I

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FOREWORD

This Summary Report on the work of the Physics Division of the Argonne National Laboratory is presented for the information of members of the Division and a limited number of other persons interested in the progress of the work.

It is merely an informal progress report. The results and data therefore must be understood to be preliminary and tentative.

The issuance of these reports is not intended to constitute publication in any sense of the word. Final results either will be submitted for publication in regular professional journals or, in special cases, will be presented in ANL Topical Reports.

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* This project is inactive. Further reports will be made when work is resumed.

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* This project is inactive. Further reports will be made when work is resumed.

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I. EXPERIMENTAL NUCLEAR PHYSICS

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1-15 The Argonne Fast Neutron Velocity Selector (5220)

Lowell M. Bollinger, Robert E. Cote¹ and George
E. Thomas

Reported by Robert E. Cote¹

About two more weeks of work will be required to finish the new rotor. Completion of the work was delayed by changing the slit system, essentially by substituting a plastic material for the monel which forms the central slit. The other six slits have been finished according to the original plan.

This change, which involved a change in the shape of the slit as well as a replacement of material, was made to minimize two undesirable effects encountered with the rotor now in use. The first of these is an edge effect which effectively broadens the neutron burst. This is particularly bad for high-energy neutrons and is caused by the fact that the material which stops the neutrons intercepts the beam gradually as the chopper rotates. The second effect is the appearance of structure introduced into the open beam by the neutron resonances in the material of the rotor. The first effect can be reduced by use of a non-tapered slit and the second by making the slit of some material which has no neutron resonances, but in which the mean free path for neutrons is small. But since non-tapered slits transmit neutrons poorly at low energies, it was decided that only one slit should be modified. The central slit of the system was therefore made larger to accommodate plastic inserts which form a slit $2 \frac{1}{16}$ in. high and 0.015 in. wide. They are made of epoxy resin strengthened by layers of glass cloth.

The detector station at 120 m and the flight tube to this station have been completed.

2-15

Neutron Detectors

(5220)

Lowell M. Bollinger, Roland J. Brown and George E. Thomas

FISSION DETECTORS

Reported by George E. Thomas

A single-plate fission detector is under construction. The foil is 5.0 x 18.0 cm and is coated with U^{235} to a thickness of 0.5 mg/cm². The foil is mounted on the bottom of the detector with a 1-cm spacing between both the foil and collector plate and the collector plate and top plate of the detector.

LIQUID SCINTILLATORS

Reported by George E. Thomas

The liquid scintillator described in the last Summary Report has been completed. The associated electronics equipment is nearing completion and this detector should be tested in the very near future. Since it has several properties quite different from those of detectors used previously, its characteristics should prove quite interesting.

ZINC SULFIDE SCINTILLATORS

Reported by Roland J. Brown

In an attempt to improve the detection efficiency of silver-activated zinc sulfide in fused boric oxide, first reported in Summary Report ANL-5667 for September through December, 1956, a laminated system of such scintillators was constructed. Such an arrangement would be expected to increase the light-gathering efficiency.

The detector was constructed of two major components. (1) A mixture of one part of silver-activated zinc sulfide to two parts of boric oxide was fused, backed with 3-mil aluminum foil and pressed to a thickness of 1.1 mm. From the resulting wafers were cut strips 1 cm by 2 in. (2) Strips of Lucite of 1-mm thickness were cut to the same dimensions.

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The detector was assembled on the face of a photomultiplier with both the neutron flux and the planes of the laminae perpendicular to the photo-surface. Separate scintillating units were formed by facing a strip of the scintillator onto each side of a strip of Lucite. Several such units, separated by the aluminum foils, were mounted on the photomultiplier. Efficient optical contact between the layers and with the photomultiplier was assured by the use of silicone grease.

The efficiency of this laminated detector was measured as a function of neutron energy by placing it in the neutron beam of the Argonne fast chopper with its layers parallel to the paths of the incident neutrons. The relative efficiency as a function of the energy of the neutrons was measured by comparison with the counts produced in a boron-plate detector that was placed between the chopper and the laminated detector.

Counting rates as a function of energy were thus simultaneously measured for the two counters. Since the absolute flux as a function of energy was known from experiments in conjunction with our measurement of the absolute fission cross section of U^{235} , the absolute detection efficiency was determined by normalizing the ratio of the counting rates. The resultant absolute efficiency of the laminated detector is shown in Fig. 1.

Fig. 1. Efficiency of the laminated detector.

Next, the relative efficiencies of three scintillating systems were measured by observing the difference in counting rate for each system when cadmium was inserted in the beam of neutrons. The three systems were: (1) The previously-described laminated detector; (2) Separate strips of the zinc sulfide and boric oxide scintillator affixed directly to the face of the photomultiplier in a plane normal to the neutron beam, and (3) Neutron Phosphor NE 400 from Nuclear Enterprises,

Limited, similarly affixed to the photomultiplier.

These were the observed differences in counting rate:

(1) Laminated scintillator	603/sec/in ²
(2) Flat strips	609/sec/in ²
(3) NE 400	1161/sec/in ²

Thus, we may conclude that the efficiency of the laminated detector is no greater than that of the flat strips. Such low efficiencies permit little useful application, and further study is not planned. Moreover, the NE 400 Neutron Phosphor which was used has only about 4% efficiency at thermal energy, far below the advertised 25-35%.

3-15 Cross Section Measurements with the Fast Neutron
Velocity Selector (5220)

Lowell M. Bollinger, Roland J. Brown, Robert E. Cote', Jeanne P. Marion, Adnan Saplakoglu, and George E. Thomas

Reported by Lowell M. Bollinger

a) DETERMINATION OF SPIN STATES FOR PU²³⁹ RESONANCES.

The analysis of the data obtained in a series of cross-section measurements on Pu²³⁹ during the past year has continued. The most significant result obtained recently is that for three resonances we are able to deduce not only the various partial widths but also the J-values. For the resonances at 41.5 and 44.5 ev, we find that J = 0 whereas for the resonance at 52.6 ev, J = 1 with a probability of perhaps 80%. These are the first resonances for any fissionable nuclide for which the J-values have been determined.

If the assignment of the J-value for the resonance at 52 ev can be made more certain, our result will be of some importance since it contradicts the theoretical suggestion that the resonances corresponding to a single

spin state are so broad as to be unobservable. This suggestion has been put forth as a possible explanation of the anomalously high fission cross section in the regions between resonances.

b) PRECISION MEASUREMENTS OF NEUTRON CROSS SECTIONS FOR U^{235}

A new method for measuring absolute fission cross sections in the thermal range of energy was described in the preceding Summary Report, ANL-5698. This method, which avoids the known uncertainties inherent in other ways of measuring absolute fission cross sections, was used in a series of measurements on U^{235} . The result obtained is 606 ± 6 barns at an energy of 0.0253 ev. This number is not quite a final value, but it is not expected to change by more than 0.5%.

A comparison of our result with those of other measurements shows that our value is the highest number yet obtained for U^{235} . In particular, it is much higher than the "world weighted average" value of 579 ± 5 barns and the "world consistent set" value of 582 ± 10 barns given in reference 1. This discrepancy has caused us to continue our study of U^{235} in the thermal range of energy by making exceptionally careful measurements of the total cross section and the relative fission cross section as functions of energy.

Our result for the total cross section is 694 ± 2 barns. This value is lower than all values previously quoted, although it is not necessarily in disagreement with other results obtained in the United States. In any case, our result is of such high statistical quality and is so reproducible that we have considerable confidence in it.

Our measurements of the relative fission cross section of U^{235} are also of superior statistical quality and many minor sources of error have been examined with care. Combining these results with those from the

¹ Supplement No. 1 to BNL 325.

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measurements of the total cross section, a curve has been derived for η/ν as a function of energy. Although the final corrections for this curve have not been completed, it seems clear that it is in definite disagreement with the energy dependence found by Palevski in direct measurements of η (see results in reference 1). Our results show that η increases slightly as energy decreases in the range from 0.01 to 0.1 ev.

Of the previous measurements of the absolute fission cross section, that which seems to be most generally accepted as being free of large sources of error has sometimes been termed the "U. S." measurement. In this measurement, the fission cross section is deduced from the relationship

$$\sigma_f = \frac{\sigma_t - \sigma_s}{1 + \alpha}$$

where $\alpha = \sigma_\gamma / \sigma_f$ and σ_γ is the radiative-capture cross section. The scattering cross section σ_s , which is small compared to σ_t , is estimated and α is deduced from the measured average value $\bar{\alpha}$ for a pile spectrum. This approach has been re-examined, using the results of our own measurements of σ_t and η/ν . A study of the literature shows that the most reliable value of $\bar{\alpha}$ is 0.180 ± 0.007 ; this value was obtained after minor corrections of the original data because of changes in other cross section quantities. To obtain α from $\bar{\alpha}$, it was assumed that, in the measurement of $\bar{\alpha}$, 4.6% of the fissions were caused by neutrons of epi-cadmium energy and that for these neutrons the effective value of α is 0.5. Under these assumptions we find that the fission cross section is 595 ± 12 barns at 0.0253 ev. It is noteworthy that both this value and the error are much larger than the result of 580 ± 7 barns which had been obtained previously from essentially the same data. This discrepancy only serves to underline the uncertainties inherent in the calculation. The major difference between our calculation and that for which the results are given in reference 1 seems to be in the treatment of the effect of epi-Cd neutrons. The available information seems to indicate that

this effect was ignored in previous analyses.

The moderate degree of agreement between the results of our two entirely different measurements of the fission cross section, namely 606 ± 6 and 595 ± 12 barns, gives us considerable confidence in the former result. It must be emphasized, however, that these values apply to an energy of 0.0253 ev and that they are not at all closely related to effective pile values or even to effective Maxwellian values. These average values depend on other cross section quantities, which, as our results for η/ν have shown, may not be well understood.

c) MEASUREMENTS of η/ν for U^{235}

In the preceding Summary Report (ANL-5698) it was reported that direct measurements of η/ν for U^{235} had been completed. These data have now been examined and those in the thermal range of energy appear to contain some serious systematic error. The measurements, therefore, are now being repeated.

4-3

Mass Distribution in Fission

(5220)

Lowell M. Bollinger, Louis W. Roeland and George
E. Thomas
Reported by Louis W. Roeland

As has been outlined in previous reports, the problem of this experiment is to detect differences in the mass distributions of the fission products produced by groups of neutrons having energies corresponding to different resonances in the fission cross section of the fissionable material being studied. The first approach to this problem is made in the following way. Filters were used in a direct beam from the pile to select energies which were predominantly in the desired resonances. This neutron energy distribution can be checked by making a transmission measurement with the chopper. The fission caused by these neutrons produces two pulses V_1 and V_2

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in a double back-to-back Frisch-grid chamber. These pulses are fed into a ratio circuit, designed by J. McMahon of the Electronics Division, which determines the ratio $V_1/(V_1 + V_2)$ in the following way. Pulse No. 1 charges a condenser to the voltage V_1 and at the same time the sum pulse starts a constant current proportional to $(V_1 + V_2)$ to discharge the condenser. A negative pulse is produced at the instant the voltage across

Fig. 2. The conversion of the ratio $V_1/(V_1 + V_2)$ into a time proportional to this ratio. (a) Voltage across condenser. (b) Corresponding pulses fed into time analyzer.

the condenser reaches a maximum and another when the voltage again reaches zero. (See Fig. 2.) The first of these negative pulses is used to start the time-of-flight analyzer, the second one to stop it. Under the assumption that the output pulse of the counter is proportional to the energy of the corresponding fragment, it can be shown that

$$\frac{V_1}{V_1 + V_2} = \frac{M_2}{M_1 + M_2},$$

where M_1 and M_2 are the masses of the fission fragments.

A systematic study of the counters was made using the resulting peak-to-valley ratio R of the mass yield curve as a criterion of excellence. The results can be summarized as follows.

1. The ratio R was the same for pressures of $\frac{1}{2}$ and 1 atmosphere of 90% A + 10% CH_4 in the chamber.
2. Although no real saturation was obtained in the graph of pulse height vs field between grid and cathode, it was shown that the peak-to-valley ratio did not change if one changed the fields within the region where the saturation curve flattens out.
3. The two counters described in the previous reports gave the same value for R .

4. A separate check of the dependence on the size of the collimator holes has not been made since the results thereof seemed obvious from the results for the α -ray distribution (see the last Summary Report, ANL-5698).

5. Runs have been made with different thicknesses of uranium foil. A slow linear variation of R^{-1} was observed, the value of R^{-1} being approximately twice as great for a foil of $120 \mu\text{g}/\text{cm}^2$ thickness as for one of zero thickness.

6. The ratio R decreases with increasing counting rate. This effect has been accounted for by chance coincidences.

After having completed the tests on our counters we started our program with some orientating studies of U^{235} . The method we adopted is the following. By means of a sample changer, a Cd sample is periodically taken out of the neutron beam and replaced by a non-resonant filter of brass or carbon of such a thickness that the counting rates under the two circumstances are equal. The two groups of data are stored in the first and second halves of the time analyzer. In this way we insure identical circumstances for both runs. It is clear that with the Cd removed the chief contribution to the fission yield is from the thermal neutrons, whereas with the Cd in the beam the contributing neutrons are determined by the fixed filters. The only difference between the two situations could be a different γ pile-up, but this has been proved to have no effect.

The mass-yield curve for thermal neutrons is used as a reference. The AVIDAC computes the ratio P of the number of counts in a channel for resonance neutrons to the number in the corresponding channel for thermal neutrons. Several runs have been made using, instead of neutrons from one resonance, those of all resonances above 1.5 ev. Figure 3 shows the dependence of P on the mass number. Apparently the peaks of the distribution for the resonance neutrons are broader than those for thermal neutrons.

Fig. 3. Typical example of a mass distribution for thermal neutrons and of the ratio P for all neutrons with energy > 1.5 ev for U^{235} .

We have repeated this measurement under slightly different circumstances and the result was always qualitatively the same. As can be seen from the chopper data for the filters used in this experiment, this effect cannot be caused by fast neutrons. The difference between the two distributions is shown most reliably on the wings of the peaks where the statistics are good. There the effect cannot be explained in terms of a background effect since the background required would have to be greater than the observed counting rate in the valley of the distribution.

The next step was to isolate the 8.9-ev resonance of U^{235} .

We succeeded in producing a beam which gave 50% of the fissions due to this resonance and 50% due to background. The influence of this background can be measured by removing the 8.9-ev resonance with Sm and measuring P again.

The results of this study are inconclusive because of poor statistics. We shifted attention to the easier study of U^{233} .

This experiment is easier because the resonances under study (1.8 and 2.3 ev) have such a huge contribution to the fission as compared to the others. Besides, the MTR group has shown from cross section behavior that these resonances interfere with each other but not with the resonance at negative energy, which is mainly responsible for the thermal cross section. Therefore it is expected that the 1.8- and 2.3-ev

resonances are associated with one spin state of the compound nucleus whereas the resonance at negative energy is associated with another spin state. This difference should also show up in the mass-yield distribution, particularly in the peak-to-valley ratio. The uranium foil used in this experiment is only $2 \mu\text{g}/\text{cm}^2$ thick to prevent excessive a pile-up.

First of all we have compared the total contribution of the two resonances with the contribution of thermal neutrons. The results seem to indicate clearly that the peak-to-valley ratios are different, the 1.8- and 2.3-ev resonances having a lower valley and probably also narrower peaks. However, we cannot be certain that this effect is real until it has been obtained under different experimental conditions.

The comparison of the results for the resonance at 1.8 ev with those at 2.3 ev was inconclusive because of statistics.

The above studies are being continued under improved instrumental conditions.

5-1 An Area Method for Analyzing Neutron Resonances (5220)

Lowell M. Bollinger and Jeanne P. Marion
Reported by Lowell M. Bollinger

In spite of rapid improvement in the techniques of measuring cross sections for neutrons of low energy, the instrumental resolution used is rarely good enough to observe, without serious distortion, the sharp resonances which are characteristic of this range of energy. For transmission measurements, therefore, the total area above the observed transmission dip is widely used to determine some functional relationship between the peak cross section σ_0 and the total width of the resonance. The many specialized techniques employed to treat data in this way have been summarized by Melkonian.¹

¹ E. Melkonian, Proceedings of the International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1955 (United Nations, New York, 1956) Vol. 4, p. 340.

The basic idea of all of them is that the nature of the relationship between σ_0 and Γ depends on the sample thickness n . Thus the independent values of σ_0 and Γ are those values which are allowed by the areas obtained for several different thicknesses of sample.

The principal weakness of the method of area analysis that has been used heretofore is its lack of sensitivity. Because the several lines of σ_0 vs Γ cross at an acute angle, small errors in the measured areas result in large errors in the derived parameters. We have developed a new area method for treating transmission data which can significantly improve the accuracy of the parameters without increasing the calculational labor involved. The basic idea of the new method is that the partial area above some limited range of energy of a transmission dip is used directly in the calculation, in contrast to the previous method in which the entire area is treated.

To make this new approach possible, the partial areas A_E' above the transmission curve within the range of energy from $(E_0 - \epsilon)$ to $(E_0 + \epsilon)$ have been calculated* for a wide range of conditions from the relationships

$$A_E' = \int_{E_0 - \epsilon}^{E_0 + \epsilon} (1 - e^{-n\sigma}) dE$$

$$\text{and } \sigma = \sigma_0 \psi(x, t) \equiv \frac{\sigma_0}{2t\sqrt{\pi}} \frac{e^{-(x-y)^2/4t}}{1+y^2} dy$$

$$\text{where } x = \frac{2}{\Gamma} (E - E_0) \quad \text{and } t = \left(\frac{\Delta}{\Gamma}\right)^2$$

In the above, σ is the cross section, E is the neutron energy, E_0 is the resonance energy, and Δ is the Doppler width of the resonance.

Values of A_E' were calculated for $n\sigma_0$ ranging from 0.1 to 150, for Δ/Γ from 0.2 to 10, and for values of ϵ/Δ of 0.5, 0.75, 1.0, 1.5, 2.5, 3.5, 5.0 and 7.5. These results have been plotted in the form of

* The calculation was done by A. J. Strecok of the Applied Mathematics Division.

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A_E'/Δ vs $n\sigma_0$ for a series of values of Δ/Γ and a fixed value of ϵ/Δ . One of them is illustrated in Fig. 4. For use in treating data, all of the curves have been drawn to a large scale on gridded paper, where the quantities involved can be read easily to an accuracy of 0.5%. The author

Fig. 4. A simplified representation of one of the families of calculated curves relating the partial areas A_E' above transmission dips to the resonance parameters.

would be pleased to supply this set of curves upon request.

Our application of the new method to actual transmission data has shown that it has the following advantages as compared to the older approach in which the whole transmission area is used.

a) The accuracy of derived parameters is improved.

Errors in parameters are usually reduced by a factor of about 1.5 although in special cases (as when the resolution width is narrower than the resonance width or when the thicknesses of the available samples are all nearly equal) the degree of improvement can be much more spectacular.

b) Resonance parameters can be derived from the results of measurements on a single sample. This is done by obtaining curves of σ_0 vs Γ for two values of ϵ/Δ and is to some extent a

probabilities of symmetric and asymmetric fission modes to the spin and parity of the state of the compound nucleus.

Measurements of ν , the number of neutrons per fission, have indicated that this quantity remains essentially constant for all resonances.² However it was felt that study of the features of the curve of yield vs mass would provide a more sensitive measure of possible differences in fission modes at different resonances.

Samples of U^{235} metal (about 90 gm, each 1 cm x 1 cm x 10 cm) were irradiated with neutrons from a crystal spectrometer in the arrangement shown in Fig. 5. Neutrons of 1.1, 3.1, and 9.0 ev were used in a series of irradiations, each lasting for about three days. The beam used in these irradiations was about 11 cm high at the position of the sample and contained about 10^4 neutrons per second in the energy region of interest. The resolution of the instrument (full width at half maximum) was about 5.3% at 1 ev and 15% at 9 ev. Background irradiations were performed by turning the crystal about 2° from the direction satisfying the Bragg condition for reflection.

Fig. 5. Horizontal cross section of the crystal spectrometer for neutrons at the Argonne Research Reactor, CP-5. The beam is monochromatized by reflection from the vertical 110 planes of a Be crystal approximately 1.5 cm x 1.5 cm x 7 cm high.

²

Auclair, Landon and Jacob, Compt. rend. 241, 1935 (1955); Zimmerman, Palevsky and Hughes, Bull. Am. Phys. Soc. 1, 8 (1956); Leonard, Seppi and Friesen, Bull. Am. Phys. Soc. 1, 8 (1956); Bollinger, Cote', Hubert, LeBlanc and Thomas, Bull. Am. Phys. Soc. 1, 165 (1956).

Standard radiochemical procedures were carried out on the irradiated samples for Sr^{89} , Ag^{111} , Cd^{115} , and Sb^{127} . Comparisons of the counting rates observed were made with samples of the same nuclides isolated from samples of normal uranium irradiated by slow (pile) neutrons, and mounted and counted in an identical manner. Calculations of the fission yields could thus be made on a relative basis, using the known yields for fission of U^{235} by slow neutrons, and avoiding corrections for geometry, scattering, absorption, etc. Initial counting rates of the order of 5 c/m were observed for Cd^{115} . This was sufficient to characterize the radiations by decay measurements. All samples were counted in an anti-coincidence shielded counter having a background of about 2 c/m. The results are summarized in Table I.

TABLE I. Fission yields in fission of U^{235} by resonance neutrons from 1-10 ev.

Nuclide	1.1 ev	3.1 ev	9.5 ev	Pile
Sr^{89}	4.8% ^a	4.8% ^a	4.8% ^a	4.8% ^a
Ag^{111}	0.020%	0.019%	0.018%	0.018%
Cd^{115}	0.013%	0.008%	0.010%	0.011%
Sb^{127}	0.11%	---	---	0.10%

a Assumed yield; others calculated relative to Sr^{89} .

The preliminary data indicate no differences in the relative probabilities of asymmetric modes (represented by Sr^{89}) and near-symmetric modes (represented by Ag^{111} , Cd^{115} , and Sb^{127}). The accuracy of the measurements of fission yield is estimated as $\pm 20\%$. The extremely low counting rates for Cd^{115} and the rather high background effect (varying from about 20% to 1.1 ev to about 50% at 9.5 ev) would preclude any observation of a real decrease in the probability of symmetric fission modes. However,

the data can certainly be taken to show that no significant increase in these modes occurs at the resonances investigated. Further studies are planned with increased sensitivity and reduced background so that regions between resonances may be investigated also.

This report will be submitted for publication.

11-15 Installation and Operation of the Van de Graaff Generator (5220)

Robert Holland and Jack Wallace
Reported by Jack Wallace

The report covers the operation of the Van de Graaff Generator in D-203 for the period April 1 through June 30, 1957.

The generator was used to accelerate protons, deuterons and alpha particles. The generator was also operated with He^3 (over 90%) as the gas in the ion source.

The following time distribution shows both the division of time and the types of experiments being performed with the Van de Graaff Generator by the group. No effort has been made to show any efficiency factor for the use of the allotted time by the various experimenters.

1. Photo-fission Cross Sections of the Heavy Elements	Clark	111.7 hours
2. Angular Distributions of Neutrons	Lane, Langsdorf	216.0
3. Angular Distribution of Protons	Lee, Schiffer	112.5
4. Angular Distribution of γ -rays	Hanna, Meyer	40.2
5. Neutron Spectra by Time of Flight	Holland	76.3
6. Irradiation of Targets	Mooring	8.3
7. Total Cross-Sections	Hibdon	35.9
8. Parity Experiment	Hanna, Preston	62.1
		<hr/> 663.0

Start-up and daily maintenance	45.0
Machine repairs and changes	377.0
Experimental setup time	83.0

Total time available (64 days x 15 hours + 26 days x 8 hours) 1168.0

During this quarter the life of the charging belts became so short that even though the demand for machine time was very great we were forced to take action to try to remedy the situation. There were two possible sources of trouble that could cause short belt life. One cause would be considered mechanical in nature and the other electrical. Not being able to determine which was the real culprit or whether both were contributing, we decided to attack both problems.

The problem which I choose to call mechanical deals with such possibilities as an improper system of maintaining the tension of the belt, improper crowning of belt pulleys, imperfections in the manufacturing of the belt, and improper width, weight or coating of the belt. Each of these possibilities was investigated and corrections were made, or are being made, to insure alleviation of any cause of error. The problem was also discussed with the belt manufacturer to see if he might have an answer to the problem. There appeared to be no glaring defects to which the trouble could definitely be attributed.

The attack on the electrical problem was also a positive action. For some time we have been aware that our belt-charging system left much to be desired. We knew that we were getting incomplete charge removal at the high-voltage end of the generator and that the belt was carrying a surplus positive charge. Another disadvantage was that our charging system at the high-voltage end of the machine also affected the focus of the beam. The third objection was that the system was so complex that it was hard to analyze what was going on. Hence the charging system at the high-voltage end has been replaced with a variable power supply that sprays a

To produce light pulses of ultrafast rise time, a light source similar to that developed by Quentin Kerns at U. C. R. L. at Berkeley has been constructed. It consists of a 125-ohm coaxial line in which is placed a relay with mercury-wetted contacts, and a simple telescope focused on the relay contacts. Light from the arc produced in the hydrogen-filled relay when the contacts close is focused upon a spot on the cathode of a photo-multiplier. The electrical pulse from the relay triggers the sweep of a

traveling-wave oscilloscope,¹ and the pulses from the last dynode and plate of the photomultipliers are applied to the two deflection helices. The rise time of the pulse from the photomultiplier is calibrated by varying the length of coaxial line in the trigger circuit. By focussing the light flashes on different areas of the photo-cathode, differences in transit times from the different places of origin of the photo-electrons may be investigated.

B. TIME-INTERVAL VERNIER

The pulses into the 125-ohm circulating line should be of minimum duration (less than 5 mμsec) and of maximum amplitude. Measurements are being made with the EFP-60 tube to determine the operating voltages that will permit greatest output current and fastest rise time.

¹ Type 2236 manufactured by Edgerton, Germeshausen and Grier, Inc., Boston, Massachusetts.

14-14 Pulsed Neutron Beams for the Van de Graaff Generator (5220)

Robert E. Holland

The data on the angular distribution of the neutrons from the reaction $^{55}\text{Mn} (p,n) ^{55}\text{Fe}$ were retaken because those mentioned in the preceding report showed large fluctuations caused by the lack of a good monitor. Although both runs gave essentially the same result, only the more recent data are presented here.

Targets were prepared by evaporating manganese on aluminum backings which were weighed before and after evaporation to obtain the target thickness. Background was obtained at each angle by reversing the target so as to present bare aluminum to the beam. A long counter kept in a fixed position below the plane of measurement served as a monitor.

Figures 6 and 7

show the angular distributions of the neutron groups corresponding to transitions to states of ^{55}Fe obtained from the reaction $\text{Mn}^{55}(\text{p},\text{n})\text{Fe}^{55}$ with a mean proton energy of 3.060 Mev and a target thickness of 38 kev. The data have been corrected for variation in the monitor count (less than 3%) and for variation in counter efficiency (less than 2% for the three lower states). The correction for transforming to center-of-mass coordinates is small (the maximum correction in angle is 1.3° and that in solid angle is less than 1%) and was not made. All neutron groups except the ground-state group were isotropic within the accuracy of measurement. The angular distribution of the ground-state group is well represented by

$$I(\theta) = 1 + \frac{1}{2} \cos^2 \theta,$$

which is the curve in Fig. 6. There were not enough data at back angles to rule out a small $\cos \theta$ term.

Fig. 6. Angular distribution of neutrons from $\text{Mn}^{55}(\text{p},\text{n})\text{Fe}^{55}$.

Fig. 7. Angular distribution of neutrons from $\text{Mn}^{55}(\text{p},\text{n})\text{Fe}^{55}$.

16-6

A New Neutron-Counting System

(5220)

Clyde Kimball and F. Paul Mooring
Reported by F. Paul Mooring

Parts for the two identical neutron counting assemblies are now being delivered from the shops. Electronic circuits are being built and should be finished soon.

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During the next quarter, tests will be made to select the actual locations of the thirty or more BF_3 counters that will be used in each assembly. It is planned to install the two new counter systems at the Van de Graaff generator during the summer. The grate floor of the Van de Graaff room has been extended to provide room for the new assemblies.

18-6 Differential Cross Sections for Neutron Resonance Scattering
(5220)

Raymond O. Lane

Angular distributions of neutrons scattered from Li^6 and Li^7 have been measured at eight angles with the large detector tanks on the circular track. Data were taken from 0.100 Mev to 0.600 Mev with narrow resolution (~ 5 kev), and from 0.600 Mev to 2.200 Mev with very broad resolutions (~ 100 kev). Use of the alternating-gradient magnetic-focusing lens provided a proton beam of 20-25 μ a on the rotating Li target which allowed data to be obtained with high resolution and good statistics for these samples for which the cross section is very low. The AVIDAC analysis of the angular-distribution data is being revised to take advantage of the added angles made available since the detector tanks have been on a circular track. It is hoped that the data on Li^6 and Li^7 can be analyzed soon. Similar measurements with high resolution have been made on S^{32} near the 0.585-Mev resonance in an attempt to determine the value of the higher order terms in the differential scattering cross section. Earlier experiments showed that $J \geq 5/2$, $l \geq 2$ for this resonance. These data, too, are awaiting analysis with the new program.

Through the collaboration of W. Miller and W. Snow of the Applied Mathematics Division, the Monte Carlo calculation of the multiple scattering of neutrons near resonances has been completed. It takes into

account directly the first three orders of scattering for the slab-type geometry used here. Because of shut-downs of the AVIDAC, only one test case has been completed so far; but all the resonance scattering data obtained so far will be corrected as soon as time on the machine is available.

The differential scattering cross section for carbon in the vicinity of the 2.07-Mev resonance will be measured soon with high resolution to determine the value of the high-order terms in the cross section and the scattering phase shifts in this region.

The semi-automatic equipment for recording the angular-distribution data on punched tape is undergoing its final testing prior to its contemplated use on the next series of measurements. This will provide data tapes ready to be fed directly into AVIDAC or GEORGE for analysis.

20-15 Energy States of Light Nuclei from Charged Particle Reactions
(5220)

Stanley S. Hanna, David R. Inglis, Linwood L. Lee, Jr.,
and John P. Schiffer
Reported by Linwood L. Lee, Jr.

The new track for the magnetic spectrometer has been completed and is ready for installation. Work is continuing on the new target chamber and other equipment for the new installation.

21-4 Study of Gamma-Rays in Nuclear Reactions (5220)

Stanley S. Hanna and Luise Meyer-Schützmeister

The angular distributions obtained in the $\text{Li}^6(\alpha, \gamma)\text{B}^{10}$ reaction have now been compared with theoretical distributions for a variety of assignments. The resonances and gamma rays which have been observed are reported in Table II. The measured angular-distribution coefficients are given in Table III. The comparison with the theoretical coefficients is

presented in tabular form in Table IV.

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TABLE II. Resonances and Gamma Rays Observed in $\text{Li}^6(\alpha, \gamma)\text{B}^{10}$.
The cross section is expressed in the form $w_\gamma = \pi \sigma_R \Gamma / \lambda^2$.

E_α (Mev)	E_{ex} (Mev)	$\Gamma(\text{lab})$ (kev)	Primary Radiation			Secondary Radiation (Mev)
			E_γ (Mev)	%	$w(\text{CM})$ $\Gamma_{\gamma\gamma}$ (ev)	
0.50 ^a	4.77 ^a		4.77	8		
			4.05	92		0.72
1.085	5.105	7	5.105	96	0.10	
			4.39	4	0.005	0.72
1.175	5.16	3	5.16	7	0.04	
			4.44	29	0.15	0.72
						2.15
			3.01	64	0.32	1.43, 0.72
						0.41, 1.02, 0.72
2.435	5.91	20	5.91	100		
2.605	6.02	5	6.02	100		

^a These values are taken from the literature.

TABLE III. Observed angular distribution coefficients in the expression $w(\theta) = 1 + A_2 \cos^2 \theta + A_4 \cos^4 \theta$ for the reaction $\text{Li}^6(\alpha, \gamma)\text{B}^{10}$. A value of A_4 is given only in cases in which it seems statistically significant. Values corrected for the finite solid angle are listed in the final columns. The error in each coefficient is approximately ± 0.1 .

B^{10} level (Mev)	E_γ (Mev)	Measured		Corrected	
		A_2	A_4	A_2	A_4
4.77	4.05	2.22	-1.4	4.4	-3.4
	0.72	-0.05	----	-0.06	----
5.11	5.11	-0.30	----	-0.35	----
5.16	5.16	0.05	----	0.06	----
	4.44	-0.20	----	-0.25	----
	3.01	-0.20	----	-0.25	----

B^{10} level (Mev)	E_{γ} (Mev)	Measured		Corrected	
		A_2	A_4	A_2	A_4
5.91	5.91	0.00	----	0.00	----
6.02	6.02	- 0.10	1.05	- 0.80	2.0

TABLE IV. Comparison of experimental and theoretical angular distributions. If the experimental values of A_2 and A_4 (Table III) can be obtained theoretically for a given assignment, the condition for this agreement is listed (unless the theoretical values are unique) and the assignment is labeled P (Possible). If, on the other hand, the theoretical values of A_2 and A_4 , as listed, are incompatible with experiment the assignment is marked N (Not possible). Borderline situations are labeled U (Uncertain). The alpha-particle and gamma-ray intensities with angular momentum equal to l are denoted by $I_{\alpha}(l)$ and $I_{\gamma}(l)$, respectively.

B^{10} level (Mev)	Assign- ment	γ -Ray (Mev)	This assignment requires	Conclusion
4.77	0^-	All	$A_4 = A_2 = 0$	N
	$1^{\pm}, 2^-$	4.0	$A_4 = 0$	N
	2^+	$\left\{ \begin{array}{l} 4.0 \\ 0.7 \end{array} \right.$	$I_{\gamma}(2)/I_{\gamma}(1) = 1.8$	P
			$A_4 \approx A_2 \approx 0$	P
	3^-	4.0	$A_4 = -0.56, A_2 = 1.33$	N
	3^+	$\left\{ \begin{array}{l} 4.0 \\ 0.7 \end{array} \right.$	$I_{\alpha}(4)/I_{\alpha}(2) = 0.92$	P
			$A_4 \approx A_2 \approx 0$	P
5.11	0^-	All	$A_4 = A_2 = 0$	N
	$1^{\pm}$	5.1	$A_2 \geq -0.10$	N
	2^-	5.1	$A_2 \geq -0.18$	N
	2^+	5.1	$I_{\gamma}(2)/I_{\gamma}(1) = 0.06 \text{ or } \infty$	P
	3^-	5.1	$A_4 = 0, A_2 = 0.70$	N
	3^+	5.1	$I_{\alpha}(4)/I_{\alpha}(2) \approx 1$	U
	4^-	5.1	$A_2 \leq -0.39$	P
5.16	0^-	All	$A_4 = A_2 = 0$	N
	1^-	$\left\{ \begin{array}{l} 5.2 \\ 4.4, 3.0 \end{array} \right.$	$A_4 = 0, A_2 = -0.10$	U
			$A_4 = 0, A_2 = -0.33$	P

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B^{10} level (Mev)	Assign- ment	γ -Ray (Mev)	This assignment requires	Conclusion
	1^+	5.2, 4.4, 3.0	$I_a(2)/I_a(0) \approx 1.5$	P
	2^-	$\begin{cases} 5.2 \\ 4.4, 3.0 \end{cases}$	$A_4 = 0, A_2 < -0.05$	U
			$I_a(3)/I_a(1) > 0.50$	P
	2^+	$\begin{cases} 5.2 \\ 4.4, 3.0 \end{cases}$	$I_Y(2)/I_Y(1) = 0.02 \text{ or } 9$	P
			$I_Y(2)/I_Y(1) = 0.01 \text{ or } 150$	P
	3^-	$\begin{cases} 5.2 \\ 4.4, 3.0 \end{cases}$	$A_4 = 0, A_2 = 0.70$	N
			$A_4 = -0.54, A_2 = 1.33$	N
	3^+	$\begin{cases} 5.2 \\ 4.4, 3.0 \end{cases}$	$I_Y(2)/I_Y(1) = 0.16$	P
			$A_4 + A_2 > 0.75$	N
5.91	0^-	5.9	$A_4 = A_2 = 0$	P
	1^-	5.9	$A_4 = 0, A_2 = -0.10$	P
	1^+	5.9	$0 \leq I_a(2)/I_a(0) \leq 1$	P
	2^-	5.9	$I_a(3)/I_a(1) > 0.15$	P
	2^+	5.9	$I_Y(2)/I_Y(1) \approx 10 \text{ or } 0.01$	P
	3^-	5.9	$A_4 = 0, A_2 = 0.70$	N
	3^+	5.9	$I_Y(2)/I_Y(1) \approx 0.16$	P
	4^-	5.9	$A_2 \leq -0.39$	N
	4^+	5.9	$I_Y(2)/I_Y(1) \approx 0.04$	P
6.02	0^-	6.0	$A_4 = A_2 = 0$	N
	$1^\pm, 2^-$	6.0	$A_4 = 0$	N
	2^+	6.0	$A_4 + A_2 < 0.50$	N
	3^-	6.0	$A_4 = 0, A_2 = 0.70$	N
	3^+	6.0	$A_4 \leq 0.80$	N
	4^-	6.0	$A_4 = 0$	N
	4^+	6.0	$I_Y(2)/I_Y(1) = 9.0$	P

22-6 Scattering of Charged Particles (5220)
 Jan Yntema

The construction and installation of the scattering chamber is now complete. The remote control equipment and TV cameras are now operating.

24-6 The Decay of Sn^{123} (125 days) (5220)
 Bradley Burson and Loren C. Schmid
 Reported by Bradley Burson

New samples of enriched isotopes of tin have been obtained from Oak Ridge National Laboratory. After irradiation in CP-5 for 17 days, a sample of enriched Sn^{122} was allowed to "cool" for 14 days and then subjected to chemical purification to remove traces of antimony.

The gamma rays reported earlier are also seen in this source of Sn^{123} . In the earlier sample, the intensity of the peak at 1.08 Mev was approximately 0.8% of that of the 0.395-Mev peak from Sn^{113} . In the present sample the intensity of the 1.08-Mev peak is about 15% of that of the 0.395-Mev radiation. This enhancement is attributed to the greater degree of enrichment, of the new isotopes.

From the new gamma-ray spectrum, it is definitely evident that the radiation in the region of 0.60 Mev is complex. The intensity is still very low, but there appear to be two peaks representing gamma rays of 0.60 and 0.68 Mev respectively. These have intensities of 1.3% and 0.83% relative to the 0.395-Mev gamma ray. Because of the unreliability of the earlier data in this region, no effort to compare intensities is being made.

Seven of the tin isotopes were irradiated. The only source in which the 1.08-Mev peak appeared strongly was the activated Sn^{122} . This radiation persisted after chemical purification. It is therefore evident that at least one

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gamma ray is present in the decay of Sn^{123} . As has been mentioned, none have been reported to date.

We have definitely established that the 0.255-Mev gamma ray discussed earlier in this study is associated with the decay of Sn^{113} . These investigations will be discussed subsequently under a different heading —The Decay of Sn^{113} (112 days).

25-3 Angular-Distribution Measurements of Charged-Particle Reactions (5220)

Linwood L. Lee, Jr., and John P. Schiffer
Reported by John P. Schiffer

The $\text{B}^{11}(\alpha, p)\text{C}^{14}$ reaction has been studied with alpha-particle energies between 2 and 4 Mev. A target of highly enriched B^{11} was purchased for this purpose from the Atomic Energy Research Establishment at Harwell. Several of the resonances observed in the $\text{B}^{11}(\alpha, n)\text{N}^{14}$ reaction¹ were seen. The prominent resonance seen in the (α, n) reaction at 2.06 Mev was reported as entirely absent in the (α, p) yield in the work of Shire and Edge.² Our experiment is in disagreement with these measurements in that we very clearly observe this resonance with a cross section that seems considerably larger than the limits set in the earlier work. The single resonance reported in the (α, n) work at 2.60 Mev was observed as a doublet in the present work.

About twenty angular distributions, covering several of the observed resonances, have been measured. An analysis in terms of Legendre polynomials is planned in order to assign J-values to the corresponding states in N^{15} .

A paper on the $\text{Ca}^{40}(d, p)\text{Ca}^{41}$ reaction has been submitted to the Physical Review and will be published in the September 1 issue.

¹ Bonner, Kraus, Marion, and Schiffer, Phys. Rev. 102, 1348 (1956).

² E. S. Shire and R. D. Edge, Phil. Mag. 46, 640 (1955).

26-3

Measurement of Proton Strength Functions

(5220)

Linwood L. Lee, Jr., and John P. Schiffer

Reported by John P. Schiffer

The complex-potential model of the nucleus¹ has been successful in explaining the variation with atomic weight of the neutron strength function² (the average reduced partial width of nuclear energy levels divided by their spacing). A maximum in the S-wave neutron strength function is well established at $A \approx 55$. A previous search from $A = 44$ to $A = 64$ revealed no corresponding maximum in the S-wave proton strength function.³ We have extended these measurements using a different technique and find a maximum at $A \approx 75$. Independently of our work, Weisskopf and Margolis⁴ have found that adding a Coulomb correction to an intrinsic proton potential well, which differs in depth only very slightly from that used for neutrons, shifts this maximum from $A \approx 55$ to about 70.

The yield from (p,n) reactions has been used to obtain proton strength functions for $37 \leq A \leq 133$. The quantity calculated is defined by

$$\left\langle (\gamma^2)_{Av} / \bar{D} \right\rangle_{Av} \equiv Y_{\text{thick}} \left\{ 4\pi^2 \sum_l \left[(2l+1) \int_{E_0}^E S \kappa P_l dE \right] \right\}^{-1}.$$

Here Y_{thick} is the yield from a target thick compared to the range of the incident protons, l is the angular momentum of the incident protons, E_0 is the threshold energy, S is the reciprocal of the stopping power in atoms

¹ Feshbach, Porter, and Weisskopf, Phys. Rev. 96, 448 (1954).

² R. Cote and L. M. Bollinger, Phys. Rev. 98, 1162A (1955);

³ Carter, Harvey, and Hughes, Phys. Rev. 96, 113 (1954);

Karriker, Marshak, and Newson, Bull. Am. Phys. Soc. 2, 33 (1957).

³ Schiffer, Davis and Prosser, Bull. Am. Phys. Soc. 2, 60 (1957).

⁴ B. Margolis and V. F. Weisskopf, Phys. Rev. (to be published).

$\text{cm}^{-2} \text{Mev}^{-1}$, $2\pi\lambda$ is the wavelength of the protons, and $P_l = 1/A_l^2$ is their Coulomb penetrability. Measurements on thick targets of twenty-eight elements were made using proton energies up to 4 Mev from the Argonne Van de Graaff accelerator. The "long counter" employed was calibrated

Fig. 8. Graph of $\langle (\gamma^2)_{Av} / \bar{D} \rangle_{Av}$ vs atomic weight of target nuclide. The several points at one value of A indicate determinations at several bombarding energies.

Fig. 9. Graph of $\langle (\gamma^2)_{Av} / \bar{D} \rangle_{Av}$ vs X as defined in the figure. $\bar{D} = Ze^2/R$ is the barrier height. The same type of symbols represent determinations at different bombarding energies but for the same target nuclide. The symbols are repeated for every fourth target element used.

against a standard RaBe source.

Figure 8 shows the results of these measurements. The peak at $A \approx 70$ (or ≈ 75 if a correction is added for the incident proton energies) is in agreement with the calculated prediction for an S-wave maximum.

Figure 9 shows the data with the Coulomb correction included in the abscissa. A nuclear radius of $1.45 \times 10^{-13} A^{1/3} \text{ cm}$ was used here as well as in the penetrability calculations. A charge distribution of constant density and a radius of $1.20 \times 10^{-13} A^{1/3} \text{ cm}$ was assumed in computing the Coulomb correction to a 44-Mev intrinsic potential by using the WKB approximation. These assumptions are more or less equivalent to those of reference 4. The curve was calculated by assuming a resonant S-wave strength function¹ and a "black nucleus" strength function for P- and D-wave protons, but neglecting higher ℓ -values. It is not quite clear whether or not the slight indications

of peaks at $A \approx 55$ and ≈ 110 and an increase at $A \approx 130$ could be interpreted as maxima in the strength functions for protons with higher angular momenta.

It is estimated that the strength functions are accurate to better than 50% and that the relative accuracy for most of them is better than 25%. After allowing for these uncertainties, the evidence for a maximum at $A \approx 75$ is good. The agreement with the independent predictions based on the complex-potential model seems excellent. It would appear that, within the accuracy of the assumptions on which the calculations are based, the proton and the neutron potentials are equal in depth provided the same radii are taken for both.

Values of the Coulomb penetrability functions have been computed recently on the IBM 650 and will be used to obtain more accurate values of the strength function. It is also planned to study the interpretation of the data in terms of a Saxon potential instead of the square well. The feasibility of such calculations is being investigated. An extension of the measurements to higher energies for nuclei in the region $90 \leq A \leq 150$ is planned in the near future in the hope of observing the expected P-wave maximum.

A Letter to the Editor reporting on these results has been submitted to the Physical Review and will be published in the July 15 issue.

28-1 Angular Correlations in Charged-Particle Reactions (5220)

T. H. Braid

Preparations are being made to measure particle-gamma angular correlations in reactions initiated by particles from the 60-in. cyclotron—particularly in the case of inelastic proton scattering at 10 Mev. Electronic equipment is still being built and tested.

33-2

The Decay of ${}_{26}\text{Fe}^{52}$ (8 hours)

(5220)

Bradley Burson and Loren C. Schmid
Reported by Bradley Burson

This project has been inactive during the past quarter. Since no further work can be done until sources become available again, reporting will be suspended temporarily.

35-3

The Decay of 9-Hour Eu^{152}

(5220)

Bradley Burson and Loren C. Schmid
Reported by Loren C. Schmid

Seven internal-conversion-electron lines were observed for this activity in the photographic magnetic spectrographs. From the data on the work functions, five of them are interpreted as K, L_2 , L_3 , M, and N lines for a 122.1-kev transition following K-capture from europium. The difference between the K and L work functions for the remaining two lines is characteristic of gadolinium. They thus represent a transition of 345.1 kev following beta decay.

An analysis of the beta-ray spectrum in the 180° beta-ray spectrometer is planned for the future.

52-15

Gamma Rays from Fission Induced by Thermal Neutrons (5220)

Charles M. Huddleston and Carroll C. Trail
Reported by Charles M. Huddleston

Work is continuing with the new experimental arrangement consisting of a fission counter and three gamma-ray counters. Since the pile was not operating during much of the past quarter, the present series of measurements has not been completed. Preliminary results with the new gamma-ray counter, however, indicate a confirmation of our earlier findings; i. e., the angular correlation between gamma rays and fission fragments shows that the

gamma rays from fission of U^{235} are emitted preferentially in the same direction as the light fission fragment.

55-7 Capture Gamma-Ray Spectra for Neutrons with Energies
from 0.1 to 10 ev. (5220)

Bernard Hamermesh, Rauf Nasuhoglu, Sol Raboy,
Roy Ringo and Carroll C. Trail
Reported by Carroll C. Trail

The large shield for the scintillation counters is nearing completion. The containers for boron carbide and paraffin have been attached to the central lead shield. Four hundred pounds of boron carbide were used to fill the section between the lead and paraffin. The paraffin container will be filled soon.

A dry box containing a lathe and milling machine is now available. Both sodium iodide crystals will be packaged in the coming quarter.

56-6 Compton-Electron Magnetic Spectrometer for
Neutron-Capture Gamma Rays (5220)

Richard S. Preston

Preliminary designs for the spectrometer have been completed, and cost estimates are being prepared.

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60-15

7. 7-Meter Bent-Crystal Spectrometer

(5220)

Bernard Hamermesh and Robert K. Smither
Reported by Bernard Hamermesh

During the past quarter, studies have been made of the performance of the large quartz crystal (12 in. x 12 in.). The expected increase in the intensity of the diffracted beam over that obtained with the 4 in. x 6 in. crystal has been observed. In addition a study of the line widths of gamma rays has been carried out. Line widths of less than 10 seconds of arc have been found. This is to be compared with the value of 13 seconds obtained with the small crystal. Since the large crystal is 4 mm in thickness compared with 6 mm for the small crystal, the two are subject to different stresses when bent to the same radius. The line width apparently depends upon the applied stress.

In addition to the above studies, the automatic control of the spectrometer by the fringe counting system of the interferometer has been improved. Tests of long-term reliability are now in progress.

70-15

Measurements of Nuclear Moments by Angular Correlation (5220)

Victor Krohn and Sol Raboy
Reported by Victor Krohn

Because of concentration on work on the symmetry properties of neutron decay, this project is temporarily inactive.

80-15

Molecular Beam Studies

(5220)

William Childs, John Dalman and Leonard S. Goodman
Reported by William Childs

A considerable fraction of the present quarter was devoted to final adjustment of the new variable, permanent magnets, using a beam of

potassium atoms.

Several open-beam radioactive runs were made on 50-day $\text{In}^{114\text{m}}$, In produced by alpha bombardment of silver, and 14-hour Ga^{72} . In each case, the amount of activity collected was too small for data taking. Since the requirements of each experiment are somewhat different, it was decided to concentrate initially on the Ga^{72} , produced in CP-5 by neutron capture. Since the gallium can be more easily deflected than the indium in our apparatus, larger slits were inserted to increase the counting rate for the refocussed Ga^{72} .

AVIDAC calculations (of the Zeeman splitting of the hyperfine structure of the atomic $\text{P}_{\frac{3}{2}}$ state) were made for the stable gallium so that it could be used for field calibration. Resonances have been observed for the stable Ga^{69} and Ga^{71} . Measurements on the spin and magnetic moment of Ga^{72} are expected soon.

81-3	<u>Review Paper on Deposition of Atomic Beams</u>	(5230)
	Sol Wexler	

The final revision of the paper is being made.

90-15	<u>Cross Sections for 14-Mev Neutrons</u>	(5220)
	H. Casson, L. S. Goodman and L. A. Rayburn	
	Reported by H. Casson and L. A. Rayburn	

Further modifications have been made in the time-of-flight circuitry in order to improve the stability. Time resolutions (full width at half maximum) between 3 and 3.5 millimicroseconds are now obtained with excellent daily stability and with no maintenance time required in the last two months.

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Some time has been spent redesigning the flange on the ion bottle in an effort to decrease the time spent in the periodic replacement of the tip through which ions leave the ion bottle. A new tip and clean ion bottle must be installed about every six weeks.

ANGULAR DISTRIBUTION OF ELASTICALLY SCATTERED 14-MEV NEUTRONS

Absolute differential elastic-scattering cross-section measurements have been made at 25 to 30 angular positions from 10° to 165° in the laboratory coordinate system for each of the following scatterers: Zn, Sn, and Sb. The previously reported¹ measurements on Pb and Bi are being extended to 165° . The results on Pb and Bi were reported at the Washington meeting of the American Physical Society.² An attempt is being made to fit these data using a complex square-well potential.³

INELASTIC SCATTERING OF 14-MEV NEUTRONS

Time-of-flight spectra of inelastically scattered neutrons have been obtained at several scattering angles for carbon and copper, using flight paths of 50 cm and 100 cm. The energy range covered was between about 1 and 14 Mev. The data are in process of evaluation and will be reported on in the next quarterly. It is expected that additional data on these and other elements (including aluminum and iron) will be obtained during the next quarter.

¹ ANL-5667, Report I-90-13, p. 40 and ANL-5698, Report I-90-14, p. 28.

² L. A. Rayburn, Bull. Am. Phys. Soc. 2, 233 (April 1957).

³ Feshbach, Porter and Weisskopf, Phys. Rev. 96, 448 (1954).

91-15

Neutron Transport Cross Sections; Angular Distribution
of Scattered Neutrons (5220)

Raymond O. Lane, Alexander S. Langsdorf, Jr., and
Kineo Tsukada
Reported by Alexander S. Langsdorf, Jr.

The earlier experimental results which were reported in the Topical Report ANL-5567 are now scheduled for publication in the Physical Review for August 15, 1957.

In this quarter new data were obtained on Li^6 and natural Li, nitrogen as Be_3N_2 , oxygen as BeO , and reruns were made on previously measured materials: Be, Cu, Sn, Pb, and U. These data were taken with about 100 kev resolution, from 100 kev to 2.3 Mev, at eight angles equally spaced from 23° to 144° . The data have not yet been analyzed.

In this new work the circular track (ANL-5609, page 55) and steering magnet (ANL-5667, page 41) were successfully used. In addition, a magnetic alternating-gradient lens was used to focus the proton beam at the lithium target. The lens worked very well so that over $20\mu\text{a}$ of beam was used, with essentially no available beam being wasted.

In the near future we expect to measure calcium and silicon. In the fall we hope to be able to measure Gd, Sm, and Ce. These should practically complete the survey phase of this program.

It is of considerable interest to measure the energy dependence of the efficiency of our neutron counters more accurately than it can be done by comparison with a "long counter". In the endeavor to do this calibration (relatively, not absolutely), we have measured the angular distribution of scattering by polyethylene. After corrections for plural scattering and scattering by carbon, any deviations in the apparent angular distribution of hydrogen from that predicted for isotropy in center-of-mass coordinates should be ascribable to the energy dependence of the counters. The correction

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calculations will be difficult. Except for this difficulty, the method seems to be a very attractive one for flux calibrations, especially in the difficult region from about 10 kev to 250 kev. It is very different from methods being tried elsewhere.

98-14 Total Neutron Cross Sections in the Kev Region (5220)
Carl T. Hibdon

Erratum

Equation (4) on page 45 of ANL 5667 (Physics Summary Report, September-December, 1956) should read

$$Y = \pm \sqrt{\frac{\sigma_s - \sigma_{\min}}{(\sigma_m - \sigma_{\min}) - (\sigma_s - \sigma_{\min})(E/E_m)}} \left| E - E_m \right|$$

Resonances with Al²⁷

The complete list of the neutron resonances found with Al²⁷ in the region from 0 to 415 kev is given in Table V. The values for levels in Al²⁸ are obtained by multiplying the observed resonance energies by 27/(27 + 1) to correct them to values for the center-of-mass system and then adding 7.722 Mev, the energy of Al²⁸ formed by capture of neutrons of negligible kinetic energy.

TABLE V. Resonance energies of $\text{Al}^{27} + n$ and corresponding energy levels of Al^{28} .

E_r (kev)	Energy levels of Al^{28} (Mev)	E_r (kev)	Energy levels of Al^{28} (Mev)	E_r (kev)	Energy levels of Al^{28} (Mev)
35.3	7.756	208.5	7.921	308	8.019
84.5	7.803	212	7.926	310	8.021
87	7.806	216	7.930	311.8	8.022
89.5	7.808	223	7.937	316	8.027
89.8	7.809	229	7.943	344	8.053
120	7.837	233	7.947	366	8.075
140	7.856	257	7.970	370	8.079
143.5	7.860	266	7.978	374	8.082
149	7.866	271	7.983	384.8	8.093
152.5	7.869	278	7.990	395	8.103
158	7.874	283.5	7.995	404	8.111
178.5	7.894	288	8.000	407	8.114
182	7.897	294	8.005	410.5	8.118
190	7.905	300	8.011		
205	7.920	306	8.017		

Only a few of the resonances are sufficiently well isolated for it to be possible to get accurate values of their parameters. They occur mostly in clusters. It is possible to make plausible assumptions as to J values and widths that will be in accord with the observed results, but not unambiguously enough for such results to be of much significance.

The following conclusions, however, appear to be justified.

(1) Many of the 34 observed peaks must be other than s-wave resonances, i. e., must have ℓ values greater than 0. Since I for Al^{27} is $3/2$, the possible J values for $\ell = 0$ are 2 and 3. If the resonances were all of one or the other of these two types, frequent deep interference minima would have to occur between adjacent resonances having the same values of J . No indications of the expectable minima are found. Also, several resonance peaks that stand above the background (notably, the ones at 120, 158 and 257 kev) do not show the asymmetry characteristic of resonances for which $\ell = 0$.

(2) The well isolated resonance at 35.3 kev clearly shows the interference dip and asymmetry of an s-wave resonance. The peak cross-section, especially that observed using self-detection, indicates that $J = 3$, although $J = 2$ has not been ruled out conclusively. Assuming that $J = 3$, analysis by the method discussed in ANL-5567, p. 44, shows that $\Gamma = 2.05$ kev.

(3) The resonance at 120 kev is sufficiently well isolated that one can be reasonably sure from its lack of marked asymmetry that it is not an s-wave resonance. The measured peak cross section is 10.3 barns above the background, and does not increase appreciably with self-detection. The expectable values for $J = 2$ and $J = 3$ at this energy are 11.8 and 15.8 barns, respectively, so $J = 2$ seems to be the more likely value. The width is close to 3 kev. The corresponding reduced width is well below the Wigner limit for $\ell = 1$, but twice that for $\ell = 2$. For this level, then, it is likely that $J = 2$ and $\ell = 1$.

A paper on this work is being prepared.

102-9

Neutron Cross Section Measurements by the Self-Indication
Technique (5220)

F. P. Mooring, J. E. Monahan, A. Langsdorf, Jr.,
and C. W. Kimball

Reported by C. W. Kimball

The measured self-indication cross section is defined as

$$\sigma^s = - \frac{1}{N} \ln \left(\frac{\int e^{-N\sigma(E)} (1 - e^{-M\sigma(E)}) R(E) dE}{\int (1 - e^{-M\sigma(E)}) R(E) dE} \right),$$

where σ^s = measured apparent self-indication cross section,

$\sigma(E)$ = true total cross section,

N = atoms/cm² of transmission sample,

M = atoms/cm² of detection sample,

$R(E)$ = product of the distribution function of the neutron spectrum
and the efficiency of the detection system.

The true total cross section may be expressed as

$$\sigma(E) = \sigma_a (1 + \delta(E)) ,$$

where $\delta(E)$ expresses the energy dependence of the cross section and σ_a is the average cross section. The moments of $\delta(E)$ are

$$\langle \delta^j \rangle = \frac{\int \delta^j R dE}{\int R dE} , \quad j = 1, 2, \dots ,$$

so that σ_a is defined by the condition $\langle \delta \rangle = 0$. An expression for the self-indication cross section in terms of the moments of the energy-dependent part of the true total cross section has been published¹ in the form

¹

J. E. Monahan and A. Langsdorf, Jr., Phys. Rev. 98A, 1147, (1955).

- 42

$$\sigma^s = \sigma_a - \left[\frac{N}{2} - \frac{M}{e^{M\sigma_{a-1}}} \right] \sigma_a^2 \langle \delta^2 \rangle + \left[\frac{N^2}{6} - \frac{M}{2} \frac{(M+N)}{e^{M\sigma_{a-1}}} \right] \sigma_a^3 \langle \delta^3 \rangle + \dots$$

Application of a numerical method² to the data obtained from preliminary experiments³ on Zr indicates that the moment $\langle \delta^2 \rangle$ may be of the same order of magnitude as $\langle \delta^3 \rangle$. When σ^s is expressed in powers of $n \equiv N\sigma_a$ and terms are kept to the order of $\langle \delta^2 \rangle^2$, the series becomes

$$\begin{aligned} \frac{\sigma^s}{\sigma_a} = & 1 + a \langle \delta^2 \rangle - \left[\frac{1}{2} \langle \delta^2 \rangle + a \left(\frac{r}{2} + \frac{1}{2} \right) \langle \delta^3 \rangle \right. \\ & \left. - a^2 \left(\frac{r}{2} + \frac{1}{2} \right) \langle \delta^2 \rangle^2 \right] n \\ & - \left[-\frac{1}{6} \langle \delta^3 \rangle + a \left(\frac{r}{4} + \frac{1}{2} \right) \langle \delta^2 \rangle^2 \right] n^2 \\ & + \frac{1}{8} \langle \delta^2 \rangle^2 n^3 + \dots, \end{aligned}$$

where

$$r = \frac{m}{n} = \frac{M\sigma_a}{N\sigma_a},$$

and

$$a = \frac{m}{e^{m-1}}.$$

2

J. E. Monahan, A Statistical Analysis of Angular Distribution Data (unpublished).

3

A. Langsdorf, Jr., Physics Division Quarterly Report, ANL-5317, p. 43 (unpublished).

It can be seen from the latter form of the series that $\langle \delta^2 \rangle^2$ must be considered to obtain $\langle \delta^3 \rangle$. If $\langle \delta^3 \rangle$ can be evaluated, the resonance parameters can be obtained for an isolated resonance.⁴

Experiments using the self-indication technique are being planned using equipment specially designed for these measurements.⁵ The elements whose cross sections are to be investigated have been chosen on the basis of measurements of the total and scattering cross section by A. Langsdorf, Jr., R. O. Lane, and J. E. Monahan.⁶

⁴ Langsdorf, Monahan, and Mooring, Phys. Rev. 98A, 1148, (1955).

⁵ F. Paul Mooring, Report I-16-6 in this Summary Report.

⁶ Langsdorf, Lane, and Monahan, (to be published).

108-9

An He³ Neutron Spectrometer

(5220)

Frank J. Lynch

1. DETECTOR USING A CERAMIC-TO-METAL
BRAZED INSULATOR ASSEMBLY

Several leaks which developed in welds and seals in the vacuum furnace were located and sealed. Cooling coils were brazed to the outside of the furnace to keep the neoprene and silicone gaskets cool. The furnace has proved satisfactory up to 1300°C. Provision has been made to admit pure H₂ into the furnace by passing electrolytic H₂ through a DeOxo purifier unit (palladium-catalyst) to remove O₂ and Linde molecular sieves (synthetic zeolite) to remove H₂O. For safety reasons, H₂ pressures in the furnace are limited to 3 cm Hg.

Tests were conducted to investigate the bonding of various

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brazing metals to Frenchtown high-alumina ceramic, using Ti and Zr as active metals. Brazing metals tried were Ag, Cu, BT solder (Ag-Cu eutectic), and Au, in the forms of powder, wire and sheet. Successful bonding was obtained with all metals except Au. Both TiH_2 and ZrH_2 were satisfactory as active metals, but TiH_2 appeared to give somewhat more consistent results. A mixture of 90% powdered BT solder and 10% powdered TiH_2 with Zapon lacquer as binder gave very good results. BT wire with an 8% Ti core was at least as good. The processing consisted of baking out and evacuating at $300-400^{\circ}C$, then firing 5 - 10 minutes at $1000^{\circ}C$. Oxidation was reduced by admitting H_2 when the oven had cooled to $600^{\circ}C$. When Cu is used, it must be oxygen free. When powdered Cu is used, it is first reduced in H_2 at about $400^{\circ}C$. Firing in H_2 was not successful.

The jigs used to hold the parts in alignment have been redesigned. One satisfactory seal has been constructed, and another is nearly completed.

110-2 Storage of Pulse-Height Data on Magnetic Tape (5220)

James B. Baumgardner and Frank J. Lynch
Reported by James B. Baumgardner

Work with the Ampex model 500 tape recorder has been abandoned, owing to the difficulties anticipated in obtaining and maintaining the performance characteristics required for this work. A new tape-transport mechanism has been designed and shop work for this unit essentially completed. The machine is being wired and assembled, after which a study will be made to evaluate the various methods of recording pulse-height data; i. e., direct, FM, and digital. It is believed that several of these methods will find application, depending on the widely differing requirements in recording data.

117-4

Measurement of Neutron Half-Life Using a Diffusion Cloud Chamber (5220)

H. Bryant, G. Caglioti, N. D'Angelo and C. M. Huddleston

Reported by G. Caglioti and N. D'Angelo

The details of the construction of the cloud chamber have been described in Topical Report ANL-5745 and a shorter paper describing its novel features has been submitted for publication.

121-2

Spin-Momentum Correlation in the Beta Decay of Polarized Li^8 Nuclei (5220)

M. T. Burgy, W. C. Davidon, T. B. Novey, G. J. Perlow, and G. R. Ringo

Since the time and equipment needed to continue this project are being used by the experiment on the symmetry properties of neutron decay, this work is temporarily inactive.

123-2

The Symmetry Properties of Neutron Decay (5220)

M. T. Burgy, R. J. Epstein (Electronics Division), T. B. Novey (Chem. Div.), S. Raboy, G. R. Ringo and V. L. Telegdi (U. of Chicago)

Since the neutron is one of the simplest entities showing beta-emission, the symmetry properties of the decay of the neutron are clearly

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of interest in connection with the recent advances^{1,2,3} in our knowledge of the character of beta decay. In an attempt to improve the understanding of the nature of the neutron's beta decay, we have measured the relative probability of beta-emission by the neutron in the directions respectively parallel and antiparallel to the spin of the neutron.

This measurement was made with the arrangement shown in outline in Fig. 10. The neutrons measured were in a thermal beam taken

Fig. 10. Horizontal section through the apparatus used in detecting the decay of polarized neutrons. The section is taken at the level of the center of the beam. The angle between the beam and the mirror is greatly exaggerated for clarity.

- ¹ Wu, Ambler, Hayward, Hoppes and Hudson, Phys. Rev. 105, 1413 (1957).
- ² Garwin, Lederman and Weinrich, Phys. Rev. 105, 1415 (1957).
- ³ J. L. Friedman and V. L. Telegdi, Phys. Rev. 105, 1681 (1957).

from the Argonne Research Reactor, CP-5, through a hole 85-3/4 in. long, 1/4 in. wide, and 8 in. high. This beam was polarized by reflection from a 5 in. high mirror of 95% Co and 5% Fe magnetized in a vertical direction by a field of about 250 oersteds.⁴ At a grazing angle of about 8 minutes the reflected beam contained a total of 7×10^7 neutrons per sec and was $87 \pm 7\%$ polarized (as determined by using another cobalt mirror as an analyzer). To keep the neutrons in a definite vertical orientation, a vertical field of about 10 gauss was applied to the vacuum chamber in which the decays were observed. The lead shield in this chamber was made, in part, of an alloy including 0.5% by weight of lithium to minimize gamma rays from neutron capture. The gamma flux left after these shielding measures was less than 100 mr/hr in the beam.

Neutron decays were observed by coincidences between a beta detector and a proton detector. The beta detector was a plastic scintillator 0.21 in. thick and 5 in. in diameter. Pulses from the beta detector were accepted if they corresponded to an energy loss of 110 to 610 kev. The protons were detected by the method used by Robson⁵ and by Snell, Pleasonton and McCord,⁶ in which the protons are accelerated to about 12 kev in a system that focuses them on the cathode of an electron multiplier. In our case the cathode was an ellipse of Be-Cu 5 in. long by 4 in. high, activated in place by heating to a dull red heat by electron-bombardment.⁷ The remainder of the electron multiplier was an uncesiated dynode structure from a Dumont 6292 photomultiplier. Amplified pulses from the beta and proton detectors were fed through pulse-height analyzers into a coincidence circuit

⁴ M. Hamermesh, Phys. Rev. 75, 1766 (1949);
D. J. Hughes and M. T. Burgy, Phys. Rev. 81, 498 (1951).
⁵ J. M. Robson, Phys. Rev. 83, 349 (1951).
⁶ Snell, Pleasonton, and McCord, Phys. Rev. 78, 310 (1950).
⁷ J. M. Robson, Rev. Sci. Instr. 19, 865 (1948).

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in which a coincidence pulse was produced if (a) both proton and beta pulses were of appropriate size and (b) the proton pulse arrived between 0.2 and 1.8 μ sec after the beta pulse. Moreover, the output of the coincidence circuit was a pulse of a size which was dependent on the delay. This pulse was fed to a 20-channel pulse-height analyzer which thus gave a display of the number of coincidences vs the time following the beta pulse (up to 1.8 μ sec). In this display the neutron decays showed quite clearly as a peak near 1 μ sec delay—the time of flight to the proton counter. About 0.15 coincidence counts per minute were obtained in a typical measurement.

Measurements were made with neutrons polarized straight up and straight down and with and without a steel shim 0.010 in. thick placed at the entrance to the vacuum chamber. This shim completely depolarizes a beam of thermal neutrons and thus gives a null measurement for both field directions. The result was as follows:

$$\frac{\text{Intensity parallel to neutron spin}}{\text{Intensity antiparallel to neutron spin}} = 0.62 \pm 0.10.$$

When corrected for the solid angle of the beta detector and for the imperfections of the polarization (the mean beta velocity, $\langle v/c \rangle$, is taken as 0.80) and expressed in the usual way, the angular distribution relative to the neutron spin direction becomes

$$W(\theta) = 1 - (0.37 \pm 0.11)(v/c) \cos \theta.$$

The error given in this result is almost entirely due to the statistical fluctuations in the measurements. The estimated uncertainties in the corrections make a very small contribution.

In view of the developments referred to earlier^{1,2,3} the beta decay of the neutron is to be described by 8 parameters (some or all of which may be complex if time-reversal invariance fails). It may be of interest,

however, to compare the present result with the predictions of some simplified variants of the general theory which have been proposed.

(1) Two-component neutrino theory ⁸	-0.08 or -1.00
(2) Twin-neutrino theory ^{9, 10}	-0.54
(3) Parity conservation in Fermi interactions ¹¹	-0.22 or -0.87

In all these predictions it is assumed that

$$x^2 \equiv \frac{\text{sum of squares of G - T coupling constants}}{\text{sum of squares of Fermi coupling constants}} = 1.32.$$

In the predictions giving two values of the coefficient, the first corresponds to $x < 0$ and the second to $x > 0$. It should be noted that in the event of failure of time-reversal invariance, the GT-F interference term in the two-component neutrino theory might be reduced to make the theory consistent with the present measurement.

A report on this work has been submitted for publication.

⁸ T. D. Lee and C. N. Yang, Phys. Rev. 105, 1671 (1956). See also L. Landau, Nuclear Phys. 3, 127 (1957) and A. Salam, Nuovo cimento, 5, 299 (1957).

⁹ M. A. Preston, Can. J. Physics (in press).

¹⁰ M. G. Mayer and V. L. Telegdi, Phys. Rev. (in press).

¹¹ Alder, Stech and Winther, University of Illinois, unpublished report.

125-1 Polarization of Positrons Demonstrated by Annihilation
in Magnetized Materials (5220)

S. S. Hanna and R. S. Preston
Reported by R. S. Preston

I. ANNIHILATION IN IRON

In studies of the conservation of parity in weak interactions,¹

¹ T. D. Lee and C. N. Yang, Phys. Rev. 104, 254 (1956).

50

the longitudinal polarization of beta particles from unpolarized sources has been measured by several methods.²⁻⁵ In the present investigation a method has been developed for measuring the polarization of positrons, and the polarization of positive beta particles from Cu^{64} has been observed.

A directed beam of positrons from a Cu^{64} source impinged on the end of a cylindrical sample 4 mm in diameter, and the two-quantum yield was detected with two NaI counters placed 180° apart and operated in coincidence. Appropriate shielding suppressed radiation from positrons annihilating anywhere but in the iron sample. The sample was mounted in a magnetic field which could be made either parallel or antiparallel to the direction of the positrons and hence to the presumed polarization.

One counter, at a distance of 290 cm, had an aperture of 9×10^{-6} steradians. The second counter, at a distance of 165 cm, was uncollimated and subtended an angle of 3×10^{-3} steradians. In order to observe the angular correlation of annihilation radiation, cylindrical lead absorbers of successively increasing diameters were inserted in front of, and coaxial with, the uncollimated counter. A measurement of the angular correlation for annihilation in copper, obtained with this technique, agreed satisfactorily with the result of Lang et al.⁶

A lead absorber was selected which effectively eclipsed the central cone (half-angle equals 8.5 milliradians) of the angular distribution for iron, allowing observation of the "wings" of the distribution corresponding to annihilation in the sample by electrons of high momentum. The yield so

² Frauenfelder, Bobone, von Goeler, Levine, Lewis, Peacock, Rossi, and De Pasquali, Phys. Rev. 106, 386 (1957).

³ Lorne A. Page and Milton Heinberg, Phys. Rev. 106, 1220 (1957).

⁴ Lorne A. Page and Felix E. Obenshain, Bull. Am. Phys. Soc. 2, 260 (1957).

⁵ Frauenfelder, Hanson, Levine, Rossi, and De Pasquali, Phys. Rev. (in press).

⁶ Lang, De Benedetti, and Smoluchowski, Phys. Rev. 99, 596 (1955).

obtained was normalized to the total intensity with the absorber removed. With fields producing saturation in the iron sample, this normalized yield N was consistently higher by $(5 \pm 1)\%$ when the field was parallel than when it was antiparallel to the direction of motion of the positrons. The effect vanished when a copper sample was used. Geometrical effects were investigated by reversing the direction of the positrons and the results were not significantly different. A further check on the experimental arrangement was obtained by performing the experiment with first one half and then the other half of the large counter covered with a lead shield. In both cases the same effect was obtained. The ratio N obtained for copper is higher than for iron, in agreement with reference 5.

A plausible explanation of the above result may be summarized as follows: (1) Positrons emitted from a Cu^{64} source (spin change $1 \rightarrow 0$) are partially polarized parallel to their direction of motion, i. e., opposite to the direction observed for negative electrons.¹ (2) At the time of their annihilation the positrons still retain a substantial amount of this polarization. (3) Annihilation in iron takes place predominantly in the region midway between nuclei where the d-electrons mainly responsible for ferromagnetism have higher momentum than the s-electrons. (4) Thus when the field is parallel (electron spin antiparallel) to the positron spin, two-quantum annihilation is enhanced in the high-momentum region of the angular correlation, and when the field is reversed it is diminished.

A report on this work has been published as a Letter to the Editor, Phys. Rev. 106, 1363-1364 (June 15, 1957).

II. ANNIHILATION IN MATERIALS OTHER THAN IRON

In further studies of the positrons from Cu^{64} , the samples in which the annihilation occurs have been made of materials other than iron. Also, it has been possible to filter out varying amounts of the low-energy part

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of the positron spectrum by inserting different thicknesses of aluminum foil between the Cu^{64} source and the sample. For all of the measurements, the magnetic field, the size of the sample, and the angle eclipsed by the Pb absorber were kept constant.

Table VI summarizes results obtained so far. Fe, Co and Ni are ferromagnetic in varying degrees. Cu is not ferromagnetic, and Gd is ferromagnetic at temperatures below the Curie point, 16°C . The different results among the ferromagnetic materials reflect not only the gross differences in ferromagnetic properties, but also differences in the details of the angular correlations of the annihilation photons. These details depend on the momentum distribution of the electrons which can be aligned in a magnetic field and which can annihilate with thermalized positrons.

TABLE VI. Values of $(N_+ - N_-)/N_-$ in percent, for various samples as a function of thickness of absorber.

Sample	Thickness of aluminum absorber (mils)				
	0	4	8	12	16
Co	5.4 ± 0.8	6.0 ± 1.0	9.4 ± 1.2	11 ± 1.9	11 ± 2.5
Fe(steel)	3.2 ± 1.0	6.0 ± 1.1			
Fe(Armco)			8.0 ± 1.4		
Ni	-0.3 ± 0.9	-0.1 ± 1.0			
Cu	0.5 ± 1.2		0.1 ± 1.2		
Gd ($T=20^{\circ}\text{C}$)			2.2 ± 2.9		
Gd($T=-180^{\circ}\text{C}$)			0.0 ± 0.6		

It is seen in the table that Co and Fe show the greatest effect. The less strongly ferromagnetic Ni and the completely non-ferromagnetic materials, Gd at room temperature and Cu, show little or no effect. Gd cooled to -180°C by liquid nitrogen is strongly ferromagnetic but no effect is observed, so that the behavior of its "magnetic" electrons must be quite different from that of the corresponding electrons in Co and Fe.

The polarization of the positrons at the time of annihilation is expected to be practically equal to v/c , the value at emission. The insertion of additional aluminum foils to absorb the slower positrons selects the positrons emitted at higher velocities. The corresponding increase in polarization with increasing thickness of aluminum foil was observed and is best illustrated in the table by the sequence with the cobalt sample.

138-4

Characteristics of Multiplier Phototubes

(5230)

Warren L. Buck and Robert K. Swank
Reported by Robert K. Swank

No further experimental work has been done. The results will be published as soon as the calibrated phototube is received and the few measurements remaining can be made.

139-7

Liquid Scintillators

(5230)

Warren L. Buck and Robert K. Swank
Reported by Warren L. Buck

Previous reports on this project have presented information on the relative scintillation efficiencies of various organic liquid

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solutions.^{1,2,3} While most of the solutions studied employed toluene as the solvent, a few solutions employing p-xylene, triethylbenzene, or phenylcyclohexane were included. On the basis of these studies it was concluded that toluene is the most generally useful solvent for liquid scintillators.

More recently an investigation has been made of scintillating solutions with isopropylbiphenyl as solvent. In view of the favorable performance of these solutions, it is felt that the possibilities of using this solvent should be brought to the attention of persons interested in counting with liquid scintillators.

The isopropylbiphenyl used in this study was obtained from Monsanto Chemical Company, St. Louis, Missouri, as a technical-grade mixture composed of approximately 62% meta- and 38% para- isopropylbiphenyl. The manufacturer states that the material has a boiling range of 295-300°C and a pour point of -54°C. It was vacuum-distilled twice before use, no attempt being made to separate the isomeric components.

Data on the variation of the output of scintillation light with the concentration of the solute were obtained for isopropylbiphenyl solutions of p-terphenyl (p-TP), diphenyloxazole (PPO), and phenylbiphenyl-oxadiazole (PBD) with both air-saturated and argon-bubbled solutions. The results, along with data on corresponding toluene solutions, are summarized in Table VII.

It is noted that while the argon-bubbled isopropylbiphenyl solutions have nearly the same efficiencies as the corresponding toluene

¹ Physics Division Summary Report, ANL-5554, pp. 76-95 (unpublished).

² Physics Division Summary Report, ANL-5609, pp. 67-75 (unpublished).

³ Physics Division Summary Report, ANL-5698, pp. 50-55 (unpublished).

solutions, the quenching effect resulting from dissolved oxygen is less in the isopropylbiphenyl solutions. Thus when air-saturated solutions are employed, the use of isopropylbiphenyl as solvent results in somewhat greater yields of photons, especially when PPO is used as the solute.

TABLE VII. Relative light outputs of some liquid scintillators.

Solvent	Solute (g/l)	Relative photon yield		Air: argon ratio
		air	argon	
Isopropylbiphenyl	p-TP (5)	1.03	1.29	0.80
	PPO (5)	0.95	1.10	0.86
	PBD (9)	1.05	1.21	0.87
Toluene	p-TP (5)	0.98	1.29	0.76
	PPO (5)	0.82	1.08	0.76
	PBD (10)	1.00	1.23	0.81

Determinations of the quenching resulting from addition of diphenylmercury revealed that this effect also is less severe in isopropylbiphenyl solutions than in the corresponding toluene solutions. For example, addition of only 9 g/l diphenylmercury to a toluene solution containing 5 g/l PPO produces a 50% reduction in photon yield, while 38 g/l of the mercury compound are required to achieve the same degree of quenching of the light output with the corresponding isopropylbiphenyl solution. This apparently greater immunity of isopropylbiphenyl solutions to quenching effects is considered to warrant further study.

At room temperature isopropylbiphenyl has a density $\approx 13\%$ greater than that of toluene. The resulting increased density of atomic electrons in isopropylbiphenyl solutions should give a significantly larger

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cross section for the Compton scattering process. This fact, together with the possibility that significant amounts of mercury or other heavy elements can be incorporated in isopropylbiphenyl solutions without causing prohibitively great quenching, should be of interest to those concerned with the application of liquid scintillators to the detection of gamma rays.

Experience has shown that a serious fire hazard may result from the use of large volumes of liquid scintillators. In this respect isopropylbiphenyl offers an advantage in that it has a relatively high flash point of 139°C (compared with 5°C for toluene and 25°C for p-xylene) and very low volatility at room temperature. During an experiment conducted to determine relative rates of loss by evaporation at room temperature, a sample of isopropylbiphenyl suffered less than 0.1% loss while similar samples of toluene and p-xylene showed losses of 52% and 20% respectively. The low volatility of isopropylbiphenyl should contribute both to the safety and to the convenience of its use.

It is noted that when cooled to the temperature of dry-ice isopropylbiphenyl is a transparent glassy solid, whereas toluene remains a liquid and p-xylene freezes as a multicrystalline mass. Possible ways of exploiting this behavior of isopropylbiphenyl at low temperatures in connection with scintillation counting have been suggested but have not yet been investigated experimentally.

142-9

Electron Accelerator

(5220)

Robert K. Swank

The testing of this device has been completed. The original design and construction of the electron accelerator and the pulsing circuits were completed about one year ago by Dr. H. B. Phillips. Since then the

present author has been responsible for the development of the detection equipment and the testing of the complete system. Although further improvements in the system are feasible, and will undoubtedly be made in the future, it appears that the present performance of the machine is good enough to permit accurate measurements of nearly all known scintillators. The performance of the system at the present time is outlined below:

A. Electron accelerator

1. maximum electron energy = 100 kev
2. peak current = $10 \mu\text{a}$
3. minimum pulse width = 10^{-10} sec
4. thickness of window = 0.000 07 inch (nickel)
5. energy in pulse of minimum length $\sim 10^9 \text{ ev.}$
6. estimated energy loss in window $\sim 50\%$
7. rate of energy dissipation in scintillator = $5000 \text{ Mev/m}\mu\text{sec}$

B. Detector

1. photomultiplier - 1P28
2. optical efficiency $\sim 5\%$
3. spread of transit lines in multiplier
(standard deviation) $\sim 0.3 \text{ m}\mu\text{sec}$
4. time constant (RC) of anode circuit $\sim 0.7 \text{ m}\mu\text{sec}$
5. rise time of pulse in cable - $< 0.1 \text{ m}\mu\text{sec}$
6. rise time of oscilloscope $\sim 0.2 \text{ m}\mu\text{sec}$

The time response of the whole system exclusive of the scintillator is essentially that of the anode circuit of the photomultiplier. Under these circumstances, mean lifetimes $\geq 1.4 \text{ m}\mu\text{sec}$ can be measured with considerable accuracy, and those down to $1.0 \text{ m}\mu\text{sec}$ can be measured to an accuracy of $\sim 10\%$. Preliminary measurements indicate that the commonly-used scintillators have mean lifetimes greater than $2.0 \text{ m}\mu\text{sec}$. Reducing the time

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constant of the anode circuit would require construction of a special photomultiplier. Mere reduction of the load impedance below the present value of 75 ohms results in an underdamped response. Although the construction of a special photomultiplier is feasible, it is not expedient now for two reasons:

Fig. 11. Circuit diagram of detector circuit used with the electron accelerator. Resistances are in ohms and capacitances in microfarads; L_1 and L_2 are lengths of RG-63U cable with transit times of 20 μsec and 40 μsec respectively; H is a helix of the EG & G traveling-wave oscilloscope; PC is the photocathode; D_1 , D_2 , etc., are dynodes; and A is the seventh dynode used as the anode of the photomultiplier.

(1) The present performance of the system appears to be adequate for most work.

(2) The next improvement should be the radical step of making the measurement inside the phototube instead of bringing out an electrical signal. A brief study of several methods of doing this indicates that a time resolution of 10^{-11} to 10^{-10} sec may be achieved.

Since any basic changes in the system appear to be far in the future, the present project will be terminated with this report.

A diagram of the detector circuit is given in Fig. 11. Decay plots of two liquid scintillators are shown in Fig. 12.

Fig. 12. Decay of luminescence of two scintillating solutions of PBD in toluene after excitation by an impulse from the electron accelerator. In the upper curve, the decay of luminescence is dominated by energy transfer from solvent to solute, and in the lower curve, the decay is characteristic of the solute.

143-9

Plastic Scintillators

(5230)

Louis J. Basile

In a previous report¹ mention was made of some studies concerning the effect that the temperature of polymerization has on the light output of plastic scintillators. Results which were reported showed that samples which were polymerized at a higher temperature had a higher light output.

More recently Shimizu et al.² have published results on their studies on polystyrene-terphenyl scintillators. They investigated the efficiency of plastic scintillators as a function of the degree of polymerization. Samples of p-terphenyl-styrene solutions were poly-

¹

Physics Division Summary Report, ANL-5609, p. 81.

²

S. Shimizu, F. Hirayama, and S. Okamoto, Annual Report on the Research Application of Artificial Radioactive Isotopes in Japan, Vol. 3, (1956).

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merized at different temperatures, shorter heating times being used at higher temperatures. For example, at 190°C the samples were heated for a period of 4 hours, as compared to 8 days at 100°C . The degree of polymerization was obtained by viscosity measurements. Results show that for low solute concentrations, polymerizing the samples at a lower temperature produces a scintillator having a higher light output. Using their data, the authors propose a scheme of energy transfer which involves the polymer chain.

We have decided to investigate this problem more thoroughly. Tentative plans are to polymerize samples for different periods of time at each of several different temperatures. The average molecular weight of the polymerized samples will be determined by relative measurements of the viscosity of a solution of the polymer.

During the past quarter most of our efforts have been directed toward obtaining and calibrating the viscometric equipment. In preliminary work on one phase of the problem, samples of p-terphenylstyrene and PBD-styrene have been polymerized at 110°C . The duration of heating was varied from 50 to 200 hours. Results show that as the heating time increases, the light output increases and in some cases goes through a maximum. Samples polymerized for short times show marked crazing, indicating incomplete polymerization.

145-2

Handbook of Nuclear Instruments and Techniques

(5230)

R. K. Swank

A contribution was made on Chemical Dosimeters.

149-7

Dynamic Condenser Magnetometer

(5220)

Bradley Burson and Loren C. Schmid
Reported by Bradley Burson

As described in the previous report, the dynamic condenser was disassembled in order to rebuild the rotor sections. This was done (1) to increase the mechanical strength and (2) to improve the wave form. The work is complete and the instrument reassembled and restored to operation.

Each of the three rotor sections consists of eight plates. These were previously welded together by running a bead of aluminum along the hub connecting the plates and spacers together at their edges. Apart from the unsatisfactory outcome of this technique as evidenced by a broken weld, the method was not feasible with the new plate design. The new sections are pinned together by four stainless steel rods which pass through the plates and spacers, and are welded at the ends to the collets which are attached to each end of the section. Only experience in use will show the reliability of this particular choice of design.

Two changes were made in the shape of the plates themselves. To reduce fringing effects, the section near the shaft was extended to interleave slightly at all times with the stator plates. This change slightly increased the minimum value of the capacitance of the rotor to either stator in the "out" position, but removes the sharp discontinuity inherent in the earlier design. Further, a small error was found to have been made in the original function from which the shape of the plate was computed. A new template was made in order to rectify this error.

The results of the modifications have justified the effort of making them. The total harmonic content present in the output signal has been reduced by more than a factor of two. The total harmonic content is now less than 3% of the 30-cycle fundamental. Quantitative measurements were not

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made on the individual components, but from oscilloscope patterns, it is apparent that the 90-cycle component is still the prevalent constituent.

The beta-ray spectrometer is now being used and a number of spectra have been run. An attempt is being made to establish experimentally that the magnetometer controls the spectrometer in a linear fashion throughout its designed range.

An investigation of the Public Service Company's record and reputation has shown that deviations in frequency of the order of from 3 to 10 parts per ten thousand might occur. Since variations of this magnitude can appreciably influence the measurement of the intensities of internal conversion lines, a stabilized 60-cycle generator is being constructed to drive the synchronous motor.

As soon as the calibration is complete, the report will be submitted for publication.

II. MASS SPECTROSCOPY

18-7 Lead Ages of Meteorites (5220)

David C. Hess and Royal Marshall*
Reported by David C. Hess

Several samples of lead from meteorites have been measured. The most interesting data were expected from lead extracted from troilite, (sulfide phase) taken from the Toluca (iron) meteorite. It was hoped that this lead would represent primeval lead since it should have been separated from uranium and thorium compounds in the formation of the body. The results showed a large amount of lead, which appeared almost normal. Since there is much more lead than expected, it must be suspected that the sample was contaminated with ordinary lead at some time before its analysis.

* Enrico Fermi Institute of Nuclear Studies.

19-1 Measurement of Silver from the Troilite Phase of a Meteorite (5230)

David C. Hess and Royal Marshall*
Reported by David C. Hess

At the suggestion of Dr. H. C. Urey, silver was extracted from the troilite (sulfide phase) of the Toluca (iron) meteorite. If the original condensation and separation into the silicate, iron and sulfide phases took place within a few million years after nucleogenesis, a possible fractionation of Pd and Ag between these phases (e. g., Pd might be concentrated in the iron phase¹) could cause the ratio of Ag^{107} to Ag^{109} to vary from one phase

* Enrico Fermi Institute of Nuclear Studies

¹ E. Goldberg, A. Uchiyama and H. Brown, *Geochim. et Cosmochim. Acta* 2, 1 (1951).

64

to another as a result of the beta decay of Pd^{107} with a half-life of about 7×10^6 years.²

The yield of silver from 18.4 gm of troilite was no more than 30 micrograms. The silver dithizonate was converted to silver nitrate, part of the sample was placed on a tungsten filament and a small amount of boric acid was added. The filament was heated to dry the sample and the assembly was placed in the mass spectrometer.

The $\text{Ag}^{107}/\text{Ag}^{109}$ ratio observed agrees within experimental error with the ratio obtained from a sample of jeweler's silver.

² Parker, Creek, Herbert and Lantz reported by Hollander, Perlman and Seaborg, Revs. Modern Phys. 25, 469 (1953).

20-3 Tritium Age Measurements of Meteorites (5220)

Frederick Begemann,*† Johannes Geiss* and David C. Hess
Reported by David C. Hess

The work previously reported by F. Begemann, Johannes Geiss and D. C. Hess is scheduled for publication in the Physical Review, July 15, 1957. An abstract was given in earlier report.¹

Since the previous work was concerned with a single sample, it was felt that more recent meteorites should be studied if possible. A sample of a recent (1952) fall has become available but measurements have not yet been made on the sample.

* Enrico Fermi Institute of Nuclear Studies.

† Now at Physikalisches Institut, University of Bern.

¹ Physics Division Summary Report, ANL-5667, p. 71.

28-2 Kinetics of Chemical Reactions in the Gas Phase (5230)

Joseph Berkowitz* and William A. Chupka

Reported by William A. Chupka

No work has been done on this project pending delivery of a monochromator and construction of a more efficient source chamber for the mass spectrometer.

* University of Chicago.

29-9 Gaseous Species in Equilibrium at High Temperatures (5230)

Joseph Berkowitz,* William A. Chupka and Mark G. Inghram

Reported by William A. Chupka

The mass spectrometric technique described in previous reports¹ has been used in the study of the vaporization of beryllium oxide, uranium oxide and aluminum carbide.

I. BERYLLIUM OXIDE

A beryllium oxide crucible was placed inside a tantalum Knudsen cell and heated to temperatures up to about 2250°K. The effusing vapor, as analyzed by the mass spectrometer, was found to consist mostly of BeO molecules. The vapor pressure was measured to be about 4×10^{-8} atmos at 2223°K and the heat of vaporization was calculated to be $\Delta H_o^\circ = 167$ kcal/mole. This yields a dissociation energy of $D_o^\circ = 4.9$ ev for the BeO molecule.

II. URANIUM OXIDE

Uranium dioxide was vaporized from a tantalum Knudsen cell

* University of Chicago.

¹ W. A. Chupka and M. G. Inghram, J. Phys. Chem. 59, 100 (1955).

and the vapor was analyzed mass spectrometrically. At the beginning of the run the vapor consisted of about 70% UO_2 (g) and about 30% UO_3 (g). However, the intensity of the UO_3 decreased steadily with time by well over an order of magnitude. This behavior is explained by the fact that the uranium dioxide, as initially loaded into the crucible, contains excess oxygen corresponding approximately to the formula $\text{UO}_{2.02}$. As the sample is vaporized, the composition changes to give $\text{UO}_{2.00}$ which then further evaporates without change in composition. When the composition of the vapor had apparently become constant, a small amount of UO was also detected. A very crude equilibrium constant was measured for the reaction: $2\text{UO}_2(\text{g}) \rightarrow \text{UO}(\text{g}) + \text{UO}_3(\text{g})$. The entropy of the gaseous species was calculated from estimated molecular constants. The ΔH_0° of the above reaction was then calculated to be about +30 kcal/mole.

A search was made for higher polymers of UO_2 in the vapor. None was conclusively found and an upper limit of about 1 part in 10 million was set for the dimer, trimer and tetramer. This is in contradiction to the postulate of Ackerman, Gilles and Thorn² that a dimer U_2O_4 (g) forms a large fraction of the vapor at high temperatures. It appears possible to re-interpret their data in terms of appreciable amounts of UO , UO_3 and perhaps other species in the vapor.

The above data yield a crude value for the sum of the bond energies of UO and UO_3 . This value is about 27.5 ev. In the light of previous results with other molecules, we estimate that the bond energy of UO will be slightly greater than one-half that of UO_2 which is given as 14.4 ev by Ackerman, Gilles and Thorn. Thus, we estimate the dissociation energies of UO and UO_3 to be roughly 7.5 and 20.0 ev, respectively. Further work employing reducing and oxidizing conditions should allow accurate determination of these values.

²Ackerman, Gilles and Thorn, J. Chem. Phys. 25, 1089 (1956).

III. ALUMINUM CARBIDE

Mixtures of aluminum and carbon were evaporated from a Knudsen cell and the vapors were analyzed mass spectrometrically. The vapor consists predominantly of Al atoms with about 0.1% of Al_2C_2 molecules. A thermodynamic calculation based on our data for the reaction $\text{C(s)} + \text{Al(g)} \rightarrow 1/2 \text{Al}_2\text{C}_2(\text{g})$ yields $\Delta H^\circ_{\text{O}} = -16.5$ kcal/mole. Thermodynamic functions for $\text{Al}_2\text{C}_2(\text{g})$ were calculated assuming a linear AlC_2Al configuration and using estimated vibrational frequencies. Taking the heat of sublimation of C_2 as 190 kcal/mole, the energy of dissociation of Al_2C_2 into $2 \text{Al(g)} + \text{C}_2(\text{g})$ is calculated to be 223 kcal/mole. It is interesting to note the similar stability of the Al_2O molecule (atomization energy = 254 kcal/mole). This suggests a similarity of behavior between C_2 and O, analogous to the behavior of CN (with one more electron than C_2) as a pseudo-halogen. Since C_2 has a much higher electron affinity than C or C_3 one may expect C_2 to form more stable metal carbide molecules. Thus, our results suggest that where the activity of carbon is near unity, the most likely metal carbide molecules should be dicarbides.

34-13

$\text{A}^{40} - \text{K}^{40}$ Dating of Meteorites

(5220)

Peter Eberhardt,* Johannes Geiss*† and David C. Hess
Work Reported by David C. Hess

The work previously reported by two of us (Johannes Geiss and David C. Hess) has been submitted to the Astrophysical Journal for publication.

Some further work will be done separately and also in connection with the tritium dating problem.

* Fermi Institute for Nuclear Science.

† Now at Physikalisches Institut, Univ. of Bern.

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38-5 Mass Spectrometric Study of Charged Atomic and Molecular
Products of Nuclear Transformation (5230)

D. C. Hess and S. Wexler

Positively charged fragments from the dissociation of 1, 2-dibromoethane by isomeric transition of 4.58-hr $\text{Br}^{80\text{m}}$ and β - γ decay of 35.9-hr Br_2 and from the disruption of tritiated ethane by beta decay of tritium were observed in the completed mass spectrometer, MA-23.

The results in the $\text{Br}^{80\text{m}}$ transition indicate the presence of multiply charged bromine ions as well as an apparent violent disruption of the dibromoethane molecule. The following ions have been identified thus far: Br^+ , Br^{2+} , possibly Br^{3+} , Br^{4+} , Br^{6+} , Br^{8+} , $(\text{C}_2\text{H}_4\text{Br})^+$, $(\text{CH}_2\text{Br})^+$, positive ions in the range from $(\text{C}_2\text{H}_4)^+$ to C_2^+ , C^+ , C^{++} , H_2^+ and H^+ . The many fragments detected in this decay are the result of the high positive charge which develops in the Br^{80} atom following internal conversion. Auger cascades which fill vacancies in the inner electronic shells cause the loss of numerous electrons from the molecule. An average charge of +10e has been measured¹ for the dissociation products of $\text{C}_2\text{H}_5\text{Br}^{80\text{m}}$. Several modes of disruption are apparently open to the dibromoethane molecule.

In contrast to the violence done to the molecule in internal conversion, the effect in beta decay is relatively mild. When Br^{82} incorporated in 1, 2- $\text{C}_2\text{H}_4\text{Br}_2$ undergoes transformation to Kr^{82} , the only ionic fragment observed at low pressures was $(\text{C}_2\text{H}_4\text{Br})^+$. Neither the initial product from the beta transition, $(\text{C}_2\text{H}_4\text{Br}-\text{Kr})^+$, nor Kr^+ were found. As the pressure of radioactive gas is increased, the $(\text{C}_2\text{H}_4)^+$ ion appears. The ratio of intensity of this fragment to that of $(\text{C}_2\text{H}_4\text{Br})^+$ increases with the pressure. The $(\text{C}_2\text{H}_4)^+$ fragment thus appears to be formed in a collision of the vibrationally excited $(\text{C}_2\text{H}_4\text{Br})^+$ with a $\text{C}_2\text{H}_4\text{Br}_2$ molecule in the source chamber. Study of the disruption of this molecule is continuing.

¹ S. Wexler, Phys. Rev. 93, 182 (1954).

The yields of the ionic fragments from the dissociation of C_2H_5T gas² following beta decay of tritium are presented in Table VIII.

TABLE VIII. Fragmentation of C_2H_5T from β -decay of tritium.

Fragment	Fractional yield at stated total source pressures			
	$\approx 3 \times 10^{-6}$ mm	$\approx 4.5 \times 10^{-6}$ mm	$\approx 9 \times 10^{-6}$ mm	$\approx 2.4 \times 10^{-5}$ mm
C_2^+	0.015	0.02	0.016	0.016
C_2H^+	0.036	0.042	0.045	0.039
$C_2H_2^+$	0.069	0.063	0.078	0.065
$C_2H_3^+$	0.056	0.063	0.074	0.065
$C_2H_4^+$	0.01	0.005	0.01	0.01
$C_2H_5^+$	0.79	0.79	0.77	0.77
Mass 30	0.011	0.02	0.02	0.024
Mass 31	0.012			0.024

The data obtained at several over-all pressures of active gas in the source show that little change in the relative abundances occurs over an eight-fold variation of pressure. We therefore feel confident that the ions observed come directly from the fragmentation resulting from the beta transition and not from secondary processes such as beta ionization and charge exchange.

Ions of the type $(CH)^+$ were found in less than 0.01 yield at the higher pressures, but these may be due to the presence of a small impurity of tritiated methane in the sample. Even if these ions are indeed the result of breakage of the C-C bond in ethane, their low yield suggests that no violent disruption of the molecule occurs following the beta transition.

²

The sample of tritiated ethane was prepared for us by K. E. Wilzbach of the Chemistry Division.

Further, the absence of H^+ , H_2^+ and He^+ in the mass spectrum demonstrates that the charge stays with the heavy fragment. Perhaps the most striking aspect of the data is the depressed intensity of the $(C_2H_4)^+$ fragment. This effect may possibly give an insight into the mechanism of the dissociation process as well as the maximum electronic and vibrational energy given to the $C_2H_5^+$ radical ion in the beta transition of H^3 to He^3 .

Calculations along this line are in progress.

The machine used in these studies of radioactive decay is pictured schematically in Fig.13. It is a 60° magnetic analyzer of 12 in. radius and uses a 16-stage silver-magnesium electron multiplier to detect the ions.

To avoid an increase in background at the multiplier because of streaming of uncharged, undecayed particles (atoms or mole-

Fig. 13. Mass spectrometer for radioactive gases.

cules depending on the experiment), the system has multiple differential pumping. The detector end has two 20 l /sec glass mercury pumps, one of which pumps the detector region directly while the other pumps on the analyzer tube. These two regions are connected essentially only by the slit through which the ions pass. One metal mercury pump having a rated speed of 450 l/sec is connected to the region immediately before the magnet. This region is coupled to the tube by an aperture which must be larger than that at the collector because of divergence of the beam. A fourth pump with a speed of 450 l /sec, evacuates another chamber which contains a 90° spherical-sector electric deflector of 3 in. mean radius. The entrance of the electric deflector faces the outlet of the ion chamber. Since the exit aperture of this chamber is a hole of 11/16 in.

diameter, there is a considerable amount of un-ionized gas escaping. Because of the conical shape of the ion chamber, this gas forms a crude uncharged beam which is scattered by the spherical deflector plate. The beam is thus converted to a random gas and the pump mentioned before is able to extract most of it. Without the deflector, most of the neutral beam would strike the analyzer tube at the bend in the magnet and much of it would find its way up to the detector. The detector would then operate in a larger partial pressure of radioactive gas and the background would be higher. Even with this arrangement, shielding of the detector is still necessary to reduce the background produced by radiation from active material which collects in the traps.

The ion source used with the spherical deflector is a stainless steel cone with a half angle of 5° and a length of 80 in. Inside, mounted on feed-through insulators, are 39 rings which approximately define the source region. A spherically symmetrical potential distribution (with the center of the sphere corresponding to the apex of the cone) is obtained by applying appropriate voltages to the rings. This gives a guide field whose lines of force are essentially radial, directed toward the (projected) apex of the cone. There will thus be an ion beam converging to a point and then diverging. This diverging beam is crudely refocussed at the source slit region by the spherical-lens effect of the 90° deflector. We have then a diverging beam of half angle 5° . The spectrometer accepts a half angle of about $3\frac{1}{2}^{\circ}$ so all of the available solid angle of the spectrometer is filled.

Preliminary experiments were carried out to measure the charge states of potassium daughter ions from β^{-} -decay of $^{41}_{19}\text{K}$. Singly charged K ions were observed in approximately 95% of the decays, K^{++} in about 5% and K^{3+} in about 0.5%. These studies were conducted in the 1.2ℓ cone described in the previous summary report.

40-2

Fragmentation of Methane and Methyl Bromide

(5230)

James Morrison * and Henry E. Stanton

Reported by Henry E. Stanton

Studies of the break-up under electron impact were carried on in continuation of the work previously reported, and the results have a bearing on the heat of vaporization of carbon. This quantity has been in dispute for several years, the argument being centered about two values, ≈ 120 kcal/mole and ≈ 170 kcal/mole. The findings here support the higher value.

It has been reported by McDowell and Warren¹ that C^+ ions created from methane under electron impact are formed without kinetic energy. On the basis of this and measurements of appearance potentials, they believe the fundamental process to be

This leads to the lower value for the heat of sublimation of carbon.

As reported last time,² the kinetic energy of the fragment ions was measured in MA-17, and it was found that the C^+ ions had an initial energy of ~ 0.1 ev. Somewhat more must be carried away by the hydrogen atoms or molecules formed in the break-up.

If this additional energy is included in Eq. (1), the energy balance does not conform to known values of the various bond energies. Accordingly, the process which best seems to fit the experimental findings is

¹ C. A. McDowell and J. W. Warren, Disc. Faraday Soc. 10, 53 (1951).

² Physics Division Summary Report, ANL-5698, Fig. 19.

Assuming this relation, and using the definitions,

$$\begin{aligned} A(X^+) &= \text{the appearance potential to form } X^+, \\ I(Y^+) &= \text{ionization potential of the gas atom } Y, \\ D(U-V) &= \text{the bond energy of the atoms } U \text{ and } V \text{ in a molecule,} \end{aligned}$$

the energy equation is

$$A(C^+) = I(C^+) + 4D(C-H) - D(H-H) + K. E. \quad (3)$$

From measurements to be described later, $A(C^+)$ was found to be 26.7 ev and the K. E. term ~ 3 ev, which is consistent with the direct measurements. It is known that $D(H-H) = 4.48$ ev and $I(C^+) = 11.27$ ev. One then finds $4(D-H) = 16.91$ ev.

The heat of formation of methane with all elements in their standard states is known to be 0.74 ev.

Hence if the heat released in the reaction is designated by ΔH , one can compare the equation,

found in these experiments with the equation,

for the elements in their standard states to get the equation,

This heat of sublimation ΔH_{subl} agrees with the "high value" well within experimental errors.

The appearance potential $A(C^+)$ was determined in MA-17 as a check with the values in the literature to make sure that the same processes were involved. A typical trace is shown in Fig. 14 where a similar curve for Ne^+ has been superimposed for calibration and comparison. One notes that the approach to the axis for low electron energies is much more gradual for C^+ than Ne^+ . This indicates that the C^+ is formed with initial kinetic

Fig. 14. Typical curve of ionization efficiency for the formation of C^+ and Ne^+ by electron impact. For comparison, the two curves are shown on the same set of axes.

energy, as found also by the energy analysis.

The possible existence of initial kinetic energy in the formation of C^+ is more clearly evident in Fig. 15 where the second derivatives of the curves shown in Fig. 14 are plotted as a function of electron energy. The relatively narrow peak of Ne^+ in Fig. 15 is characteristic of the formation of ions initially at rest, the width being due to the distribution of energies in the ionizing electrons. For C^+ , however, the increased width of the second derivative curve indicates that the total kinetic energy

Fig. 15. Curves showing the second derivative of the ion intensity with respect to the ionizing electron voltage. The relatively narrow peak of Ne^+ indicates formation with the atom at rest, whereas the wide peak of C^+ indicates initial kinetic energy.

in the reaction is approximately equal to the half width. In both cases, the maxima of the curves give the appearance potentials of the ions, which are close to the generally accepted values.

This material is in preparation for publication in the Journal of Chemical Physics.

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V. THEORETICAL PHYSICS, GENERAL

2-15 Excited States of Light Nuclei (5220)
Dieter Kurath

There has been some interest in measuring the lifetime of the 3.57-Mev second excited state of Li^6 because it is easy to produce. A calculation of the lifetime of this M1 transition from a state with $J = 0, T = 1$ to the ground state ($J = 1, T = 0$) shows that it is very short. The computed value is relatively insensitive to the spin-orbit coupling parameter and is

$$\tau \approx 7.5 \times 10^{-17} \text{ sec.}$$

This report terminates the study of excited states of light nuclei. The results are contained in a paper entitled, "Radiative Transition Widths in the 1p-Shell", Phys. Rev. 106, 975 (1957).

3-5 Dynamics of Nuclear Collective Motion (5220)
David R. Inglis and Kiuck Lee
Reported by David R. Inglis

The possibility of stable pear-shaped deformations of nuclei is treated by a perturbation theory starting from the nucleon wave functions of a spheroidal harmonic-oscillator potential, without spin-orbit coupling. The mixing of states of opposite parity tends to stabilize the deformation and is opposed by the cohesiveness of nuclear matter that favors a spherical shape. The former is calculated explicitly for a number of cases and the latter is estimated by imposing a constant-volume condition in a simple

manner closely analogous to a more familiar treatment of spheroidal deformations. In this approximation the mixing of the states is not quite enough to overcome the competing effect, so it merely "softens" the nucleus and does not stabilize a pear-shaped deformation. The difference between the competing effects varies between about three and twenty percent in various favorable cases considered. Spin-orbit coupling brings states of opposite parity closer together, as is familiar in the formation of the "magic number" groups, and it is expected that its primary effect is, through the energy denominators, to increase the tendency to pear-shaped nuclei enough to make some of them stable. A report on this work has been submitted for publication.

Because this treatment suggests a mechanism whereby the fission-saddle may be asymmetric, it is of interest to examine other attempts to explain fission asymmetry, particularly the behavior of the droplet model. The deformed shape is so far from spherical that it is awkward to use an expansion in spherical harmonics, and an approximate treatment in terms of small deviations from a cylinder capped by hemispheres is instructive. Such a cylinder itself becomes unstable to fission only for a surface tension about half as strong as the empirical value. A neck starts to form more easily, but still requires rather weak surface tension. It starts to form considerably more easily in the symmetric position; but if, nevertheless, it is started asymmetrically an estimate based on the hydrodynamics indicates that it develops at first slightly more rapidly in a way that may be associated with a reduced mass.

No further reports on this title are expected for the next year because of absence of the authors.

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5-3 Intermediate Surface Coupling in Even-Even Nuclei (5220)

B. James Raz

In order to investigate the transition region between weak and strong coupling in the Bohr-Mottelson collective model, a series of calculations using intermediate surface coupling have been initiated. This study is aimed at explaining the observed deviations from pure rotational spectra by examining the variation of theoretically predicted spectra of even-even nuclei with changes in a) the two-particle interaction and b) the strength of surface coupling. Specifically, the spectra of two equivalent particles with $j = 7/2$ are being calculated, taking account of the two-particle interaction found suitable for Ca^{43} and including varying strengths of surface interaction.

During the reporting period, the energy levels and the associated eigenfunctions for $I = 0, 2, 4$ and 6 , and the values of $B(E2)$ for $I = 0$ and $I = 2$ have been computed for a fixed two-body interaction and varied amounts of surface coupling.

At present the calculations, in which the strength of the two-body interaction is varied, are being run on the AVIDAC.

The results indicate that the observed level spacing can be obtained for reasonable choices of the parameters and that the observed variation of $B(E2)$ with energy can also be obtained with these parameters.

A full report of this project is now being prepared for publication.

9-1

Collective Effects of O^{17} (5220)

B. James Raz

Upon the appearance of a new measurement of the quadrupole

moment of O^{17} the following paper was written as a Letter to the Editor of the Physical Review and will appear in the August 15 issue.

The very short lifetime of the first excited state of O^{17} at 0.872 Mev¹ can be accounted for easily by the introduction of small collective effects.² If the assumption is made that the parameters of the theory are the same for all levels of a given nucleus, the lifetime of the first excited state determines theoretically the quadrupole moment of the ground state. This prediction of the value of the quadrupole moment was much larger than the experimentally measured value³ of $Q = -0.005 \times 10^{-24}$ cm². Recently this quantity has been remeasured⁴ and the new experimental value is in excellent agreement with the prediction based on the lifetime of the first excited state.

$$\tau = 2.5 \pm 1 \times 10^{-10} \text{ sec} \quad (\text{reference 1}) \quad (1)$$

$$Q (\text{theory}) = -0.030 \pm 0.006 \times 10^{-24} \text{ cm}^2 \quad (2)$$

$$Q (\text{experiment}) = -0.026 \pm 0.009 \times 10^{-24} \text{ cm}^2 \quad (\text{reference 4}) \quad (3)$$

This relationship is calculated by using perturbation theory, since the collective effects are small. If the assumption is made that $(\hbar\omega)^2$ is much greater than 1 Mev, then only one parameter remains in the solutions. This parameter is $\langle |k(r)| \rangle / C$, where $k(r)$ is the radial function that determines

¹ J. Thirion and V. L. Telegdi, Phys. Rev. 92, 1253 (1953).

² A. Bohr and B. R. Mottelson, K. Danske Vidensk. Selsk. Mat.-fys. Medd. 27, No. 16 (1953); J. P. Elliott and B. H. Flowers, Proc. Roy. Soc. A229, 526 (1955); F. C. Barker, Phil. Mag. Ser. 8, 1, 329 (1956); see also B. J. Raz, thesis, University of Rochester, 1955 (unpublished).

³ Geschwind, Gunther-Mohr, and Silvey, Phys. Rev. 85, 474 (1952).

⁴ M. J. Stevenson, Bull. Am. Phys. Soc. 2, 31 (1957) and private communication, and Physical Review (to be published).

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the effective coupling and C is the surface deformation parameter.⁵ The value of $\langle |k(r)| \rangle / C$, which is determined from Eq. (1) and used in Eq. (2), is 0.21 ± 0.04 if R_0 is taken as $1.41 A^{1/3} \times 10^{-13}$ cm.

Thus, on O^{17} the straightforward application of the collective model with weak coupling gives consistent results.

⁵ See Bohr and Mottelson, reference 2.

15-5 Energy-Level Density of a System of Fermi Particles
(5220)

Norbert Rosenzweig

The following is the abstract of a paper which has been submitted to The Physical Review for publication.

Some features of the influence of shell structure on the level density of a highly excited nucleus (≈ 10 Mev) are studied on the basis of an idealized independent-particle model for which accurate formulas can be obtained in closed form. The theory is especially useful for estimating the ratio of the level densities of two nuclei in which the same degenerate (shell model) levels are being filled in the ground state, but which differ by one or two units in the number of particles which occupy these levels. Observable effects persist to high energies (≈ 10 Mev) and they become very large in the neighborhood of the magic numbers. Thus, it may be possible to determine experimentally whether or not the shell model of the nucleus retains any validity at high excitations.

16-1

Analysis of Angular Distribution Data

(5220)

J. E. Monahan and Gilbert Steiner

I. CENTER-OF-MASS TRANSFORMATION MATRICES FOR THE COEFFICIENTS OF THE EXPANSION IN LEGENDRE POLYNOMIALS

Reported by J. E. Monahan and Gilbert Steiner

Consider the reaction

$$m_1 + m_2 + Q' = m_3 + m_4 ,$$

where Q' is the negative of the usual Q -value of the reaction, m_1 and m_3 are the masses of the incident and observed particles and m_2 and m_4 are the masses of the target and residual nuclei, respectively. The differential cross section for this process can be expanded in the form

$$\sigma_L(\mu_L) = (\sigma/4\pi) \sum_{l=0}^{\infty} \omega_l P_l(\mu_L) ,$$

where $\cos^{-1} \mu_L$ is the angle of scattering observed in the laboratory; or

$$\sigma_c(\mu_c) = (\sigma/4\pi) \sum_{l=0}^{\infty} \eta_l P_l(\mu_c) ,$$

where $\cos^{-1} \mu_c$ is the corresponding angle in the center-of-mass system:

$$\frac{(1-\mu_c^2)^{1/2}}{\mu_c + \gamma} = \frac{(1-\mu_L^2)^{1/2}}{\mu_L} ,$$

where

$$\gamma^2 = \frac{m_1 m_3 (m_3 + m_4)}{m_2 m_4 (m_1 + m_2)} \frac{E_r}{E_r + Q'} .$$

E_r is the initial energy of relative motion in the center-of-mass system.

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The relations between the coefficients ω_l and η_l are

$$\eta_l = (2l + 1) \sum_{l'} \zeta_{ll'} (2l' + 1)^{-1} \omega_{l'},$$

and

$$\omega_l = (2l + 1) \sum_{l'} \zeta_{ll'}^{-1} (2l' + 1)^{-1} \eta_{l'}$$

where

$$\zeta_{ll'} = \frac{2l' + 1}{2} \int_{-1}^1 d\mu_L P_l(\mu_c) P_{l'}(\mu_L),$$

and

$$\zeta_{ll'}^{-1} = \frac{2l' + 1}{2} \int_{-1}^1 d\mu_c P_l(\mu_L) P_{l'}(\mu_c).$$

The evaluation of these integrals, correct to terms of order γ^3 , gives

$$\begin{aligned} \zeta_{ll'} = & \left\{ 1 - \gamma^2 \frac{l'(l'+1)(2l'^2 + 2l' - 3)}{2(2l' - 1)(2l' + 3)} \right\} \delta_l^{l'} + \gamma \left\{ \frac{l'(l' - 1)}{2l' - 1} \delta_l^{l' - 1} \right. \\ & - \left. \frac{(l' + 1)(l' + 2)}{2l' + 3} \delta_l^{l' + 1} \right\} + \gamma^2 \left\{ \frac{(l' + 1)(l' + 2)(l' + 3)^2}{2(2l' + 3)(2l' + 5)} \delta_l^{l' + 2} \right. \\ & + \left. \frac{l'(l' - 1)(l' - 2)^2}{2(2l' - 1)(2l' - 3)} \delta_l^{l' - 2} \right\}, \end{aligned}$$

and

$$\begin{aligned} \zeta_{ll'}^{-1} = & \left\{ 1 - \gamma^2 \frac{l'(l' + 1)(2l'^2 + 2l' - 1)}{2(2l' - 1)(2l' + 3)} \right\} \delta_l^{l'} + \gamma \left\{ \frac{(l' + 1)(l' + 2)}{2l' + 3} \delta_l^{l' + 1} \right. \\ & - \left. \frac{l'(l' - 1)}{2l' - 1} \delta_l^{l' - 1} \right\} + \gamma^2 \left\{ \frac{l'^2(l' - 1)(l' - 2)}{2(2l' - 1)(2l' - 3)} \delta_l^{l' - 2} + \frac{(l' + 1)^2(l' + 2)(l' + 3)}{2(2l' + 3)(2l' + 5)} \delta_l^{l' + 2} \right\}. \end{aligned}$$

For scattering, γ reduces to m_1/m_2 so that γ^3 is less than 0.001 even for scattering from an element as light as carbon. Thus if an expansion

$$\sigma_c(\mu_c) = (\sigma/4\pi) \sum_{\ell=0}^{N-1} \eta_{\ell} P_{\ell}(\mu_c) ,$$

with N finite, can be justified for a differential scattering cross section, then the corresponding expansion,

$$\sigma_L(\mu_L) = (\sigma/4\pi) \sum_{\ell=0}^{N+1} \omega_{\ell} P_{\ell}(\mu_L) , \quad (1)$$

is accurate to terms of order γ^3 .

II. STATISTICAL ANALYSIS

Reported by J. E. Monahan

In order for Eq. (1) to be an accurate representation of the differential cross section $\sigma(\mu)$ for values of μ other than those at which data are taken, it is necessary that N be sufficiently large that ω_{ℓ} is essentially zero for $\ell > N+1$. The purpose of this note is to describe a criterion for the sufficiency of the representation (1) for a given finite value of N .

Let $C(\mu_j)$ denote the number of scattered particles measured by the detector placed at the angle $\cos^{-1}\mu_j$; and let $\mathcal{P}_{j\ell}$ denote the average value of $P_{\ell}(\mu)$ for this detector. Then

$$C(\mu_j) = A \sum_{\ell=0}^{N+1} \mathcal{P}_{j\ell} \omega_{\ell} , \quad (2)$$

where A is a constant independent of j and ℓ . If Δ_j denotes the error (standard deviation) in the determination of $C(\mu_j)$, the "most probable" set of

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coefficients comprises those values $A \omega_l$ which minimize the quadratic expression

$$\chi^2 = \sum_{j=1}^s \Delta_j^{-2} \left[A \sum_{l=0}^{N+1} \rho_{jl} \omega_l - C(\mu_j) \right]^2, \quad (3)$$

where $s > N + 2$ is the number of distinct angles at which $C(\mu_j)$ is determined.

It is obvious that χ^2 is a measure of the "goodness of the fit" of the expansion (2) to the experimentally determined $C(\mu_j)$. If the fit is too good relative to the expected uncertainties Δ_j , one might suspect that terms which are statistically non-significant are included in the expansion (2) for the value of N chosen. In this case χ^2 would be a very small number. On the other hand, very large values of χ^2 would result for values of N such that significantly non-zero terms are excluded from Eq. (2). Thus for the "correct" value of N , χ^2 should be neither "too large" or "too small." It might be noted that the "correct" value of N depends on the errors Δ_j , i. e., a value of N is "correct" if it excludes only those coefficients which are zero within the statistical accuracy of the experiment.

In order for these qualitative notions to be of any practical value, it is necessary to obtain the statistical distribution of χ^2 . If it is assumed that the errors Δ_j are normally distributed, it can be shown that the quantity defined by Eq. (3) has a chi-squared distribution with $(s - N - 2)$ degrees of freedom, its expectation value and variance being given by

$$\langle \chi^2 \rangle_{Av} = s - N - 2,$$

and

$$\langle (\chi^2)_{Av} - \chi^2 \rangle_{Av}^2 = 2(s - N - 2).$$

The statistical significance of the fit for a given value of N is obtained from the probability $P(\chi^2 > \chi_p^2)$ of obtaining a value of χ^2 greater than the value χ_p^2 calculated using Eq. (3). Tables of this probability are included in most texts on Mathematical Statistics.

Since the distribution of χ^2 does not depend on any properties of the Legendre polynomials, this test can be generalized to any representation in which an experimentally determined quantity is expanded in a series of known functions of an experimental variable.

17-4 Analysis of Angular Distributions and Correlations (5220)

William C. Davidon

A paper describing the procedure for numerically locating the minimum of a function of several variables was submitted for publication in the Journal of Mathematics and Physics.

18-1 Parametric Formulation of Quantum Mechanics (5220)

William C. Davidon

In order to obtain a more satisfactory relativistic theory of scattering, particularly when large interactions are involved, an effort is being made to construct a more complete theory based on a parametric formulation of quantum electrodynamics.¹

When large interactions are involved, the development of the

¹

W. C. Davidon, Phys. Rev. 97, 1131, 1955; Phys. Rev. 97, 1139, 1955.

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19-4 Ingoing-Wave Condition in Scattering Theory (5220)
Melvin Hack

40-4 Quantum Mechanical Ergodic Theorem (5230)
 Hans Ekstein

42-4 Irreversible Processes in Quantum Mechanics (5230)
 Hans Ekstein and N. Rostoker (General Dynamics, San Diego)
 Reported by Hans Ekstein

The paper has been submitted for publication, after some modification by the co-author.

Hans Ekstein and D. Kaplan*

* Illinois Institute of Technology.

H. Ekstein, J. C. Swihart and K. Tanaka
Reported by K. Tanaka

A paper entitled "Representationless Formulation of Fixed-Particle Field Theories" was presented by H. Ekstein at the Seventh Annual Rochester Conference in April, 1957.

A paper entitled "Properties of the Fixed-Source Meson Theory" by K. Tanaka is scheduled for publication in the July 15, 1957 issue of the Physical Review.

45-8 Meson-Nucleon Interaction (5230)
 Katsumi Tanaka

Salzman's¹ perturbation result in Chew's no-recoil theory

¹ G. Salzman, Phys. Rev. 99, 973 (1955).

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for neutron-electron interaction, in which one calculates the interaction of the electrostatic field of the electron with the charged meson cloud of the physical neutron, is in serious disagreement with experiment. Treiman and Sachs² found that the higher order mesonic corrections in the framework of the Chew theory reduce the discrepancy by about 20%.

In order to examine the nucleon effects on the discrepancy, we have performed a covariant calculation of the meson-current part of the neutron-electron interaction, using dispersion relations derived by Chew et al., under the assumption that the (3,3) resonance dominates the dispersion integral. Such a covariant calculation has many advantages over the previous non-covariant calculations. It is found that the discrepancy is reduced considerably.

² S. B. Treiman and R. G. Sachs, Phys. Rev. 103, 435 (1956).

48-3

Dispersion Relations

(5210)

William C. Davidon

At the Rochester Conference on High Energy Physics, Puppi reported on an apparent discrepancy between π^- - proton scattering experiments at low energies and the corresponding dispersion relations for non-spin-flip forward scattering. An independent examination of the possibility of such a discrepancy was made here. At low energies, the dispersion relations become an identity since the scattering lengths appear explicitly in them. A numerical calculation was made at 65 Mev, at which energy the dispersion relations are no longer trivial. Agreement within the estimated experimental

uncertainties was obtained. These results were communicated to Puppi, Goldberger, and Oehme, and further work will be done on this matter when more detailed information is received from Puppi on his calculations.

50-1

Neutrino Theory

(5220)

M. Goeppert Mayer and Valentine L. Telegdi*
Reported by M. Goeppert Mayer

To overcome certain discrepancies between experiment and the predictions of conventional 2-component neutrino theory, a "twin neutrino" theory is proposed. In the more general formulation of this theory, two different 2-component neutrinos ν_1 , ν_2 of opposite screw-sense are introduced, together with their antiparticles $\bar{\nu}_1$, $\bar{\nu}_2$. In beta decay, one of these is coupled by T,V, the other by S,A. This eliminates all interference terms.

The theory is specialized to the assumption $\bar{\nu}_1 \equiv \nu_2$, i. e., to Majorana-type neutrinos. This more restricted theory is equally successful in explaining the results of the "parity experiments". It is shown that the conventional objections to the Majorana theory need not apply to this twin neutrino theory.

A paper on the subject, entitled "'Twin Neutrinos': A Modified 2-Component Theory", will appear in the Physical Review on September 1.

* University of Chicago.