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FOREWORD

The Summary Report of the Physics Division of the Argonne National Laboratory is issued monthly for the information of the members of the Division and a limited number of other persons interested in the progress of the work. Each individual project reports about once in 3 months, on the average. Those not reported in a particular issue are listed separately in the Table of Contents with a reference to the last issue in which each appeared.

This 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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I. EXPERIMENTAL NUCLEAR PHYSICS

I-1-19 Argonne Fast-Neutron Velocity Selector

(5220)

L. M. Bollinger, R. E. Cote¹, and G. E. Thomas
Reported by G. E. Thomas and L. M. Bollinger

In the initial phase of development of the Argonne fast chopper, two rotors were built to be used interchangeably within a single neutron time-of-flight system.

A third rotor has now been completed and put into service.

The general characteristics of the Argonne fast chopper as a neutron time-of-flight spectrometer have been described in a previous report.¹ The mechanical characteristics of the chopper are shown in Fig. 1. The rotor is suspended from a driving motor by a thin shaft which allows the rotor to seek its own center of rotation. The first rotor built, Rotor I, was designed to give a high intensity of neutrons and is used for partial-cross-section measurements. It has two sets of slits intersecting at right angles.

Fig. 1. Component parts of the Argonne fast chopper.

¹ L. M. Bollinger, R. E. Cote¹, and G. E. Thomas, "A Critical Analysis of the Design and Application of Neutron Choppers," Proceedings of the Second International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958 (United Nations, Geneva, 1958), Vol. 14, p. 239.

Fig. 2. Slits being formed by the electrical discharge machine.

Rotor II has only one set of slits and differs from Rotor I in other important respects. It is used chiefly for high-resolution transmission measurements.

Rotor I has been in need of replacement for some time as is indicated by its inferior characteristics in comparison with those of Rotor II. First, because of its almost spherical shape, Rotor I is rather unstable mechanically and cannot be safely used at the high speeds that are needed to obtain higher resolution. Second, the leakage of fast neutrons through the rotor is unnecessarily high. Finally, from an inadvertent

failure to normalize the Monel in Rotor I, the slit shape has been slightly distorted while operating at a speed in excess of 15 000 rpm.

The new rotor, which we shall call Rotor III, has been fabricated to replace Rotor I. The design of the slits is the same as that in Rotor I but the size and shape of the component parts of the rotor are nearly identical with those of Rotor II. The design of the new rotor can be seen in Fig. 1. It has an outer shell of Monel (10 in. o.d.) with a core of uranium 6 in. in diameter. The core consists of two pieces, an outer shell and a cylinder 2.5 in. in diameter which fits into it. This type of construction was necessary to obtain slits of the desired shape. The Monel and the uranium pieces are all pinned together to prevent slippage of the pieces.

The slits in the rotor were cut by an electrical discharge method² which permitted the slits to be formed in solid material. In this way the strength of the rotor and the accuracy of the slit dimensions were increased. In Fig. 2 we see the slits in the process of being fabricated. The shape and dimensions of the slits can be seen in Fig. 3.

The new rotor has been put into operation and is proving to be satisfactory in every respect. The expected improvement in stability has been realized. The great opacity for fast neutrons has not been checked but seems assured on the basis of tests of Rotor II. A program to increase the rotational speed has just

started. To date the speed has been increased from 15 000 rpm to 17 000 rpm. It is hoped that 22 500 rpm will ultimately be achieved. At that speed the width of the burst of neutrons will be about $1.4 \mu \text{sec}$.

ROTOR III

Fig. 3. Shape of the rotor slits.

²

D. Wall, Am. Machinist (to be published).

I-17-8 Investigation of Thin Lithium Layers (5220)

J. E. Monahan and F. P. Mooring

This project has been completed and the results have been published in a report entitled: "An Investigation of Properties of Thin Lithium Films by Use of the $\text{Li}^7(p,n)\text{Be}^7$ Reaction," J. E. Monahan and F. P. Mooring, Nuclear Instr. and Methods 6, 343-353 (March 1960).

I-18-11 Differential Cross Sections for Neutron Scattering (5220)

R. O. Lane, A. S. Langsdorf, J. E. Monahan, and
A. J. Elwyn
Reported by A. J. Elwyn

We present here in graphical form the results of an analysis of the angular distributions obtained in the scattering of neutrons from various nuclei. These measurements are a continuation of the survey of neutron angular distributions described previously,¹ except that the data presented here were obtained from measurements at eight scattering angles rather than at five as in the previous work. The results include a series of measurements of the neutrons scattered from Li^6 (96%), Li (normal), Be, C, Si, Ca, Cu, Sn, Pb, and U^{238} in the energy range from 50 kev to 2300 kev. The energy spread of the incident neutron beam was sufficient to average out most of the pronounced fluctuations due to individual scattering resonances. In addition, a series of angular distributions of neutrons scattered at resonances was measured for C^{12} , O^{16} , Si^{32} , Li^6 , and Li^7 .

A paper describing the experimental arrangement, the method

¹ A. Langsdorf, Jr., R. O. Lane, and J. E. Monahan, Phys. Rev. 107, 1077 (1957).

of data analysis, and the results of the measurements has been submitted for publication.² At present it will suffice to say that the neutrons used for this study were obtained from the proton bombardment of evaporated lithium targets in the $\text{Li}^7(p,n)\text{Be}^7$ reaction. The neutrons passed down a collimator and were incident on scattering samples in the form of flat slabs placed at the center of a circular track. The scattered neutrons were detected by oil-moderated BF_3 proportional counters in specially constructed shield tanks,³ which could be moved independently along the track. There were five such detector tanks and, except for limitations due to their size, any combination of angles between 22° and 145° could be obtained. The forward neutron flux was monitored by two additional oil-moderated BF_3 detectors.

For the measurements with broad resolution, the lithium targets produced neutrons with an energy spread of about 40 kev over the range of neutron energies between 50 and 600 kev, and neutrons with spreads of 80 to 130 kev in the range from 600 to 2250 kev. The scattering samples were chosen to give approximately 90% transmission. The Li, Ca, and Si samples were "canned" in thin-walled steel containers. For the resonance-scattering measurements, the total spread in the incident neutron beam was limited to between 5 and 10 kev. In the O^{16} measurements, "canned" samples of SnO_2 and matching Sn samples were employed.

ANALYSIS

The data are presented in terms of the coefficients B_l in the expansion of the differential scattering cross section $\sigma_s(\mu)$ in a series of Legendre polynomials $P_l(\mu)$ of the form

²

R. O. Lane, A. S. Langsdorf, Jr., J. E. Monahan, and A. J. Elwyn, Ann. Phys. (to be published).

³ Alexander Langsdorf, Jr., Fast Neutron Physics, Part I, edited by J. B. Marion and J. L. Fowler (Interscience Publishers, New York, 1960), p. 721.

$$\sigma_s(\mu) = \sum_{\ell=0}^{N-1} B_\ell P_\ell(\mu),$$

where $\mu = \cos \theta$, and θ is the scattering angle. The values of the coefficients B_ℓ were obtained from an analysis of the entire set of data by means of a least-squares procedure.

In order to obtain the proper relation between the normalized yields and the differential scattering cross section, it was necessary to make a number of corrections to the data and to determine the absolute efficiency factor for the experimental setup. Corrections for the attenuation of the primary neutron beam and for the finite resolution of the experimental equipment were made in essentially the same manner as previously described.¹ Multiple scattering of the neutrons was taken into account on the basis of an energy-dependent calculation by Monte Carlo procedures.^{2, 4} Further corrections, to take into account the variations in detector efficiency as a function of neutron energy and the effects of the second group of neutrons in the $\text{Li}^7(p,n)\text{Be}^7$ reaction (arising from a state in Be^7 at 0.43 Mev excitation), were made to the data in those cases in which the effects were considered significant.

The absolute efficiency factor was evaluated by normalizing all integrated (with respect to angle) scattering cross sections to the independently measured scattering cross section of some standard scatterer. For most of this work, the standard sample chosen was carbon.

RESULTS

Figures 4 through 18 present the results of the angular-distribution measurements and analysis. For each scattering sample, the coefficients B_ℓ are given as functions of the incident energy E . Both B_ℓ and E

⁴ W. F. Miller (to be published).

Fig. 4. The differential cross section for scattering of neutrons by Li^6 .

Fig. 5. The differential cross section for scattering of neutrons by Li^7 .

Fig. 6. The differential cross section for scattering of neutrons by Be.

Fig. 7. The differential cross section for scattering of neutrons by C^{12} .

Fig. 8. The differential cross section for scattering of neutrons by C^{12} .

Fig. 9. The differential cross section for scattering of neutrons by O^{16} .

Fig. 10. The differential cross section for scattering of neutrons by O^{16} .

Fig. 11. The differential cross section for scattering of neutrons by Si.

Fig. 12. The differential cross section for scattering of neutrons by Si.

Fig. 13. The differential cross section for scattering of neutrons by S.

Fig. 14. The differential cross section for scattering of neutrons by Ca.

Fig. 15. The differential cross section for scattering of neutrons by Cu.

Fig. 16. The differential cross section for scattering of neutrons by Sn.

Fig. 17. The differential cross section for scattering of neutrons by Pb.

Fig. 18. The differential cross section for scattering of neutrons by U.

are given in the laboratory system of coordinates. The value of E used in this work is calculated as

$$E = E_m - \frac{1}{2} \Delta ,$$

where E_m is the maximum energy of the neutrons in the incident beam and Δ is the half width of the energy distribution of the neutron beam (as determined from "rise curve" measurements just above threshold). Also shown on the figures are the differential cross sections as a function of $\cos \theta$ in the laboratory system at a number of incident energies E . Both the B_ℓ and the differential cross sections are given in barns per steradian. The solid curve through the points on the plots of B_ℓ are drawn merely to indicate the trend of the data; whereas those on the plots of differential cross sections are the results of the least-squares fitting. It is to be noted that $4\pi B_0$ is equivalent to the total scattering cross section for the element under consideration. The numerical values for the coefficients and differential cross sections are tabulated in a separate report.⁵

The error bars drawn on the figures represent the standard deviation associated with the B_ℓ . Included in such an error is the error in the total cross section of the standard scatterer, i.e., carbon. In most cases, this error gave the dominant contribution to the errors shown.

A comparison of the results of these measurements with the original five-angle data,¹ for those cases in which overlap exists, showed no differences greater than those expected on the basis of the assigned errors, except in those cases in which the B_ℓ for $\ell > 4$ were significantly nonzero.

⁵

These detailed results are tabulated in an informal report entitled "Tables of Differential Cross Sections for Neutrons Scattered from Various Nuclei," by R. O. Lane, A. S. Langsdorf, Jr., J. E. Monahan, and A. J. Elwyn. This report may be obtained from the authors.

I-19-4

Nuclear Resonance Absorption of Gamma Rays

(5220)

A. TIME DEPENDENCE OF RESONANTLY FILTERED
GAMMA RAYS FROM Fe^{57}

R. E. Holland, M. Hamermesh, F. J. Lynch

I. Introduction

In an earlier paper,¹ we showed that the intensity of the gamma rays transmitted through an absorber which is resonant to the incident gamma radiation does not decrease exponentially with time. Instead, the transmitted beam appears initially to decay faster than the rate corresponding to the lifetime τ of the emitting state. The intuitive picture which led us to undertake the initial experiments was that the resonance absorption tends to reduce the intensity at the center of the emitted line relative to the intensity in the wings. Thus the width at half maximum of the remaining peak is greater than the value $\Gamma = \hbar/\tau$ of the original peak; and the lifetime of the state appears to be correspondingly shorter.

II. Theory

A quantitative theoretical treatment was developed by describing the emitted radiation as a damped electromagnetic wave.² On passing through a medium filled with resonators, the frequency spectrum of the radiation is altered, so that its time dependence is no longer exponential. In addition to the above result, this theoretical treatment predicted that when the gamma-ray energy is shifted off the absorption resonance by the Doppler effect there are still more surprising intensity variations with time. In particular, it predicted

¹ R. E. Holland, F. J. Lynch, G. J. Perlow, and S. S. Hanna, Phys. Rev. Letters 4, 181 (1960).

² M. Hamermesh, Argonne Physics Division Summary Report, ANL-6111, p. 6, Feb. 1960.

that at certain times more gamma rays would be detected than if the absorber were absent. The medium behaves like a resonant filter and appears to "ring" in response to the incident damped radiation. As the energy shift ΔE is increased, the oscillations are moved toward shorter and shorter times so that for very large ΔE the normal exponential decay is approached.

The theoretical expression for the intensity of the transmitted radiation is

$$|a'(T)|^2 = e^{-T} \left| \sum_{n=0}^{\infty} \left[i \frac{4}{\beta} \frac{\Delta\omega}{\lambda} \right]^n \left[\frac{\beta T}{4} \right]^{\frac{1}{2}n} J_n(\beta^{\frac{1}{2}} T^{\frac{1}{2}}) \right|^2, \quad (1)$$

where $\lambda = \frac{1}{\tau}$, $T = \lambda t$, β is the absorber thickness in mean free paths at frequency ω_0 , and $\Delta\omega$ is the shift in angular frequency due to Doppler effect measured at the absorber. In particular, for $\Delta\omega = 0$ this reduces to

$$|a'(T)|^2 = e^{-T} \left[J_0(\beta^{\frac{1}{2}} T^{\frac{1}{2}}) \right]^2. \quad (2)$$

For large values of $\Delta\omega$, the series (1) converges very slowly. In this region, we use an alternate expression for $a'(t)$. The transmitted intensity is

$$\begin{aligned} |a'(T)|^2 = e^{-T} & \left| -\exp i \left[\frac{\Delta\omega}{\lambda} T + \frac{\lambda}{\Delta\omega} \frac{\beta}{4} \right] \right. \\ & \left. + \sum_{n=1}^{\infty} \left[i \frac{\beta}{4} \frac{\lambda}{\Delta\omega} \right]^n \left[\frac{\beta T}{4} \right]^{-\frac{1}{2}n} J_n(\beta^{\frac{1}{2}} T^{\frac{1}{2}}) \right|^2. \quad (3) \end{aligned}$$

In computing the time behavior of the transmitted intensity, Eq. (1) converges rapidly for

$$\frac{2}{\beta} \frac{\Delta\omega}{\lambda} (\beta T)^{\frac{1}{2}} < 1 ,$$

while Eq. (3) gives rapid convergence for

$$\frac{2}{\beta} \frac{\Delta\omega}{\lambda} (\beta T)^{\frac{1}{2}} > 1 .$$

The transmitted intensity given by Eq. (1), (2), or (3) can be written as

$$|a'(t)|^2 = \exp(-\lambda t) F(\beta, t) .$$

The deviations from exponential behavior are more easily seen if one plots the product of the counting rate with the factor $\exp(\lambda t)$. For the emitted line this product is a constant. For the transmitted line, the theory predicts that the product will vary as $F(\beta, t)$.

The theory assumes that there is a single emission (and absorption) line. However, the 14.4-keV line of Fe^{57} has a hyperfine structure of six lines.³ Since the separation of the hyperfine components is large compared to the line width, we assume that each emitted hyperfine component is absorbed only in the corresponding transition in the absorber. By use of the values for the intensities of the hyperfine components, the time dependence of the transmitted radiation is found to be

$$|a'(t)|^2 = \exp(-\lambda t) \left[1 - f + f \left\{ \frac{1}{2} F\left(\frac{\beta}{4}, t\right) + \frac{1}{3} F\left(\frac{\beta}{6}, t\right) + \frac{1}{6} F\left(\frac{\beta}{12}, t\right) \right\} \right], \quad (4)$$

where f is the fraction of gamma rays emitted without recoil. Although in

³ S. S. Hanna, J. Heberle, C. Littlejohn, G. J. Perlow, R. S. Preston, and D. H. Vincent, Phys. Rev. Letters 4, 177 (1960).

principle β is measurable, it is difficult to determine it accurately. We have used β as a parameter in fitting the theoretical formula to the experimental data. Equation (4) was evaluated on an IBM-704 computer for various values of β and the other parameters, and the calculated curve giving the best visual fit was plotted with the data. One should expect that β would be given by $N\sigma_0 f'$, where f' is the fraction of Fe^{57} nuclei which can absorb without recoil, N is the number of atoms of Fe^{57} per cm^2 , $\sigma_0 = 4\pi\lambda^2/(1+\alpha)$, λ is the wavelength of the 14.4-keV gamma ray divided by 2π , and α is the internal-conversion coefficient.

Fig. 19. Schematic diagram of equipment.

III. Equipment and Procedure

The measurements were made with a source of Co^{57} (25 000 disintegrations of Co^{57} per sec) co-plated⁴ with Fe^{56} on a thin copper foil and annealed in vacuum at 800°C . Absorbers consisted of rolled foils of Fe^{57} enriched to 75% in Fe^{57}) or normal Armco iron rolled foils annealed

at 800°C . The geometric arrangement of source, absorber, and detectors is shown schematically in Fig. 19. The source, $\frac{3}{8}$ in. in diameter, was mounted on an extension of the speaker diaphragm which could be used to shift the resonant frequency of the source by the Doppler effect. The absorber foil (1 in. in diameter) was clamped between two lucite disks mounted $\frac{3}{8}$ in. above the source. The detector for the 14.4-keV gamma ray consisted of a NaI(Tl) scintillator 1 in. in diameter and 0.006 in. thick mounted on a lucite light pipe and an RCA 7265 photomultiplier tube. A

⁴ S. S. Hanna, J. Heberle, C. Littlejohn, G. J. Perlow, R. S. Preston, and D. H. Vincent, Phys. Rev. Letters 4, 28 (1960).

second NaI(Tl) scintillator, 1 in. diameter and $\frac{1}{4}$ in. thick, served as a detector for the 123-kev gamma ray and was mounted $\frac{1}{2}$ in. from the source on a line making an angle of 120° with the line connecting the centers of the other detector and the source.

The speaker coil was driven with a peak-to-peak amplitude of $\frac{1}{8}$ in. by the amplified signal coming alternately from a triangular wave generator,⁵ and from a sinusoidal signal of 40 cps. The triangular wave caused the source to move with a constant velocity either toward or away from the absorber, except during the short interval of reversal of direction. This constant velocity produced a small constant increase or decrease in gamma ray energy through the Doppler effect. On the other hand, the sinusoidal signal, because of its much higher frequency, produced a wide range of energy shifts; most of the time the gamma rays were not resonant nor even nearly resonant with the absorber. Other sources of absorption, such as the photoelectric effect would be scarcely affected by the energy shift. Thus we observed the effect of both nonresonant and resonant absorption for small energy shifts with the triangular wave applied to the voice coil and we observed the effect of nonresonant absorption alone with the sinusoidal voltage applied to the voice coil.

Because the average geometric arrangement was slightly different for the two signals, measurements were taken without an absorber, and the sinusoidal signal was adjusted slightly to bring the coincidence counting rate within 1% of the counting rate with the triangular drive.

The over-all performance of the system was investigated by observing the width of the central dip in transmission. This was 20% wider

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Model 202A function generator, manufactured by Hewlett-Packard Co., Palo Alto, California.

than expected for the thickest absorber and 40% wider for the thinnest. Calibration was made by observing the frequency of the transmission minimum for the first satellite. This should occur at a velocity of 0.088 in./sec as determined by measurements³ made on the lathe. The velocity (0.0037 in./sec) for an energy shift of $1\Gamma = \hbar/\tau$ was obtained by a proportional frequency reduction in the function generator. The construction and performance of the transducer system is described in Sec. B.

The circuits for measuring the coincidence rate as a function of time delay after formation of the 14.4-kev state are shown schematically in Fig. 19 and were the same (except for slight modifications) as those used previously to measure the lifetimes of excited states of nuclei.⁶ The output of the time-to-pulse-height converter was stored in the right half of the 256-channel analyzer when the voice coil was driven with the triangular wave and in the left half when the voice coil was driven with the sinusoidal voltage. During a run the triangular wave and sinusoidal voltages were applied alternately for 4-min. intervals by a timing mechanism, and data were accumulated over a 24-hr period. Signals from slow amplifiers and single-channel analyzers set on the photopeaks of the two gamma rays were required in order to record an event.

Because of the method of recording data, slow drifts were not important. The calibration of the time-to-pulse-height converter (as obtained by using the data from the sinusoidal run to measure the lifetime of the 14.4-kev state of Fe^{57}) remained constant within 1.5% over a period of 1 month. A slow drift of the peak channel was also observed (about $\frac{1}{4}$ channel per day). The converter was linear to within 1% in the region of interest.

⁶ F. J. Lynch and R. E. Holland, Phys. Rev. 114, 825 (1959); R. E. Holland and F. J. Lynch, Phys. Rev. 113, 903 (1959).

IV. Results and Discussion

The results of a typical measurement for the thickest absorber foil (2.7 mg/cm^2 of Fe^{57} , isotopic enrichment 75%) is shown in Fig. 20. The upper part of the figure shows a conventional semilogarithmic plot of the data after subtraction of background due to accidental coincidences. This background was determined from the counting rate at times preceding the peak shown in Fig. 20. In general it was less for the part of the run in which the source was moved at constant velocity than for the part in which the source was vibrated sinusoidally because the counting rate in the 14.4-kev detector was less in the former condition. The total number of accidental coincidences was 2.5% of the total number of true coincidences for the data with vibrated source shown in Fig. 20. The steep rise at the left side of the figure represents the time

resolution of the fast circuit; it corresponds to a resolution curve with a full width at half maximum of $25 \text{ m}\mu\text{sec}$. The curve obtained with vibrated source shows the exponential decay with a half-life of $0.10 \mu\text{sec}$ in agreement

Fig. 20. a) Semilogarithmic plot of delayed time spectra taken with source and absorber (2.7 mg/cm^2 of Fe^{57} , isotopic abundance 75%) stationary and with source and absorber vibrated relative to one another. b) Data of Fig. 20a replotted with ordinate multiplied by $e^{\lambda t}$ in order to compare with theoretical expression given by the solid line.

with previous measurements.⁷ The curve obtained with the stationary source demonstrates the effect we expected.

The lower portion of Fig. 20 shows the same data plotted in such a way as to exhibit the deviations from exponential decay predicted in Sec. II. Here the count in each time channel has been multiplied by $e^{\lambda t}$, where λ is the decay constant and t is the time, and the resulting numbers have been adjusted so that the average value of the vibrated data was equal to unity after the initial rise. Data in several adjacent channels were averaged when the counting rate was low. Vertical bars give the standard deviations as calculated from the number of counts. The

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Nuclear Data Sheets, National Academy of Sciences - National Research Council, Washington 25, D.C. (1959).

Fig. 21. Time spectra obtained with various energy shifts of the emitted gamma ray. The absorber was the same as in Fig. 20. The energy shift ΔE is given in terms of the line width deduced from the mean life of the state, $\Gamma = \hbar/\tau$. The dashed curves give the time spectra when the source is vibrated, the solid curves are the theoretical predictions.

solid curve shown was calculated for this absorber from the prescription given at the end of Sec. II, with the thickness parameter β adjusted for best fit to the data. This value of β was twice that expected from the thickness of the absorber.

Figure 21 gives typical results for a number of runs in which the source was moved at constant velocity alternately toward and away from the absorber, and data were accumulated without distinguishing the direction of motion. This motion of the source produced a shift in energy of the emitted gamma ray. The amount of the shift, ΔE , is given on the figure

Fig. 22. Time spectra obtained with various energy shifts of the emitted gamma ray. The absorber was a rolled foil (1.27 mg/cm^2 of Fe^{57} , isotopic abundance 75%). The energy shift ΔE is given in terms of the line width deduced from the mean life of the state, $\Gamma = \hbar/\tau$. The dashed curves give the time spectra when the source was vibrated, the solid curves are the theoretical predictions.

Fig. 23. Time spectra obtained with various energy shifts of the emitted gamma ray. Absorber was rolled foil (0.20 mg/cm^2 of Fe^{57} , natural isotopic abundance). The energy shift ΔE is given in terms of the line width deduced from the mean life of the state, $\Gamma = \hbar/\tau$. The dashed curves give the time spectra when the source was vibrated, the solid curves are the theoretical predictions.

in terms of $\Gamma = \hbar/\tau$, the expected full width at half maximum of the emitted line. The data taken with the source vibrated has been represented in these figures by the light dashed line in order to keep the number of data points from becoming so large as to be confusing. The solid curve is as before a theoretical curve. Similar data for a thinner foil (1.27 mg/cm^2 of Fe^{57} in an enriched foil) are shown in Fig. 22 and for a still thinner foil (0.22 mg/cm^2 of Fe^{57} in a normal isotopic concentration in Fig. 23.

Not shown are data which were obtained to verify the prediction of the theory that the delayed time spectrum depends only on the magnitude of the shift in gamma-ray energy and not on its sign. A run was made in which data were accumulated only during travel of the source in one direction and the result was compared with that obtained when data were accumulated during travel in both directions. No difference could be observed between the two runs.

All of the data have been compared to the theoretical expression, the values of parameters given in Table I being used. These are all

TABLE I. Values of parameters used with theory of Sec. II to fit data in Figs. 20, 21, 22, 23, and 24.

Parameter	Value	Comment
f	0.6	Fraction of 14.4-kev gamma rays emitted without recoil
f'	0.6	Fraction of Fe^{57} nuclei absorbing without recoil
α	15	Internal conversion coefficient
σ_0	$1.48 \times 10^{-18} \text{ cm}^2$	Peak absorption cross section for no hyperfine splitting
β	$2 N \sigma_0 f'$	Thickness parameter of theory. (This value is twice the expected value.)
N	- - -	Number of Fe^{57} nuclei per cm^2 in absorber. (Obtained from weight of foil)

as expected except β ; all theoretical curves are plotted for a value of β twice that obtained from the weight of the absorber foil. With this reservation and when allowance is made for the effect of finite resolution time, the fit between theory and experiment is fairly good. In particular, the predicted overshoot was observed; this is most noticeable in Fig. 21, where the curves for 5 Γ , 7 Γ and 11 Γ show that, at certain times, a higher intensity is obtained with the absorber than without it.

Fig. 24. Transmission (relative to the vibrated condition) of enriched Fe^{57} absorber obtained at $\frac{1}{2}\tau$ and 4τ after formation of the 14.4-kev state. The solid and dashed curves represent the theoretical predictions, the circles the experimental data points.

maximum decreases from about 3Γ at $t = \tau/2$ to about 0.7Γ at $t = 4\tau$. The half width measured without consideration of time was about 1.6Γ for this particular absorber ($1.27 \text{ mg/cm}^2 \text{ Fe}^{57}$).

In some cases the discrepancies are larger than experimental error. A number of possible sources of deviation from the theory were investigated. First, the theory assumes that no scattered radiation was detected. However, the geometric arrangement we used in order to keep the coincidence rate high was such that any appreciable scattering would have been detected. We made a crude check of this by increasing the distance from the source to detector from $\frac{3}{4}$ in. to 2 in. The fact that no change in the time spectra other than the reduced counting rate was observed indicates that scattered radiation was not contributing to the effect. Second, the source and detector might be polarized (because of permanent magnetization or by stray magnetic field) and thus change the

We have chosen to plot the relative transmission as a function of time, using the energy shift ΔE as a parameter to label the various curves. This has the advantage of allowing a direct estimate of the effect of time resolution. One could, of course, plot the transmission as a function of ΔE with the time as a parameter. This is done in Fig. 24 which shows the theoretical and experimental transmission (relative to that of the vibrated condition) vs ΔE for the times $t = \tau/2$ and $t = 4\tau$ after the formation of the excited state. Note that the apparent half width at half

relative intensities and polarizations of the hyperfine lines. To test for static polarization of source and detector, transmission measurements were made with various orientations of the clamped source and absorber. No effect larger than the statistical accuracy of 1% was found. In another measurement, an upper limit of 5 gauss was put on the local magnetic field, with a probable value close to the earth's field. These two observations make it unlikely that the source or absorbers were polarized. Third, because the measured line widths were somewhat greater than they should have been, one should perhaps average over a range of energy shifts in the region of the nominal displacement ΔE . A series of curves were calculated by averaging the curves for a given ΔE over a Gaussian distribution of ΔE . Although the agreement between theory and experiment could be improved in some cases in this way, it was worse in other cases and no net improvement resulted.

B. LINEAR-MOTION GENERATOR FOR MOSSBAUER EXPERIMENTS

J. Baumgardner

Method

One of the more attractive methods of providing accurately controlled motion of sources or absorbers in experiments involving the Mossbauer effect is by the use of suitable loudspeaker mechanisms. In this application, a moving-coil loudspeaker acts as a linear motor, cone displacement being proportional to voice-coil current within the limits imposed by the restoring force provided by the suspension system. Loudspeakers designed specifically for low-frequency sound reproduction with relatively large cone excursions have suspension characteristics permitting displacements as great as 1 in. peak to peak with good linearity. The motion of such a device is inherently free of spurious vibrations associated with rotating or sliding members in mechanical systems. The only spurious vibrations present are

Fig. 25. Transistorized driving amplifier.

those caused by environmental acoustic and mechanical disturbances. It is possible to make accurate measurements of these spurious vibrations so that their effects on a particular experiment may be evaluated and suitable steps taken to reduce them to acceptable levels. This may be done by mechanically driving the cone a measured distance at a low frequency and measuring the voltage

generated by the voice coil. When this calibration has been made, the motions resulting from acoustic and mechanical vibrations may be determined by the voltages they generate. It has been found that placing the loudspeaker mechanism in a soundproofed enclosure reduces these effects considerably. Measurements made under these conditions show that spurious movements correspond to velocities of less than 0.0001 in./sec, and further reductions are possible in quieter surroundings.

A suitable driving amplifier circuit employing direct-coupled power transistors has been developed to permit the application of controlling voltages of various time-amplitude functions, and of frequencies from dc to several hundred cycles per second. These voltages have been obtained from a Hewlett-Packard Model 202 function generator. The circuit for this amplifier is shown in Fig. 25.

Performance

Several methods were used to test the amplifier for linearity. A dc check was made by applying equal increments of voltage to the amplifier input and measuring the resulting movement of the speaker cone with a micrometer. The movement proved to be linear within the accuracy of measurement (2%) over a total excursion of 0.2 in. for the

Jensen 8-in. Flexair woofer employed. Intermodulation distortion tests on the amplifier showed less than 1% distortion at 6 v rms output, and about 0.15% at the 2 v rms level used for Mössbauer experiments. Linearity for low-frequency triangular-wave input was tested in the following way. The output signal, which is opposite in phase from the input, was mixed with the input signal and adjusted in amplitude to provide cancellation. Any remaining signal represents noise or distortion. This signal was found to be 15 mv for an output of 12 v peak to peak, or about 0.1%.

The duration of the mechanical transients due to the inertia of the speaker cone and attached sample holder was measured by observing the duration of the transient voltage generated by a sudden displacement of the voice coil, and found to be

less than 25 msec. These transients occur at the peaks of the triangular wave when the direction is suddenly reversed, and amount to less than 1% of the period for frequencies of 0.2 cps or less. Mössbauer transmission curves (Fig. 26) obtained with the loudspeaker drive system are essentially the same as those obtained on the precision lathe, for the same Mössbauer source and thin absorber. The speaker drive assembly, consisting of the speaker and source holder, absorber holder, detectors, and preamplifiers, was housed in a plywood cabinet vibration isolated from the floor and lined with 1-in. rock-wool sound insulation. This drive system has been successfully employed for several months in an experiment on delayed coincidence measurements of resonantly filtered gamma rays from Fe^{57} , as described in the preceding report.

Fig. 26. Transmission relative to that in unvibrated condition vs energy shift due to Doppler effect, obtained with a 1.27-mg/cm² Fe^{57} absorber.

I-95-2 Total Neutron Cross Section for C^{12} from 500 kev to 1350 kev (5220)

C. M. Huddleston, R. O. Lane, L. L. Lee, Jr., and F. P. Mooring

This project has been completed and the results have been published in a report entitled: "Total Neutron Cross Section for C^{12} from 500 kev to 1350 kev," C. M. Huddleston, R. O. Lane, L. L. Lee, Jr., and F. P. Mooring, Phys. Rev. 117, 1055-1056 (February 15, 1960).

✓ I-102-16 Neutron Cross Sections by Self-Detection (5220)

C. M. Huddleston, J. E. Monahan, and F. P. Mooring
Reported by C. M. Huddleston

In previous determinations of the energy dependence of the efficiency of the counter assembly used in the self-detection measurements,^{1,2} a long counter (assumed to be very nearly flat in response) was compared with the counter assembly over a range of neutron energies from about 1 kev to 1 Mev. Figure 27 shows a typical result. The general trend of the curve, indicating an increase in the efficiency of the counter assembly with increasing energy, is believed to be close to correct because, as explained in reference 2, such a variation in response accounts for earlier results with bismuth. However, it does not seem reasonable that the efficiency of the counter tank should exhibit the structure shown in Fig. 27 below 300 kev.

¹ C. W. Kimball, A. S. Langsdorf, Jr., and F. P. Mooring, Physics Division Summary Rept. ANL-5818 (Oct.-Dec. 1957), p. 15.

² C. M. Huddleston, J. E. Monahan, and F. P. Mooring, Physics Division Summary Rept. ANL-6111 (Feb. 1960), p. 19.

It was, therefore, decided to make an independent determination of the efficiency of the counter assembly. For this purpose, a gas scintillation counter was built. The gas cell, operating with xenon at 30 psig, contained a stainless steel foil (20 cm^2 in area) onto which uranium (enriched to 93% U^{235}) was deposited in the form of U_3O_8 to a thickness of 1 mg/cm^2 .

Figure 28 shows the efficiency of the counter tank relative to the fission detector. Statistical errors average about $\pm 10\%$.

As another check, the long counter was used again to calibrate the counter tank. This time the long counter was placed behind the monitor tank, so that the monitor tank served as a collimator and protected the long counter from scattered neutrons. The results of this measurement are shown in Fig. 29.

Agreement is quite good between the results of these two measurements, and

Fig. 27. Energy dependence of the efficiency of the counter assembly relative to a long counter. (Earlier result.)

Fig. 28. Energy dependence of the efficiency of the counter assembly relative to a fission detector.

Fig. 29. Energy dependence of the efficiency of the counter assembly relative to a well collimated long counter.

the variation in efficiency of the counter assembly with neutron energy is now fairly well established. The earlier results of Fig. 27 must have been due to scattering of neutrons by iron and aluminum near the target.

II. MASS SPECTROSCOPY

II-18-11

Lead Ages of Meteorites

(5230)

David C. Hess and Royal Marshall*

INTRODUCTION

The "age" of rocks, minerals and meteorites is of interest to the cosmologist and the geologist. The fact that certain meteorites^{1,2} have ages³ of about 4.5 Ae and that the average lead on the surface of the earth, when determined in a similar manner, also has this age^{4,5} leads to the assumption of a common origin for meteorites and the earth. "Lead" ages depend on several assumptions: (1) the original lead had the composition of the lead found in iron meteorites. (2) The composition of this lead is modified by the addition of decay products of uranium and thorium. (3) The geochemical history of the object is known or fits some simple assumptions.

For the case of some meteorites, more lead was found than could be accounted for under the above assumptions.^{1,6} We have therefore made additional measurements on meteorites in order to solve this dilemma.

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¹ C. C. Patterson, *Geochim. et Cosmochim. Acta* 7, 151-153 (1955).

² R. R. Marshall and D. C. Hess, *J. Chem. Phys.* 28, 1258-1259 (1958).

³ 1 aeon (Ae) = 10^9 yr. This definition has been introduced by Urey [*H. C. Urey, Year Book of the Physical Society, London* (The Physical Society, London, 1957), pp. 14-29].

⁴ F. G. Houtermanns, *Nuovo cimento* 10, 1623 (1953).

⁵ C. Patterson, G. Tilton, and M. Inghram, *Science* 121, 69-75 (1955).

⁶ H. Hamaguchi, G. W. Reed, and A. Turkevich, *Geochim. et Cosmochim. Acta* 12, 337-347 (1957).

The concentration of lead in meteorites is in the range from near one part per million downward to hundredths of a p.p.m. This means that if 25 g of meteorite are used, the total yield may be a few micrograms. This requires sensitive methods of measurement and extreme precautions against contamination of the sample lead by any other lead. Since one source of severe contamination is air-borne lead,⁷ the time of exposure to air during processing should be kept to a minimum. The evaporation technique used helps in this and also reduces the volume of reagents required in completing the lead separation.

METHODS OF CALCULATING AGE

The isotopic composition of lead changes in the presence of uranium and thorium. The decay of uranium causes changes in the amounts of Pb^{207} (from U^{235}) and Pb^{206} (from U^{238}), while Th^{232} changes the amount of Pb^{208} . Since the Pb^{204} is not changed by natural radioactive decay chains, it is used as a reference. The ratios of isotopes⁸ $\alpha = [\text{Pb}^{206}]/[\text{Pb}^{204}]$, $\beta = [\text{Pb}^{207}]/[\text{Pb}^{204}]$, and $\gamma = [\text{Pb}^{208}]/[\text{Pb}^{204}]$ are usually used to describe various leads and are convenient in making calculations.

Let us assume that, at some time T in the past, the meteorite was formed with lead of isotopic composition given by α_T , β_T , γ_T and relative amounts of uranium and thorium given as $\mu_T = [\text{U}^{238}]/[\text{Pb}^{204}]$, $\kappa_T = [\text{Th}^{232}]/[\text{U}^{238}]$, and $\epsilon_T = [\text{U}^{235}]/[\text{U}^{238}]$. Since the simplest model we can assume is that in which there is no geochemical change (an assumption supported by A-K age measurements), then we should have at the present time

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G. R. Tilton, C. Patterson, H. Brown, M. Inghram, R. Hayden, D. Hess, and E. Larsen, Jr., *Bull. Geol. Soc. Am.* 66, 1131-1148 (1955).

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The brackets mean "concentration of" in grams per gram, μg per μg , etc.

$\mu = \mu_T \exp(-\lambda_1 T)$. The U^{238} decayed to Pb^{206} so $a = a_T + \mu_T [1 - \exp(-\lambda_1 T)]$; and since $\mu_T = \mu \exp(\lambda_1 T)$, it follows that

$$a = a_T + \mu [\exp(\lambda_1 T) - 1] , \quad (1)$$

and similarly

$$\beta = \beta_T + \mu \epsilon [\exp(\lambda_2 T) - 1] \quad (2)$$

$$\gamma = \gamma_T + \mu \kappa [\exp(\lambda_3 T) - 1] , \quad (3)$$

where the ratios without subscripts are the values now (e.g., $\epsilon = \epsilon_T [\exp(\lambda_1 T)] / [\exp(\lambda_2 T)]$) and λ_1 , λ_2 , and λ_3 are decay constants for U^{238} , U^{235} , and Th^{232} , respectively. A more extensive development of these formulas has been given, for example, by Geiss.⁹

The values a_T , β_T , and γ_T are taken from the measurement on the lead from an iron meteorite which contains negligible uranium (or thorium). A good value can also be obtained by extrapolating back from various lead measurements. One can of course only say that this is the most primeval lead measured so far.

The age can be calculated from Eqs. (1) and (2) without a knowledge of the value of μ , since all uranium measured in meteorites so far has a value of ϵ within 10% of the terrestrial value.

EXPERIMENTAL PROCEDURE

The surfaces of portions of a meteorite were cleaned by grind-

⁹ J. Geiss, Z. Naturforsch. 9A, 218 (1954).

ing or chiseling and rinsing with nitric acid and distilled water. Iron meteorites were sawed (with a diamond saw) to sizes that would fit in the crucibles. Stone meteorites were crushed in a stainless steel mortar (which was cleaned with concentrated hydrochloric acid between samples). The stainless steel contained less than 10 p.p.m. of lead.

Aliquots of the meteorite were weighed into cylindrical carbon crucibles made of high-purity graphite.¹⁰ The crucibles held 20 to 25 g of sample.

For runs made to determine the concentration, spike solution containing lead enriched in Pb^{206} was added.¹¹ For all runs, the surface of the powder was wetted with dilute nitric acid and dried to form a crust which resisted "puffing" of the powder which could be caused by trapped gases at the beginning of volatilizations. In some cases Pb^{212} was used as a tracer to determine yields. With the yield known, a colorimetric estimate (in the dithizone extraction) can be made of the amount of lead. Beta particles from the Bi^{212} daughter of the Pb^{212} were counted.

The crucible was placed on a pedestal of alumina or quartz. When quartz was used, a small, expendable, quartz ring was placed between the crucible and the pedestal. In some cases a quartz cylinder was used as a heat shield and a 100°C higher operating temperature was achieved ($1300\text{--}1400^\circ\text{C}$ vs $1200^\circ\text{--}1300^\circ\text{C}$ as measured with an optical pyrometer). This arrangement was enclosed in a double-walled water jacket (inner wall of quartz) and the crucible was heated by an induction

¹⁰ The graphite was obtained from United Carbon Products Co., Inc., Bay City, Michigan.

¹¹ The isotopic ratios of this spike (kindly supplied by Dr. G. R. Tilton of the Carnegie Institution of Washington) were $(\text{Pb}^{206}/\text{Pb}^{204}) = 8630$, $(\text{Pb}^{206}/\text{Pb}^{207}) = 16.4$, and $(\text{Pb}^{206}/\text{Pb}^{208}) = 213$.

heater. A slow stream of pure dry nitrogen (filtered through a sintered glass disk of medium porosity) passed through the jacket and out at the top through a moist plug of quartz wool. This apparatus is a modification of that of¹² Edwards and Urey.

The material which condensed on the quartz wall of the water jacket was rinsed through the quartz wool and out of the jacket with concentrated nitric acid and distilled water. A rapid dithizone extraction followed. Lead could be isolated within about a half hour at this stage. About 1 μ g of the extracted lead, in the form of a nitrate solution, was placed on a tantalum filament and dried. A drop of saturated boric acid solution (boric acid in nitric acid) was added and the filament heated slowly to a dull red heat. The filament was then mounted in the mass spectrometer.

The heating current for the filament was controlled by a current regulator. The ions were detected with an electron multiplier, the output of which was amplified by a vibrating-reed electrometer and then recorded on a strip-chart recorder.

Since it was found that lead could be easily leached from a borosilicate glass wall with nitric acid, most of the "glassware" used was quartz or polyethylene. Only the separatory funnels were borosilicate glass. All the chemical ware was initially cleaned with hot concentrated potassium hydroxide, rinsed, placed in hot concentrated nitric acid, and finally rinsed.

Tests with spike lead suggested that the tantalum filaments might be contributing almost 0.1 μ g of lead. Therefore, the surface of the tantalum filament was cleaned by dipping it in concentrated nitric acid and then in distilled water.

¹² G. Edwards and H. C. Urey, *Geochim. et Cosmochim. Acta* 7, 154-168 (1955).

To allow correction to be made for contamination lead introduced in phases of the experiment from which it could not be eliminated, blank runs were made by evaporating spike lead from a graphite crucible and then processing as with an unknown.

RESULTS

Table II gives the concentration of lead in seven stone meteorites, some of which have been measured by different methods. Five of these were done in the present work by isotopic dilution. The values obtained are shown in Table III. The blank correction amounts to $1.5 \pm 0.4 \mu\text{g}$ of lead per volatilization so there is some uncertainty in the results.

The isotopic ratios in some of the chondrites, corrected for contamination, are shown in Table IV.

The ages calculated from these data are shown in Table V together with values of μ and κ . The measured and calculated values agree within a factor of two.

Families of curves can be plotted from Eqs. (1) and (2) with α as abscissa and β as ordinate. If values of α and β are calculated for a fixed final or initial ratio ¹³ of uranium to lead but for various values of T , a curve such as that joining PL and AC is obtained. If T is fixed, a plot of α and β for various final (or initial) ratios of uranium to lead produces straight lines ("isochrons"). The values listed in Table V are plotted in Fig. 30. It is seen that the points lie close to a straight line corresponding to $T = 4.6 \text{ AE}$, except for Holbrook-N(b) (4.0 AE but with considerable uncertainty). We therefore conclude that the meteorites were formed

¹³

The slopes and values will be different but the general configurations of curves will be similar whether initial or final ratios are chosen.

TABLE II. Concentration of lead in stone meteorites.

Meteorite	Amount of Pb (p.p.m.)				
	Present work	Reed et al. (1958)	Marshall and Hess	Edwards and Hess (1956)	Patterson (1955)
Richardton	0.05 _g	-	0.11 ^a	-	-
Holbrook	0.28	0.38	0.32	0.28 ^b	-
Forest City	0.09 ₀	<0.15	0.095	-	0.4
Beardsley	0.13	0.15 ^c	-	-	-
Plainview	0.46	-	-	-	-
Modoc	-	<0.09	-	0.3	0.9
Nuevo Laredo	-	0.76 ^d	-	-	0.7 ^e

^a Average of two isotopic dilution experiments.

^b Average of five values for the amount of Pb recovered after volatilization from 15-g samples, each run corrected for 1 μ g contamination.

^c Recalculated on the basis of the isotopic composition reported in this paper. (Table IV).

^d Recalculated on the basis of corrected values for the analysis by G. Edwards and D. C. Hess, Proceedings of the Second Conference on Nuclear Processes in Geologic Settings, Pennsylvania State University, 1955 (NAS-NRC Pub. 400) pp. 100-108.

^e Reported as 0.68 p.p.m. by J. H. Reynolds and J. I. Lipson, *Geochim. et Cosmochim. Acta* 12, 330-336 (1957).

Fig. 30. The α - β diagram for lead from chondrites. PL indicates primeval lead [reference 1] and AC is average modern crustal lead [G. L. Bate, J. R. Huizenga, and H. A. Potratz, *Geochim. et Cosmochim. Acta* 12, 225-237 (1957)]. Other letters designate meteorites referred to in the text and in Table V [e.g., Rb refers to the (uncorrected) isotopic composition of lead found in our second analysis of the Richardton chondrite]. The solid straight line is the isochron for 4.6 Ae . The curved line represents the evolution of lead in the crust of the earth.

TABLE III. Quantities of lead observed for chondrites by isotopic dilution.

Sample	Amount of sample (g)	Amount of Pb determined by isotopic dilution (μg)	Concentration of Pb (p.p.m.)
Richardton	17.45	1.87	0.019
	11.56	2.58	0.091
AVERAGE RICHARDTON			0.055
Holbrook-N	10.36	1.90	0.036
	10.04	3.50	0.32 ^a
Holbrook-M 1	14.02	4.77	0.21
	10.31	6.77	0.51
Holbrook-M 2	9.41	6.15	0.49
	10.49	2.78	0.12
AVERAGE HOLBROOK			0.28
Forest City-1	10.57	2.51	0.093
Forest City-2	4.87	1.95	0.086
AVERAGE FOREST CITY			0.090
Beardsley	9.48	2.78	0.13
Plainview	10.87	6.57	0.46

^a No quartz shield was used in this experiment. Blank correction was 0.25 μg of lead.

TABLE IV. Isotopic composition of lead in stone meteorites
(corrected for contamination)

Sample	$[\text{Pb}^{208}]/[\text{Pb}^{204}]$ (α)	$[\text{Pb}^{207}]/[\text{Pb}^{204}]$ (β)	$[\text{Pb}^{208}]/[\text{Pb}^{204}]$ (γ)
Richardton a)	27.57	22.13	48.51
Richardton b) ^a	>38.2	>27.7	>56.3
Holbrook-N a)	17.5 ₂	15.5 ₂	38.9 ₃
Holbrook-N b)	21.2 ₀	15.2 ₂	35.5 ₃
Holbrook-M 1	16.6 ₈	14.5 ₇	35.6 ₈
Holbrook-M 2	16.0 ₄	14.0 ₄	33.8 ₂
Beardsley	13.6 ₇	12.4 ₀	31.8 ₅
Plainview	14.8 ₇	13.6 ₁	34.0 ₀

^a Because the lead from Richardton (b) is very radiogenic and its concentration has a large uncertainty, the isotopic ratios have not been corrected for contamination.

TABLE V. Lead-lead ages and geochemical ratios computed from the isotopic compositions of lead from chondrites.^a

Sample	Pb-Pb Age ($\text{\AA}$)	μ_1 (Calculated from isotopic composition of lead)	μ_2 (From measured concentra- tions) ^b	K_1 (Calculated from isotopic composition of lead)	K_2 (From measured concentra- tions) ^{b, c}
Richardton (a)	4.6 ₉	17.1 ₃	9.5	4.3 ₂	3.1 ₉
Richardton (b)	4.61 ^d	>28	>23.8	3.70 ^d	
Holbrook-N (a)	4.6 ₈	7.6 ₂	2.6	4.83	3.0 ₉
Holbrook-M 1	4.54	7.1 ₁		3.51	
Holbrook-M 2	4.48	6.6 ₀		2.68	
Beardsley	4.27	4.5 ₀	4.5 ^e	2.27	4.4 ₅ ^e
Plainview	4.58	5.2 ₆	[1.4] ^f	3.43	-
Forest City	4.50 ^g	9.80 ^g	7.4	3.97 ^g	3.8 ₅
Average crustal lead	4.51	9.18 ^h	-	4.07 ^h	-

^a Values of the physical constants used for the calculations in this table:

$\lambda_1 = 0.153_{69} \text{\AA}^{-1}$
 $\lambda_2 = 0.972_{16} \text{\AA}^{-1}$

E. H. Fleming, Jr., A. Ghiorso, and B. B. Cunningham,
Phys. Rev. 88, 642-652 (1952).

$\lambda_3 = 0.488_{13} \text{\AA}^{-1}$
 $\epsilon = 1/137.7$

F. E. Senftle, T. A. Farley, and N. Lazar, Phys. Rev. 104,
1629 (1956).

F. E. Senftle, L. Stieff, F. Cuttitta, and P.K. Kuroda, Geochim.
et Cosmochim. Acta 11, 189-193 (1957).

$\alpha_T = 9.50$
 $\beta_T = 10.36$
 $\gamma_T = 29.49$

Patterson, reference 1.

^b With uranium concentrations of Hamaguchi et al., reference 6.

^c With thorium concentrations of G. L. Bate, J. R. Huizenga, and H. A. Potratz,
Geochim. et Cosmochim. Acta 12, 225-237 (1957).

Footnotes for TABLE V continued.

- ^d Calculated from ratios corrected for estimated contamination.
- ^e Uranium concentration = 0.011 p.p.m. (G. W. Reed, personal communication).
- ^f Based on only one measurement of the lead concentration. Average uranium content for chondrites assumed to be 0.011 p.p.m.
- ^g From isotopic composition given by Patterson, reference 1.
- ^h R. R. Marshall, *Geochim. et Cosmochim Acta* 12, 225-237 (1957). The slight differences between the values for μ and κ in the above table and the ones published in 1957 are because of the slightly different sets of values for the physical constants.

4.6 Ago either in their present form or in a form which has changed by processes which did not change the uranium and lead in the material.

II-39-2

Kinetic Energy of Organic Radicals

(5230)

H. E. Stanton

This work has been discontinued as a separate project and will appear hereafter as a part of Project II-40, Fragmentation of Organic Molecules.

II-40-6

Fragmentation of Hydrocarbons

(5230)

H. E. Stanton

The reactions induced by bombarding atoms and molecules with electrons having energies ranging from a few hundred to a few thousand ev have become increasingly important because of the effects of β rays on

biological systems, and problems concerning the stopping of fast electrons in matter. The fragmentation of molecules under electron bombardment in this energy range has not been studied extensively. Tuitsky, Kurpiyanov, and Tikhomirov¹ reported some experiments on halogen derivatives of hydrocarbons, obtained by use of electrons with energies up to about one kilovolt in a mass spectrometer. Wexler² has described the yield of fragments in some halogenated hydrocarbons when the halogen nucleus was radioactive.

The experiments to be reported here were concerned with the yield of fragments and their kinetic energy distributions when neopentane and normal heptane were bombarded by electrons with energies varying from 70 ev to about 2.4 kev.

When single atoms are under electron bombardment, the ionization efficiency curve rises as the electron energy is increased from the appearance potential, reaches a broad maximum around 100 to 200 ev, and thereafter decreases indefinitely as the electron energy is raised into the kev region. In the energy region above a few hundred volts the Born approximation generally applies.³ The resulting theoretical cross section for formation of the ion is proportional to $E^{-1} \log E$, where E is the electronic energy, for those transitions which are optically allowed. For those transitions which are not optically allowed, the cross section falls off as E^{-1} .

The bombardment of molecules is considerably more complicated because of diffraction effects and the fact that each atom produces inelastic scattering independently. For the energies used here, however, similar asymptotic behavior may apply. In addition, molecules may break up in different ways, and produce fragment ions whose masses may depend on the

¹ Tuitsky, Kurpiyanov, and Tikhomirov, Symposium on Radiation Chemistry—Academy of Science of the U.S.S.R., Moscow (1955).

² S. Wexler and D. C. Hess, J. Chem. Phys. 62, 1382 (1958).

³ H. S. W. Massey and E. H. S. Burhop, Electronic and Ionic Impact Phenomena (Oxford University Press, 1956), Chap. III, Sec. 3.2.

energy transfer in the impact and on the mode of dissociation. This latter phenomenon was investigated for neopentane and normal heptane.

The investigation was carried out on the energy-selecting mass spectrometer MA-17 equipped with the source for electron bombardment. This source focuses an electron beam of variable energy through the ion box, in a direction at right angles to the ion slit. This was regulated to a constant value, and electron currents of from $0.5\text{ }\mu\text{a}$ to $10\text{ }\mu\text{a}$ were used.

The ions formed by the impact were drawn out of the ion box and given an initial acceleration of 500 v before entering the energy analyzer. After leaving there, they were given an additional acceleration of 7500 v (± 40 v for fine tuning) prior to entering the mass analyzer. Mass sweeping was done magnetically. A run consisted of an energy sweep across the peak and back again for a given ion, the integrated intensity being recorded together with the background counts. The ion current issuing from the energy analyzer was also monitored as a check on operation.

The mass spectrum for normal heptane (C_7H_{16}) as obtained from MA-17 is shown by the right-hand members of the doublets in Fig. 31(a). The left-hand members form the mass spectrum as given in Project 44 of the American Petroleum Institute.⁴ Several of the very tiny peaks were omitted because of intensity limitations or high background peaks in MA-17. All peaks of both mass spectra were normalized relative to the arbitrary standard of 100 for mass 43. The ordinate scale is logarithmic with a datum line of 0.01. This type of scale was necessary because of the wide variations in peak height, but it has the disadvantage that very small differences in the figure may represent a sizeable factor in the total count.

⁴

Project 44, American Petroleum Institute, Chemical and Petroleum Research Laboratory, Carnegie Institute of Technology, Pittsburgh 13, Pennsylvania, October 31, 1957.

Fig. 31. (a) Mass spectrum of n-heptane bombarded by 70-ev electrons. The left-hand peak at each mass number is the result obtained by MA-17. These are to be compared with the right-hand peaks, taken as standards, which were found at the Bureau of Standards and reported in Project 44 of the American Petroleum Institute. Ordinates are the logarithms of the relative yields normalized to 100 for mass 43. (b) The mass spectra obtained from MA-17 for n-heptane at electron energies of 230 v (left members) and at 2100 ev (right members). Both spectra were normalized to 100 at mass 43.

The spectrum given by MA-17 clearly differs from that of project 44. From masses 15 to 43, the values found here are less than those of the "standard," and for most of the peaks of masses greater than 43 the yields from MA-17 are greater. For mass 15, MA-17 yielded 2.6 compared to an accepted value of 4.88; and at mass 100, MA-17 gave 46.6 as compared to a standard of 13.1. The differences at masses 53 and 54 may be real, or may be due to errors since both peaks were small and had large background corrections.

These differences in yields may be presumed to be due to the use of a multiplier as the final detector in MA-17. The amplitude of the output pulse of the multiplier is, among other things, an increasing function of the number of particles striking the first dynode. Since the mass-15 peak comprises one carbon atom and 3 hydrogen atoms, its pulse height will be considerably less than for mass 100 for which there are 7 carbon atoms and 16 hydrogen atoms. Amplifier discriminations and the like make the final counting rate dependent on the pulse-height distribution.

In Fig. 31 (b) is shown a comparison between relative yields for electron energies of 230 v (left-hand member of each pair of peaks) and 2100 v (right-hand member). In this comparison, it turned out that all the peaks obtained at 2100 v were at most equal to, and usually less than, the comparable peak found for 230 v. Both spectra were normalized to the same height for mass 43, which was the largest peak in all spectra. Unfortunately, the relationship between the yields shown in Fig. 31 (b) were not rigorously maintained because of vagaries in the machine response, background peaks, etc. Runs were made for electron energies of 70, 230, 400, 750, 1000, 1400, 1800, and 2100 ev; and sequential comparison involving runs for electron energies of more than 230 ev showed rather definitely that, relative to the yield of mass 43 in n-heptane, the ionic yield of practically all fragments decreased as the electron energy increased. For several of the fragments, this decrease amounted to a factor of 2 or more, while for some others the change was trivial.

In general, the larger peaks (i.e., at masses 29, 57, 71, 85, 100) changed least. These fragments are all generated either by the ionization of the original molecule (mass 100) or by the rupture of the bond between adjacent carbon atoms. The other peaks (except mass 15) were formed by the removal of one or more hydrogens. The relative decrease in

Fig. 32. The generally upper curve represents the product of the electron energy by the yield of ions of mass 43 from n-heptane, plotted as a function of the electron energy. The generally lower curve is a similar plot for the ions of mass 57 from neopentane.

yield of these fragments appeared to increase as the number of hydrogens that were removed increased. The decrease in relative yield also correlated well with the appearance potential for the particular fragment (where available). Thus, in Fig. 31 (b) the change in yield was insignificant for the parent ion (mass 100), whose appearance potential is listed as 10.3 v; whereas the yield of $C_3H_3^+$ (mass 39), whose appearance potential is 23.4 v, changed by a factor of 3.

Of course the "absolute" yield (i.e., the total intensity for fixed source pressure and electron current) decreased

markedly for all fragments as the electron energy increased. This conforms to the theory for production of atomic ions as outlined above. The results are shown in Fig. 32, where the yield of the fragment of mass 43 from n-heptane multiplied by the energy of the bombarding electrons is plotted as a function of the electron energy. Also included is the corresponding curve for the fragment at mass 57 (the principal one) from neopentane. If a transition is optically allowed, the curve should asymptotically approach a straight line with a positive slope, and if not allowed, it should level off if the theory is applicable. Further checking would be required to determine whether either curve in Fig. 32 agrees quantitatively with this theory.

The analysis of the data for neopentane indicated that the fragment of mass 57, which was the most abundant one for all energies,

Fig. 33. (a) Comparison of the mass spectrum of neopentane as obtained in MA-17 with 100-ev electrons with the spectrum given in Project 44 for 70-ev electrons. (b) Comparison of the mass spectra at bombarding energies of 100 ev (left) and 2400 ev (right) for neopentane.

decreased in yield faster with electron energies than other fragments. For this comparison, the selection of the peak at mass 55 or the parent peak at mass 72 would have been preferable.

The mass spectrum for neopentane obtained in MA-17 and compared with the findings of Project 44 are shown in Fig. 33 (a), while the comparison of mass spectra for electron energies of 100 and 2400 ev is shown in Fig. 33 (b).

The same general conclusions seem to apply, however, as for normal heptane.

III. CRYSTALLOGRAPHYIII-10-2 The Crystal Structure of Lithium Tungstate (5230)

W. H. Zachariasen and H. A. Plettenger

Reported by W. H. Zachariasen

Many years ago one of us¹ reported that the compounds Be_2SiO_4 (mineral phenacite), Zn_2SiO_4 (willemite), Li_2BeF_4 , Li_2MoO_4 , and Li_2WO_4 were isostructural. Shortly afterwards W. L. Bragg² described the structure of phenacite, and Bragg and Zachariasen³ the structure of willemite.

Since no reliable results for the bond lengths of the tungstate group are available in the literature, a determination of all atomic coordinates in the lithium tungstate structure was carried out.

The dimensions of the hexagonal cell with 18 molecules and of the rhombohedral cell with 6 molecules are:

Hexagonal cell: $a = 14.361 \pm 0.003 \text{ \AA}$, $c = 9.602 \pm 0.002 \text{ \AA}$

Rhombohedral cell: $a = 8.888 \pm 0.002 \text{ \AA}$, $\alpha = 107.78^\circ \pm 0.03^\circ$.

The space group is $R\bar{3}$, and all atoms are in general positions (i. e., none of their coordinates are determined by symmetry conditions so all three coordinates must be determined). Referred to hexagonal axes (which are used in the following unless otherwise specified) the equivalent coordinates

¹ W. H. Zachariasen, Norsk. geol. Tidsskr. 9, 65 (1926).

² W. L. Bragg, Proc. Roy. Soc. (London) A113, 642 (1927).

³ W. L. Bragg and W. H. Zachariasen, Z. Krist. 72, 518 (1930).

are⁴

$$(0,0,0) \left(\frac{1}{3}, \frac{2}{3}, \frac{1}{3} \right) \left(\frac{2}{3}, \frac{1}{3}, \frac{2}{3} \right) + \\ \pm (x,y,z) (-y, x-y, z) (y-x, -x, z) .$$

DETERMINATION OF THE ATOMIC POSITION

The final values of the parameters were deduced with the aid of a least-squares refinement carried out on an IBM-704 machine using the Busing-Levi⁵ program. The atomic coordinates reported for the phenacite structure were used as a starting point and isotropic temperature factors were assumed. Because of the small effect of lithium, no attempt was made to vary the temperature factor for these atoms, and a value of $B = 2.5 \text{ \AA}^2$ was presupposed.

The refinement process gave an R-factor of 0.065 (including zeros) and the results shown in Table VI.

TABLE VI. Final parameters (hexagonal axes).

	x	y	z	B in $\text{\AA}^2$
W	-0.02035 ± 0.00007	0.19537 ± 0.00007	0.25069 ± 0.00010	0.176 ± 0.025
O _I	0.1117 ± 0.0016	0.2112 ± 0.0016	0.2500 ± 0.0021	1.11 ± 0.36
O _{II}	-0.0010 ± 0.0016	0.3275 ± 0.0016	0.2502 ± 0.0021	1.04 ± 0.35
O _{III}	-0.0909 ± 0.0016	0.1238 ± 0.0016	0.0993 ± 0.0021	1.68 ± 0.35
O _{IV}	-0.0970 ± 0.0016	0.1235 ± 0.0016	0.4028 ± 0.0021	0.95 ± 0.34
Li _I	-0.014 ± 0.004	0.191 ± 0.004	0.591 ± 0.005	(2.5)
Li _{II}	-0.027 ± 0.004	0.187 ± 0.004	0.911 ± 0.005	(2.5)

⁴ The notation and terminology used in the specification of the coordinates is that of the International Tables for X-Ray Crystallography (International Union of Crystallography, Kynoch Press, Birmingham, England, 1952), Vol. 1.

⁵ W.R. Busing and H. A. Levi, Oak Ridge National Laboratory Report 59-4-37.

THE BOND LENGTHS

The atomic coordinates of tungsten have been found with a precision of 0.001 Å. The corresponding accuracy is 0.02 Å for oxygen and 0.05 Å for lithium atoms.

The bond lengths in the oxygen tetrahedra about tungsten and lithium are

W — O _I = 1.79 ± 0.02 Å,	
W — O _{II} = 1.77 ± 0.02 Å,	
W — O _{III} = 1.78 ± 0.02 Å,	
W — O _{IV} = 1.81 ± 0.02 Å,	
Li _I — O _I = 1.87 ± 0.08 Å,	Li _{II} — O _I = 1.88 ± 0.08 Å
Li _I — O _{II} = 2.10 ± 0.08 Å,	Li _{II} — O _{II} = 1.98 ± 0.08 Å
Li _I — O _{IV} = 1.80 ± 0.08 Å,	Li _{II} — O _{III} = 2.00 ± 0.08 Å
Li _I — O _{IV} = 1.80 ± 0.08 Å,	Li _{II} — O _{III} = 2.02 ± 0.08 Å

The WO₄ tetrahedron is regular within experimental error, the W—O bond angles ranging from 106° to 112°.

The average Li—O bond length (1.96 Å) is slightly smaller than the value (2.00 Å) observed in Li₂O. However, in the latter structure each oxygen is bonded to eight lithium atoms, so that the Li—O bond length presumably is increased because of lithium-lithium repulsion.

V. THEORETICAL PHYSICS, GENERAL

V-4-13

Investigation of Nuclear Structure

(5220)

M. Goeppert-Mayer and R. D. Lawson

This project has been terminated with the publication of a paper entitled "Harmonic Oscillator Wave Functions in Nuclear Spectroscopy," R. D. Lawson and M. Goeppert-Mayer, Phys. Rev. 117, 174-184 (January 1, 1960).

PUBLICATIONS SINCE THE LAST REPORT

PAPERS

KINETICS OF UNIMOLECULAR DECOMPOSITION OF EXCITED ALKYLAMINE IONS

William A. Chupka and Joseph Berkowitz.....(Project II-28)
J. Chem. Phys. 32, 1546-1553 (May 1960).

GALILEAN INVARIANCE AND THE SCHROEDINGER EQUATION

Morton Hamermesh.....(Project V-30)
Ann. Phys. 9, 518-521 (April 1960).

NUCLEAR ENERGY LEVELS OF Na^{24} . I

Carl T. Hibdon.....(Project I-98)
Phys. Rev. 118, 514-532 (April 15, 1960).

DIFFERENTIAL CROSS SECTIONS FOR NEUTRON RESONANCE SCATTERING FROM Na^{23}

R. O. Lane and J. E. Monahan.....(Project I-18)
Phys. Rev. 118, 533-535 (April 15, 1960).

SOME SIMPLE FEATURES OF THE MÖSSBAUER EFFECT

Harry J. Lipkin (Consultant at ANL, Summer, 1959)..(Project I-19)
Ann. Phys. 9, 332-339 (February 1960).

THE MAGNETIC MOMENT OF THE LAMBDA

K. Tanaka.....(Project V-45)
Proceedings of the Midwest Conference on Theoretical Physics,
Purdue University, April 1-2, 1960, pp. 12-15.

ABSTRACT

ATOMIC BEAM STUDIES OF 27-HR Ho^{166}

L. S. Goodman, W. J. Childs, Richard Marrus,* Ingvar P. K. Lindgren,*
and Amado Y. Cabezis* (U. of Cal., Berkeley).....(Project I-80)
Bull. Am. Phys. Soc. 5, 344 (June 15, 1960).

ADDITIONAL PAPERS ACCEPTED FOR PUBLICATION

HETEROGENEOUS REACTIONS STUDIED BY MASS SPECTROMETRY. I. THE REACTION OF $B_2O_3(s)$ WITH $H_2O(g)$

David J. Meschi, William A. Chupka, and Joseph Berkowitz.. (Project II-29)
J. Chem. Phys. in July 1960 issue.

HETEROGENEOUS REACTIONS STUDIED BY MASS SPECTROMETRY. II. THE REACTION OF $Li_2O(s)$ WITH $H_2O(g)$

Joseph Berkowitz, David J. Meschi, and William A. Chupka.. (Project II-29)
J. Chem. Phys. in July 1960 issue.

THE ISOTOPIC COMPOSITIONS AND CONCENTRATIONS OF LEAD IN SOME CHONDRITIC STONE METEORITES

David C. Hess and Royal R. Marshall (U. of Chicago).... (Project II-18)
Geochim. et Cosmochim. Acta in November 1960.

BRANCHING RATIOS FOR THE DECAY OF p-SHELL HYPERNUCLEI

R. D. Lawson and Manuel Rotenberg (U. of Chicago)..... (Project V-11)
Nuovo cimento.

STRIPPING REACTIONS AND THE STRUCTURE OF LIGHT AND INTERMEDIATE NUCLEI

Malcolm H. Macfarlane and J. B. French (U. of Rochester). (Project V-9)
Revs. Modern Phys. in July issue.

ENERGY DEGRADING-FOCUSING OF CYCLOTRON BEAM

W. J. Ramler, J. L. Yntema, and M. Oselka..... (Project I-22)
Nuclear Instr. and Methods.

BARYON MASS SPECTRUM

Katsumi Tanaka..... (Project V-45)
Phys. Rev. in August 15, 1960 issue.

STANDARD BORON SOLUTIONS FOR NEUTRON ABSORPTION MEASUREMENTS

S. Wexler
Nuclear Sci. Eng.

PERSONNEL CHANGES IN THE ANL PHYSICS DIVISION

NEW MEMBERS OF THE DIVISION

Resident Research Associates (Summer)

Mr. William R. Anderson, Department of Physics, University of Illinois, Navy Pier, Chicago. Luminescent properties of irradiated and unirradiated liquid scintillators. At Argonne June 13 to August 12, 1960. Host: L. J. Basile.

Dr. Richard H. Capps, Department of Physics, Northwestern University. High-energy theoretical physics. At Argonne June 28 to August 23, 1960. Host: M. Hamermesh.

Dr. Max Dresden, Department of Physics, University of Iowa. Lectures on dispersion relations; quantum theory of transport phenomena; nonrelativistic quantum field theory. At Argonne June 8 to about September 16, 1960. Host: M. Hamermesh.

Dr. Arthur K. Kerman, Department of Physics, Massachusetts Institute of Technology. Pairing correlations in the many-body problem. At Argonne June 15 to September 15, 1960. Host: D. R. Inglis.

Dr. Ernest Klema, Department of Nuclear Science and Engineering, Northwestern University. Empirical model for correlating nuclear data; development of semiconductor particle detector. At Argonne June 3 to September 16, 1960. Host: M. Hamermesh.

Dr. William D. McGlinn, Department of Physics, Northwestern University. Analytic properties of scattering amplitudes and their application to dispersion relations. At Argonne June 6 to September 20, 1960. Host: M. Hamermesh.

Mr. Marvin C. Mertz, Department of Physics, Valparaiso University. Study of the isotope shift in Cs by means of microwave excitation and optical pumping. At Argonne May 31 to September 1, 1960. Host: L. S. Goodman.

Dr. B. James Raz, Department of Physics, State University, College on Long Island. Cooperative phenomena in nuclei near closed shells. At Argonne June 6 to June 23, 1960. Host: M. Hamermesh.

Dr. Edward Shipley, Department of Physics, Northwestern University. Lifetimes of excited states of nuclei. At Argonne June 15 to September 16, 1960. Host: R. E. Holland.

Dr. Masao Sugawara, Department of Physics, Purdue University. Shell-model level splittings and nucleon-nucleon L - S potential from the pion-field theory (with A. Arima); nucleon-nucleon potential inside heavy nuclei (with A. Arima); effect of intermediate boson upon the gamma-ray spectrum in radiative decays of $\pi^\pm$ and $K^\pm$ mesons into leptons (with K. Tanaka); implications and application of the Mandelstam representation of relativistic dispersion relation. At Argonne June 6 to September 10, 1960. Host: M. Hamermesh.

Drs. H. A. Tasman, Laboratorium voor Massaspectrografie, Amsterdam, the Netherlands. High temperature thermodynamic studies with a mass spectrometer; development of ion source; electron impact studies. At Argonne May 31 to about December 15, 1960. Host: W. A. Chupka.

Consultant

Dr. Gianfausto Dell'Antonio, Department of Physics, Northwestern University. High-energy physics. Lectures on dispersion relations. Came to Argonne on June 1, 1960. Host: M. Hamermesh.

Resident Student Associates (Summer)

Mr. Morris Firebaugh, graduate student, University of Illinois. Working with F. P. Mooring on self-indication measurement of the total cross section of Co. At Argonne June 9 to September 9, 1960.

Mr. Paul Liebenauer, graduate student, Case Institute of Technology. Working with J. L. Yntema on polarization of 22-Mev protons and (d, He^3) pickup reactions in nuclei with $A \approx 60$. At Argonne June 6 to September 1, 1960.

Mr. Norman Newman, graduate student, University of Minnesota. Working with S. Wexler on the preparation of radioactive organo-metallic compounds. At Argonne June 13 to about September 15, 1960.

Mr. James Stewart, graduate student, Yale University. Working with L. S. Goodman on a study of the isotope shift in Cs by means of microwave excitation and optical pumping. At Argonne May 27 to August 26, 1960.

Mr. Hans Toffer, graduate student, Iowa State University, Ames. Working with R. O. Lane on the magnet to flip the neutron spins in the apparatus to measure angular distributions of scattered polarized neutrons. At Argonne June 20 to August 30, 1960.

Student Aides (Summer)

Mr. Dewayne Beery, Manchester College. Working with S. B. Burson on a study of decay schemes of neutron-deficient nuclides by use of scintillation techniques and the 180° beta-ray spectrometer. At Argonne June 2 to August 26, 1960.

Mr. Larry Bogan, Case Institute of Technology. Working with L. M. Bollinger on the reduction of transmission data on Tl and Ba. At Argonne June 6 to September 16, 1960.

Mr. David P. Colvin, Louisiana Polytechnic Institute. Working with W. L. Buck on a modification of the apparatus for measuring the decay times of scintillations. At Argonne June 13 to September 1, 1960.

Mr. Roger Dilling, Manchester College. Working with S. B. Burson on decay schemes of odd-odd nuclei by use of the scintillation coincidence spectrometer. At Argonne May 31 to September 6, 1960.

Mr. Byran Gore, Cornell University. Working with D. C. Hess on measurements of the lead-lead ages of meteorites. At Argonne June 20 to about September 15, 1960.

Mr. Ralph Hager, University of Minnesota. Working with R. K. Smither on measurements of the neutron-capture gamma-ray spectrum of Cd^{114} by use of the bent-crystal spectrometer. At Argonne June 13 to September 16, 1960.

Mr. David Hall, Antioch College. Working with S. S. Hanna on Mössbauer measurements of gamma-ray absorption in B^{10} produced by alpha bombardment of Li^6 at the Van de Graaff accelerator. At Argonne June 20 to August 26, 1960.

Mr. Gordon James, Northwestern University. Working with D. C. Hess on measurements of argon-potassium ages of meteorites. At Argonne June 16 to about September 23, 1960.

Miss Elsa Meints, Radcliffe College. Working with S. S. Hanna on measurements of nuclear resonance gamma-ray absorption by means of the Mössbauer effect. At Argonne June 13 to September 23, 1960.

Mr. Robert Raser, Wheaton College. Working with L. S. Goodman on apparatus associated with the atomic beam machine. At Argonne June 15 to September 6, 1960.

Mr. Wesley Shanks, California Institute of Technology. Working with J. R. Wallace on the 50-kv accelerator to test ion sources. At Argonne June 13 to September 9, 1960.

Mr. Lindsay Skinner, Northwestern University. Working with T. H. Braid on making solid-state radiation detectors. At Argonne June 7 to September 20, 1960.

Mr. Charles Thiel, Purdue University. Working with R. K. Smither on the neutron-capture gamma-ray spectrum of Cd^{114} by means of the bent-crystal spectrometer. At Argonne June 3 to September 9, 1960.

Mr. Bruce Thomas, Grinnell College. Working with W. L. Buck and A. Weinreb on transmission measurements on different samples of LiF and liquid scintillators in the vacuum ultraviolet region. At Argonne June 8 to September 2, 1960.

Mr. G. Thomas Tissue, Beloit College. Working with L. J. Basile on energy transfer in plastic scintillators. At Argonne June 6 to August 23, 1960.

Mr. Charles Wyman, Carleton College. Working with G. J. Perlow on nuclear magnetic resonance in Fe^{57} by means of the ^{57}Fe Mossbauer effect. At Argonne June 7 to September 10, 1960.

DEPARTURES

Dr. Herbert A. Grench joined the Physics Division as a Resident Research Associate on November 11, 1957. He has collaborated with S. B. Burson on studies of the decay schemes of short-lived radioactive nuclides (Projects I-24, I-37, and I-39). He terminated at ANL on May 27, 1960 to go to Lockheed Aircraft Corporation, Missiles and Space Division, Sunnyvale, California.