correlation of Scattered Annihilation Radiation	C.S. Wu, I. Shaknov

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Serial Number	Title	Author
CUD 43	Beta-Spectrum of Calcium^{45}	P. Macklin, L. Feldman L. Lidofsky, C. S. Wu
CUD 44	Photographic Methods of Measuring Neutron Intensities	M. Blau, I. W. Ruderman, J. Czechowski
CUD 45	"P" Report for July, August, and September, 1949	J. R. Dunning
CUD 46	Beta-Spectrum of Helium^{6}	V. Perez-Mendez, H. Brown
CUD 47	"P" Report for October, November, and December, 1949	J. R. Dunning

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E. LIST OF PUBLICATIONS

Title	Author	Publication	Date
The Scattering of Slow Neutrons by Paramagnetic Crystals	I. W. Ruderman, W. W. Havens, Jr. L. J. Rainwater, T. I. Taylor	The Physical Review, 75, No. 5, pp. 895-896	March 1, 1949
Beta-Ray Spectrum of Cu^{64} and the Ratio of N+/N-	C. S. Wu, R. D. Albert	The Physical Review, 75, No. 7, pp. 1107-1108.	April 1, 1949
Beta-Spectrum of A^{41}	H. Brown, V. Perez-Mendez	The Physical Review, 75, No. 8, pp. 1276-1277.	April 15, 1949
Interaction of Neutrons with Electrons in Bismuth	L. J. Rainwater, I. I. Rabi, W. W. Havens, Jr.	The Physical Review, 75, No. 8, p. 1295.	April 15, 1949
A Precise Determination of the Slow Neutron Cross Section for the Free Proton	E. Melkonian, L. J. Rainwater, W. W. Havens, Jr.	The Physical Review, 75, No. 8, p. 1295.	April 15, 1949
Scattering of Slow Neutrons by Paramagnetic Crystals	I. W. Ruderman, W. W. Havens, Jr., T. I. Taylor, L. J. Rainwater.	The Physical Review, 75, No. 8, p. 1296	April 15, 1949
Slow Neutron Velocity Spectrometer Studies: Al, Cr, C, Fe, Ni	W. W. Havens, Jr. L. J. Rainwater	The Physical Review, 75, No. 8, p. 1296.	April 15, 1949
Beta-Ray Spectra of Cu^{64}	R. D. Albert, C. S. Wu.	The Physical Review, 75, No. 8, p. 1286.	April 15, 1949

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Title	Author	Publication	Date
Beta-Ray Spectra of C^{14}	L. Feldman, C. S. Wu	The Physical Review, 75, No. 8, p. 1286.	April 15, 1949
Beta-Ray Spectrum of RaE	R. Morrissey, C. S. Wu	The Physical Review, 75, No. 8, p. 1288.	April 15, 1949
Production of Radioactive Gases by Deuteron Bombardment of Gaseous Targets	H. Brown, V. Perez-Mendez	The Physical Review, 75, No. 8, p. 1286.	April 15, 1949
On the Spin and Beta-Spectrum of Cl^{36}	C. Longmire, C. S. Wu, C. H. Townes	The Physical Review, 76, No. 5, pp. 695-6.	September 1, 1949
Interpretation of Beta-Spectra from Thick Sources	L. Feldman, C. S. Wu	The Physical Review, 76, No. 5, pp697-8.	September 1, 1949
Nuclear Spin and Quadrupole Moment of Cl^{36}	C. H. Townes, L. C. Aamodt	The Physical Review, 76, No. 5, pp. 691-2.	September 1, 1949
Beta-Spectrum of O^{15}	V. Perez-Mendez, H. Brown	The Physical Review, 76, No. 5, p. 689.	September 1, 1949
Radioactivity of Chlorine^{36}	C. S. Wu, C. H. Townes, L. Feldman.	The Physical Review, 76, No. 5, pp. 692-3.	September 1, 1949
Beta-Ray Spectrum of Chlorine^{36}	C. S. Wu, L. Feldman	The Physical Review, 76, No. 5, pp. 693-5.	September 1, 1949
Beta-Ray Spectrum of Be^{10}	C. S. Wu and L. Feldman	The Physical Review, 76, No. 5, 698-9.	September 1, 1949

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Title	Author	Publication	Date
Improved Baffle System for Helical Focusing Beta-Ray Spectrometer	L. Feldman, C. S. Wu	The Physical Review, 76, No. 1, p. 180.	July 1, 1949
Beta-Spectrum of Y^{91}	C. S. Wu, L. Feldman	The Physical Review, 76, No. 5, p. 696-7.	September 1, 1949
Heavy Particles in Cosmic-Ray Stars	M. Blau, M. Block, J. Nafe	The Physical Review, 76, No. 6, p. 860.	September 15, 1949
Scattering of Slow Neutrons by Paramagnetic Crystals	I. W. Ruderman	The Physical Review, 76, No. 11, pp. 1572-84.	December 1, 1949.
A High Resolution Scale-of-Four	V. Fitch	Review of Scientific Instruments, 20, No. 12, pp. 942-4.	December, 1949
Precise Determination of the Slow Neutron Cross Section of the Free Proton	E. Melkonian	The Physical Review, 76, No. 12, pp. 1744-49	December 15, 1949
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Title	Author	Publication	Date
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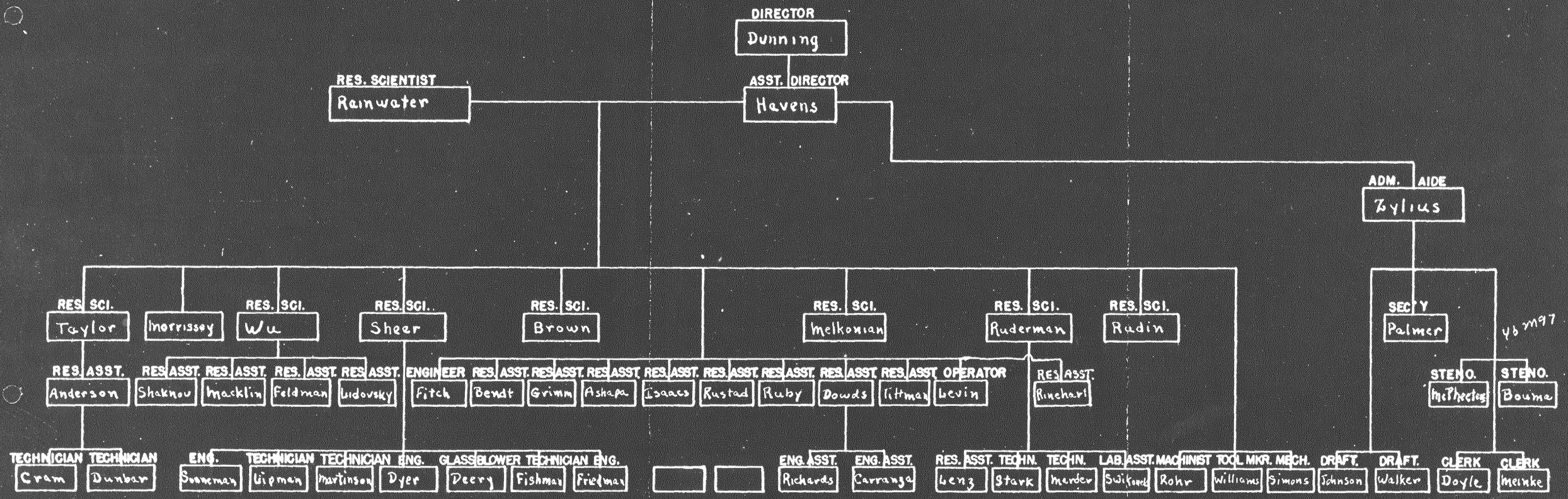
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