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RESEARCH AND DEVELOPMENT REPORT
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Physics and Mathematics (UC-34)

TID-4500, August 1, 1959

UNITED STATES ATOMIC ENERGY COMMISSION

Research and Development Report

ANNUAL SUMMARY RESEARCH

REPORT IN PHYSICS

July 1, 1959-June 30, 1960

by

Ames Laboratory Staff

September 1960

Ames Laboratory

at

Iowa State University of Science and Technology

F. H. Spedding, Director

Contract W-7405 eng-82

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ANNUAL SUMMARY RESEARCH REPORT IN PHYSICS

For the period July 1, 1959 - June 30, 1960

**This report is prepared from material
submitted by the group leaders
of this Laboratory**

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ANNUAL SUMMARY RESEARCH REPORT IN PHYSICS

(July 1, 1959 - June 30, 1960)

Under the direction of F. H. Spedding, G. W. Fox, R. G. Barnes, B. C. Carlson, G. C. Danielson, R. H. Good, Jr., C. L. Hammer, D. E. Hudson, E. Iloff, E. N. Jensen, J. M. Keller, L. J. Laslett, S. Legvold, D. C. Lu, D. W. Lynch, H. Mahmoud, M. G. Stewart, C. A. Swenson, D. J. Zaffarano

Theoretical Physics1. Spherically Symmetric Charge Distributions (B. C. Carlson)

A paper entitled "Spherically Symmetric Charge Distributions," by B. C. Carlson, was submitted for publication in the American Journal of Physics.

Abstract--The classical electrostatic self-energy of a spherically symmetric charge distribution is written as the integral of an energy density that differs from the usual squared electric field strength. This density vanishes in empty space surrounding the charge distribution. It is sometimes a convenient choice for integration, as is shown by two examples of interest in nuclear physics: the harmonic-well distribution and the distribution with Fermi shape. The self-energy of the Fermi distribution is given to good accuracy by a polynomial of fifth degree in the skin thickness. The form of the energy density is generalized to be valid for distributions not having spherical symmetry.

2. Density Distributions in Stellar Galaxies (B. C. Carlson)

The method of Wyse and Mayall¹ for estimation of density distributions in stellar galaxies from observed rotational velocities has been extended to a more realistic model. It is assumed that the surfaces of constant density are a family of similar concentric ellipsoids. The results are easier to use than those obtained by Wyse and Mayall from a thin-disk model.

3. Four-Fermion Interactions with Spin 3/2 Neutrinos. (R. H. Good, Jr. and C. L. Hammer)

A paper entitled "Four-Fermion Interactions with Spin 3/2 Neutrinos" by R. H. Good, Jr. and C. L. Hammer was published in Physical Review 117, 889-890 (1960).

Abstract--Beta decay involving a spin 3/2 neutrino in weak competition with the spin 1/2 neutrino has been investigated. This process could explain the deviations from allowed shapes in the Gamow-Teller interactions recently reported by Langer et al., but it would then be in disagreement with μ -decay observations.

4. Massless Particles (R. H. Good, Jr.)

A paper by R. H. Good entitled, "Massless Particles", has been submitted for publication in the American Journal of Physics.

¹ A. B. Wyse and N. U. Mayall, Astrophysical Journal 95, 24 (1942).

Abstract--This paper gives a discussion of massless particles, especially the two-component neutrino and the photon, in the light of modern ideas about space reflection. The emphasis is on the physical arguments and mathematical details are omitted.

5. Electrodynamic Quantization Process (R. H. Good, Jr. and C. L. Hammer)

A paper entitled "Electrodynamic Quantization Process" by C. L. Hammer and R. H. Good, Jr. was submitted for publication in the Annals of Physics. (Co-author C. L. Hammer of Experimental Physics Group III).

Abstract--Recently a quantum theory of the free Maxwell field was given that avoided discussion of nonphysical photons. The extension to include the interaction with electrons is given in this paper. This approach leads to a formulation equivalent to the gauge-independent theory of Belinfante and Lomont. A complete discussion of the integrals of motion is given, including their connections with displacement operators.

6. Knight Shift in Sodium Tungsten Bronze (J. M. Keller)

A paper entitled "Conduction Electrons in Sodium Tungsten Bronze"

by J. M. Keller is scheduled for publication in the July, 1960 issue of the Journal of Chemical Physics.

Abstract--The vanishing of the Knight shift of Na^{23} in sodium tungsten bronze is interpreted in terms of an inverted conduction band.

Experimental Physics

1. Nuclear Studies

1.1 Beta Ray Spectrometry (E. N. Jensen)

The following papers have been published, covering work in beta-ray spectrometry: "Continuous Electron Spectrum Accompanying K Capture", by H. Daniel, G. Schupp and E. N. Jensen, Phys. Rev. 117, 823 (1960).

Abstract--The continuous electron spectrum accompanying K capture has been observed, in the case of Cs^{131} , in three different ways: by measuring coincidences between one K x-ray and an electron, by measuring coincidences between two K x-rays and an electron, and by measuring the single electron spectrum. Furthermore, coincidences between two K x-rays have been measured. The coincidence data were taken with scintillation counters while the single electron spectrum was taken with a magnetic spectrometer.

The electron spectrum, including the absolute intensity, and the probability for a double hole in the K shell are both found to be in agreement with the theory of Primakoff and

Porter.¹

"Beta-Gamma Directional Correlation in the Decay of Co^{60} and Na^{22} ", by H. Daniel and G. W. Eakins, Phys. Rev. 117, 1565 (1960).

Abstract--The differential and integral beta-gamma directional correlations in the decay of Co^{60} and Na^{22} have been measured with scintillation counters. Both beta transitions are allowed but have high ft-values. Therefore, small anisotropies are not excluded. In the case of Co^{60} the anisotropy was found to be zero for all beta energies above 0.06 Mev; the integral anisotropy was measured to be $A = -0.0003 \pm 0.0017$ (standard deviation). In the case of Na^{22} the results seem to indicate an energy dependence of the anisotropy; the value is uncertain because of coincidences between positrons and annihilation quanta.

A paper, "Transition Intensities in the Tl^{208} Beta Decay and the $\text{Bi}^{212} \rightarrow \text{Po}^{212}$ Decay Scheme, and the Bi^{212} Branching Ratio", by G. Schupp, H. Daniel, G. W. Eakins, and E. N. Jensen has been accepted for publication in Physical Review.

Abstract--Studies were made on the Pb^{212} (ThB) active deposit by means of gamma singles and beta-gamma, gamma-gamma, gamma-alpha, and gamma-gamma-alpha coinci-

¹ H. Primakoff and F. T. Porter, Phys. Rev. 89, 930 (1953).

dence measurements. The singles and coincidence gamma-ray spectra were recorded on an RCL 256-channel analyzer, and an intermediate-image beta-ray spectrometer was used in the beta-gamma work. Beta intensities of 4.6 ± 0.2 , 23.9 ± 0.8 , 22.7 ± 0.7 , 48.8 ± 2.7 , and $< 0.5\%$ were obtained for the 1.04-, 1.29-, 1.52-, 1.80-, and 2.38-Mev groups, respectively, of the $\text{Tl}^{208} \rightarrow \text{Pb}^{208}$ decay. Existence of the 1.800-Mev gamma ray in Po^{212} was established and $11.2 \pm 0.7\%$ of the $\text{Bi}^{212} \rightarrow \text{Po}^{212}$ disintegrations were determined to go by way of the 0.727-Mev transition. Relative intensities of 11.1 ± 0.7 , 1.7 ± 0.3 , 0.66 ± 0.07 , 0.16 ± 0.04 , 0.99 ± 0.08 , 0.49 ± 0.05 , 2.8 ± 0.2 , and 0.17 ± 0.03 were found for the 0.727-, 0.786-, 0.893-, 0.953-, 1.073-, 1.513-, 1.620-, and 1.800-Mev gamma rays, respectively, in Po^{212} . The ratio of alpha to total disintegrations for the Bi^{212} decay was measured to be 0.3596 ± 0.0006 .

1.2 Studies of High-Energy Particle Accelerators (L. J. Laslett and C. L. Hammer)

A computational and analytic study has been made of the applicability of resonant extraction from an alternating-gradient particle accelerator, as a sequel to earlier work^{1, 2, 3, 4} pertaining to constant-gradient

machines. Results of this work have been reported in an oral paper⁵ presented before the American Physical Society, and in a MURA report.⁶

¹ C. L. Hammer and A. J. Bureau, Rev. Sci. Instr. 26, 594 (1955).

² C. L. Hammer and A. J. Bureau, Rev. Sci. Instr. 26, 598 (1955).

³ L. Jackson Laslett and Charles L. Hammer, Bull. Amer. Phys. Soc. Ser. II, 3, 180 (1958).

⁴ C. L. Hammer and L. J. Laslett, Proc. 2nd International Conference on the Peaceful Uses of Atomic Energy (Geneva, Switzerland), v. 30, pp. 151-157 (September, 1958).

⁵ C. L. Hammer and L. Jackson Laslett, Bull. Amer. Phys. Soc. Ser. II, 5, 225 (1960).

⁶ L. Jackson Laslett and Charles L. Hammer, Midwestern Universities Research Association report MURA-145 (1959, unpublished).

A study has been made, following a suggestion made by Dr. Symon of the MURA group, of an injection method in which the inherent non-linearity of equations governing particle motion in fixed-field accelerators is explicitly employed. The initial phases of this work involved an analytic and computational study of somewhat simplified non-linear differential equations believed characteristic of the essential features of radial motion in a FFAG accelerator when the permissible amplitude of motion is governed by the $\sigma_r = 2\pi/3$ resonance, and the results of this preliminary study were summarized in a series of MURA reports. In application to particle accelerators, the general methods and results are more than slightly related to those which pertain to the ejection method studied by Dr. Blosser in connection with Michigan State University proposals for extraction from a 3-sector AVG cyclotron. The results of the present work were summarized in a paper by L. Jackson Laslett and K. R. Symon, "Computational Results Pertaining to Use of a Time-Dependent Magnetic Field Perturbation to Implement Injection or Extraction in a FFAG Synchrotron", prepared for the 1959 International Conference on High-Energy Accelerators and Instrumentation and in a more detailed report, (MURA-561) by L. J. Laslett and K. R. Symon, "Computational Results Pertaining to Use of a Time-Dependent Magnetic Field Perturbation to Implement Injection or Extraction in a FFAG Synchrotron by use of the $\sigma_r = N/3$ Resonance".

Abstract--The use of the $\sigma_r = N/3$ resonance to implement injection (or extraction) in a FFAG accelerator is examined and computational examples of some of the expected performance features are presented. The field of the accelerator is considered to be perturbed by a "field bump", whose period is equal to three periods of the basic (unperturbed) magnet structure, so that the radial oscillations represented by particle trajectories with amplitudes near the stability limit undergo a phase change of substantially $2\pi/3$ in passing through one sector of the unperturbed machine and a change of 2π in the basic period of the perturbed accelerator. It is shown that the boundary of the stable area in radial phase space, which normally is roughly triangular in the unperturbed accelerator, can be opened up at one of the vertices of this separatrix by a suitably-phased perturbation of the type described and that through the fixed point in this region of the diagram a new, modified separatrix will pass to enclose the stable phase area of the perturbed accelerator. Particles injected so that the initial portions of their phase trajectories pass around this latter phase area will be captured, with full phase density, as the perturbation is decreased (ultimately to zero) and as the stable phase area, in consequence, becomes enlarged. It is seen that injection with

full phase density may be expected if the injector at all times covers the entire region of phase space from which particles must originate in order to surround the growing phase area of the accelerator. Computational examples, with simplified equations of motion, show that the region which thus must be covered by the injector can be that enclosed by a boundary of rather simple shape, and is substantially free of filamentation, if injection occurs every three sectors (as in a three-sector accelerator). It also is found, however, that the requisite phase area to be covered by the injector becomes quite tortuous if transformed through an additional three sectors, as would be required to define the area needed with six-sector injection. The inclusion of axial motion in the computational examples showed that an orderly, efficient transfer of phase volume into the stable region of the unperturbed accelerator could be achieved by this method with three-sector injection and that the phase region which then should be covered by the injector again was enclosed by a single boundary. Examples are given of phase curves which are similar in their essential topological features to those used in the aforementioned study but which represent the dynamics of radial motion in a spirally-ridged FFAG accelerator, the field-modification which was applied as a perturbation in this

case being taken, for convenience, as an additional scaling field which follows the same logarithmically-spiralling pattern as that characterizing the unperturbed accelerator.

A joint paper (MURA-559) by D. W. Kerst, E. A. Day, H. J. Hausman, R. O. Haxby, L. J. Laslett, F. E. Mills, T. Ohkawa, F. L. Peterson, E. M. Rowe, A. M. Sessler, J. N. Snyder and W. A. Wallenmeyer, entitled "Electron Model of a Spiral Sector Accelerator", was submitted to the Review of Scientific Instruments.

Abstract--A six-sector spiral ridge FFAG accelerator has been constructed and successfully operated to accelerate electrons from 35 to 180 kev kinetic energy. Acceleration was by betatron action, supplemented by radio-frequency acceleration when desired. The design was based on magnetostatic and orbit computations performed with the Illiac digital computer, and the subsequent performance was found to be in good accord with these computations. Tuning coils permitted variation of the basic parameters about the design values suggested by the computations, so that an experimental investigation could be made concerning the importance of near-by resonances. The theoretical basis of the computational work and the specific results obtained are

first described, followed by a résumé of the constructional features and magnetostatic measurements. Tests with the operating model are then reported, comprising a resonance survey, injection studies, perturbation studies, and the use of radio-frequency acceleration. The frequencies of radial and axial betatron oscillation at the nominal operating point were respectively $\nu_x = 1.40$ and $\nu_y = 1.12$, and the resonance survey indicated this operating point to be centrally located within a region of relatively large intensity which was bounded by the resonances $\nu_y = 1.0$, $\nu_x = 1.5$, and (less markedly) $2\nu_y - \nu_x = 1$. Injection from a deflector-structure with a thin septum permitted efficient injection to be achieved either by concomitant rapid acceleration of the injected electrons or, alternatively, by use of a time-dependent radial electric field applied as a perturbation. Experiments with a protracted injection pulse permitted the observation of phenomena attributable to space-charge effects. A suitable frequency-modulation schedule permitted successful acceleration of a substantial fraction of stacked electrons through the transition energy. Appendices described a modulator, with negative-feedback stabilization, to permit protracted injection; a magnetometer, used in the magnetic-field measurements; and the essentials of Parzen's theory of perturbations,

which was found to account satisfactorily for the results of the perturbation experiments.

Some computational studies have been in progress concerning the stability of particle orbits in an accelerator of the type proposed by Budker.¹ The computational work² primarily has been concerned with the stability of radial motion in the presence of certain imperfections in the magnetic field provided by the postulated high-intensity electron beam of this device. Because of the large number of resonances which the protons must pass through in the course of acceleration, it is perhaps not surprising that the computations continue to indicate that imperfections (periodic disturbances) in the field provided by the electron beam effect seriously the stability of proton orbits in this proposed accelerator.

Current work, primarily in collaboration with Dr. A. M. Sessler of the Ohio State University and Mr. V. K. Neil of the Lawrence Radiation Laboratory at the University of California (Berkeley), has been concerned with an estimation of possible collective effects in high-intensity particle accelerators. Such effects could be of many forms, as appreciable ohmic losses from image currents induced in the metallic walls of the vacuum chamber, excessive radiation from small windows in the chamber wall, significant interaction with an active or passive acceleration cavity, or the generation of instability in a coasting beam by mutual interaction between the beam and a resonant elec-

tromagnetic mode. The fields which have been studied up to the present time have been of the type which would be engendered within a toroidal chamber (azimuthal symmetry) by a beam for which the linear charge density is expressible in the form

$$\lambda = \sum \lambda_n \cos n(\phi - \omega_0 t) ,$$

and hence the rather large radiative loss which evidently could occur through small windows unwisely present in the chamber wall can only be estimated very roughly. The progress which has been made on the other facets of this problem has been aided by an ancillary investigation, made with the Cyclone electronic digital computer at Iowa State University in collaboration with Mr. William Lewish of the Department of Statistics, in which the properties of the characteristic functions and characteristic values of solutions to Bessel's equation have been investigated for cases in which the order is high, the annular width (measured by $\eta \frac{b-a}{b+a}$ is small, and the solutions of interest are the first solutions which conform to the Neumann boundary condition ($dZ/dr = 0$) or to the Dirichlet boundary condition ($Z = 0$) at the radii a and b . This work, which has been accompanied by a parallel analytic investigation, is now nearing to completion.

1.3 Photoelectric Effect and Pair Annihilation with Large Momentum Transfer (C. L. Hammer)

A paper entitled, "Photoelectric Effect and Pair Annihilation with Large Momentum Transfer" by David S. Moroi has been accepted

for publication in Physical Review.

Abstract--Photoelectric effect and pair annihilation in hydrogen with large momentum transfer are studied since they offer a test of quantum electrodynamics at short distances. The proton structure is described by two covariant form factors determined by the elastic electron-proton scattering. The differential cross sections are calculated in the Born approximation in the Laboratory system, neglecting the binding energy of the hydrogen atom. The results are analyzed in the extreme relativistic energy range and in the special case that the outgoing electron (photon) comes off perpendicular to the incident beam direction. The total cross sections are also calculated in the high energy approximation as a matter of consistency. A 10% experiment is necessary to probe the electron or positron propagator at distances $\sim .90 \times 10^{-13}$ cm, $.46 \times 10^{-13}$ cm, and $.32 \times 10^{-13}$ cm for incident energies 50 Mev, 100 Mev and 150Mev, respectively. The differential cross sections are quite small, 10^{-42} - 10^{-40} cm²/sr. If the same calculation is applied to an atom with higher atomic number Z , the differential cross sections for the above processes increase by the factor Z^5 , neglecting the screening effect.

In a gold target the differential cross sections are of the order of $10^{-33} - 10^{-31} \text{ cm}^2/\text{sr}$.

1.4 Self Consistent Fields (C. L. Hammer)

Recently Overhauser has shown¹ that if one assumes an interaction potential of the form

$$V = -\beta \int \rho^2 dx \quad (1)$$

where β is a constant and $\rho(x)$ is the particle density, then the solutions²

$$\phi_k = [ge^{ikx} + (E_k - \omega_k)e^{i(k-2k_0)x}] [L(g^2 + (E_k - \omega_k)^2)]^{-1/2} \quad (2)$$

for $0 \leq k \leq k_0$ and

$$\phi_k = [ge^{ikx} + (E_k - \omega_k)e^{i(k+2k_0)x}] [L(g^2 + (E_k - \omega_k)^2)]^{-1/2}$$

for $-k_0 \leq k \leq 0$;

are a self-consistent solution in the Hartree sense with an energy per particle (fermions) lower than the plain wave solution which is also self-consistent. Overhauser has applied these ideas to nuclear structure¹ showing that if Eq. (1) applies, the nucleus has a ground state approximately 4 Mev per particle below the ground state obtained

¹ A. W. Overhauser, Phys. Rev. Letters 4, 415 (1960).

² The notation and the definitions of the quantities is the same as that in Ref. 1.

using plane waves if one assumes that the results of Karplus and Watson³ can be taken over directly. A difficulty here, however, is that the interaction used by K-W gives rise to nuclear saturation whereas the interaction given in Eq. (1) does not. Thus the two theories cannot be simply "welded" together since the interactions are basically different. One can clarify this difficulty if one uses in the Hartree process the two body interaction

$$U_{12}(x_1, x_2) = \frac{a}{2} + \frac{b}{2k_0^2} (p_1 - p_2)^2 \delta(\xi^2/\lambda^2 - 1) + \text{h.c.} \quad (3)$$

for $|\xi| < \ell$ and

$$U_{12}(x_1, x_2) = 0, \text{ for} \quad (4)$$

$$|\xi| > \ell$$

where

$$\xi = x_1 - x_2, \text{ and}$$

$$p = -i \frac{\partial}{\partial x}$$

The parameter "a" represents the attractive part of the potential with a characteristic length ℓ and the parameter b represents the repulsive part of the potential with a characteristic length λ . With this interaction plain waves form a self-consistent solution and all of the results of K-W are obtained, including nuclear saturation. However, the wave functions given in Eq. (2) no longer represent a self-consistent solution so that Overhauser's results do not seem to apply to the

³ R. Karplus and K. M. Watson, Am. J. Phys. 25, 641 (1957) hereafter referred to as K-W.

nuclear case.

1.5 Pair Production (C. L. Hammer)

In calculating the pair production or bremsstrahlung cross-sections, it is usually assumed that the Born approximation or the approximation made by Bethe and Maximon^{1, 2} are sufficient. However, both of these approximations break down when one of the particles involved in the interaction has a small kinetic energy so that $\beta \ll 1$. Recent calculations by Johnson and Mullin³ indicate that considerable error is incurred by these approximations for this case. It is therefore of interest to have some experimental data which can be used as a guide for future calculations.

Such an experiment is being performed using the X-rays from the Iowa State University synchrotron to produce the pairs. It has been predicted by Parzen,⁴ using the Born approximation, that a peak at approximately mc^2 , should exist in the momentum distribution of the positron or the electron emitted at large angles with respect to the incident photon beam. The line shown in Fig. 1 without error flags shows the expected spectrum for an angle of emission of 90° with

¹ H. A. Bethe and D. G. Keiffer, Phys. Rev. 93, 768 (1954).

² H. W. Koch and J. W. Motz, Rev. Mod. Phys. 31, 920 (1959).

³ W. R. Johnson and C. J. Mullin, "An Approximate Relativistic Coulomb Scattering Wave Function" to be published in Phys. Rev.

⁴ D. G. Keiffer and G. Parzen, Phys. Rev. 101, 1244 (1956).

Figure 1

respect to the photon beam. Also shown in Fig. 1 are the very preliminary experimental results in which the positrons are emitted from a platinum foil at 90° with respect to the photon beam. The difference between the position of the peaks cannot be accounted for entirely by coulomb effects. More precise calibration of the magnetic spectrometer used to detect the positrons is necessary before the discrepancy can be discussed further or before absolute cross-sections can be given.

1.6 Accurate Method for Measuring Internal Conversion Coefficients

(D. C. Lu)

A paper entitled "Accurate Method for Measuring Internal Conversion Coefficients" by D. C. Lu is scheduled for publication in the July 1, 1960 issue of Physical Review.

Abstract--To reveal the effect on internal conversion due to the nuclear structure and extension, measurements are needed which have higher accuracy than is attainable for currently used methods. This article describes how, under certain conditions, the absolute value of the total internal conversion coefficient can be measured to $\pm 0.5\%$ by the use of a large NaI(Tl) detector with a thin well-type window. Complications

encountered in the comparison between experimental and computed values are mentioned.

1.7 Gamma-rays Following the Beta-decay of Ag^{113} (D. C. Lu)

Preliminary results of our investigation of gamma-rays following the beta-decay of Ag^{113} indicate the presence of 10 previously unreported γ - rays. A tentative decay scheme based on γ - γ coincidences has been worked out.

1.8 The Photoproton Yield from Be^9 (M. G. Stewart)

The Iowa State University electron synchrotron was used to study the photoproton yield from Be^9 for a range of photon energies from the threshold for the reaction (16.89 Mev) up to 40 Mev. The yield was determined by counting the 0.8 second Li^8 beta activity between the synchrotron beam bursts. A coincidence telescope was used to count those betas with energies greater than about 2 Mev. The energy calibration of the synchrotron was determined from the injection energy and the $\text{Be}^9(\gamma, p)$ mass threshold. The 17.24 Mev break in the $\text{O}^{16}(\gamma, n)$ yield was used as a check.

Absorption of the photons into discrete energy levels seems to be indicated by rather sudden changes in the slope of the yield curve. The energy levels observed are 17.45 Mev ($\Delta E \sim 0.15\text{Mev}$), 17.72, 18.00, 18.44, 19.04, 19.92, 20.27, and 20.94 Mev. Figure 2 shows a portion of the yield curve up to about 23 Mev. The relation between the

Figure 2

electron momentum and the integrator setting is given by $p = (0.463 I + 0.142) \text{ Mev/c}$.

The relative cross-section was calculated using the Penfold-Leiss tables. A fourth degree analytic curve was approximately fitted to the experimental yield curve. The difference between the analytic curve and the yield curve was plotted, and a smooth curve was drawn through these points. The smoothed difference curve plus

the analytic curve was then used in determining the cross-section. Figures 3 and 4 show the relative cross-section and the relative integrated cross-section using the 0.200 Mev bin widths. Figure 5 is the cross-section calculated from the smoothed integrated cross-section. The general shape and position of the peak agrees with that given by Haslam, et al.;¹ however, some structure is apparent.

1.9 Transitions in Mirror Nuclei (M. G. Stewart)

A paper, "Branching of Transitions in Some Mirror Nuclei" by

¹ Haslam, Katz, Crosby, Summers-Gill, and Cameron, Can. J. Phys. 31, 210 (1953).

Figure 3

Figure 4

Figure 5

W. L. Talbert and M. G. Stewart, is scheduled for publication in the July 1, 1960 issue of Physical Review.

Abstract--The possibility of branching in the decays of Na^{21} , Mg^{23} , Al^{25} , Si^{27} , S^{31} , and Ca^{39} has been investigated using NaI(Tl) scintillation detectors. The nuclear gamma rays emitted as a result of branching transitions were detected in coincidence with the accompanying positron annihilation radiation.

Branching was found to the first excited states of the daughter nuclei in the decays of Na^{21} , Mg^{23} , and S^{31} with intensities (compared to the total decay) of 2.2, 9.1, and 1.1%, respectively.

The decays of Al^{25} , Si^{27} , and Ca^{39} were found to have no detectable branching to the lower excited states of the daughter nuclei, and upper limits of less than

one percent were placed on the branching ratios for such branches. The lack of branching in the decay of Al^{25} to the 0.98-Mev level of Mg^{25} favors a unified model description for the nuclear states involved.

1.10 Photo-deuteron to Photo-proton Yield Ratio for Copper (E. L.

Iloff and D. J. Zaffarano)

Photo-deuteron to photo-proton yield ratios for X-ray beams of energies less than 100 Mev have been measured by many other investigators. Two experimental techniques have been used. One of these techniques provides identification of the emitted particles by measurements of grain density and range in nuclear emulsions, and the other makes use of the particle-track curvature and range in a magnetic cloud chamber. For most of the elements measured the deuteron to proton-yield ratios were found to be less than 0.03, but measurements of three elements have resulted in much higher ratios (0.15 or greater). Four separate experiments¹⁻⁴ have reported such a high ratio for copper, one for cobalt³ and one for sulfur.⁵

¹ Byerly and Stephens, Phys. Rev. 81, 473 (1951) and Phys. Rev. 83, 54 (1951).

² Smith and Laslett, Phys. Rev. 86, 523 (1952).

³ B. Forkman, Ark. Fys. 11, 265 (1956).

⁴ Medicus, Grant and Demers, Bull. of Am. Phys. Soc. 3, 382 (1958).

⁵ L. S. Ring, Jr., Phys. Rev. 99, 137 (1955).

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distribution and cross section for these events were compared to those calculated for diffraction from black disks of radii corresponding to the geometric cross sections for silver and bromine in appropriate proportions. The experimental results were in agreement with those calculated from the assumed model.

The mean free path in emulsion for 5.7 Bev protons (leaving out the events attributed to diffraction scattering) was found to be 37.2 ± 1.7 cm. The result is larger than the mean free path calculated for emulsion by using the nuclear geometrical radii which is about 29 cm. This is in agreement with measurements of the mean free path in emulsion by other groups for proton energies in the 2 to 10 Bev region. Information was also obtained concerning the frequencies of the more complex events.

1.12 Nuclear Instrumentation Development (E. I. Iloff)

Theoretical studies have been made of a proposed new type of electron multiplying discharge. Multiplication is to be achieved by accelerating electrons and bringing them back to the same electrode again and again to cause multiplication by electron bombardment of the electrode surface. This is to be done by means of superposed DC and AC electric fields. It has been found that for a given electron emission energy, if the applied DC and AC fields are properly adjusted (within a rather narrow region), phase stability will result and electrons can be repeatedly multiplied. The phase stable region has been

determined in terms of dimensionless parameters that depend on the initial electron emission energy, the magnitudes of the applied DC and AC fields, and the frequency. Plots of emission versus return phases have been made for a variety of values of the parameters and many other details of the particle trajectories have been studied. This means of electron multiplication is being considered for application to an image intensifying device for use in conjunction with a scintillation chamber for high energy particle detection.

2. Solid State Studies (G. C. Danielson)

2.1 II-IV Semiconducting Compounds

2.1.1 Phonon Drag Effect in Mg_2Si

The Seebeck coefficients (or thermoelectric powers) of several single crystals of Mg_2Si , including both n-type and p-type, have been measured from 7°K to 1000°K. Figure 6 shows the results for one particular p-type sample, 40 B-8, and one particular n-type sample, 31 B-3. The conspicuous increase in the magnitude of the Seebeck coefficient at low temperatures (20°K to 50°K) is attributed to the phonon drag effect. This effect has not been reported previously, as far as we know, in any II-IV semiconducting compounds.

In the purest sample, 34 B-3 (see Fig. 7) the effect was very large; the Seebeck coefficient increased from 800 microvolts/degree at 100°K to 3200 microvolts/degree at 20°K. The effect was smaller in sample 40 B-8 because this sample was less pure. In fact, sample 40 B-8 was doped with silver in order to make it p-type; sample 34 B-3 was undoped. The phonon drag effect should be reduced by impurities since such defects

Fig. 6—Seebeck coefficient of Mg_2Si from 7°K to 100°K. Sample 40 B-8 was p-type; sample 31 B-3 was n-type. The break in the curve at 300°K was caused by a change from soldered contacts (at low temperatures) to pressure contacts (at high temperatures). The increase in Seebeck coefficient at low temperatures was caused by the phonon drag effect. At high temperatures (over 800°K) the samples were in the intrinsic temperature range and hence both p-type and n-type crystals had the same Seebeck coefficient.

in the crystal would scatter the long wavelength phonons which, through the phonon-electrons interaction, carry the electrons (in n-type material) along the direction of the temperature gradient.

Not only impurities scatter these phonons; boundary scattering is equally important, and was responsible largely for the decrease in the Seebeck coefficient from its maximum at 20°K to zero at zero degrees K. We believe that twinning of the crystals, which was present in some cases, is also effective in increasing the phonon scattering and decreasing the magnitude of the Seebeck coefficient.

All of these phonon scattering effects are shown in Fig. 7. Sample 34 B-3* was the same sample as 34 B-3 but the thickness was reduced from 1.15 mm to 0.87 mm. The length, 6.6 mm, and the width, 1.6 mm, were unchanged. The decrease in thickness, as in the case of germanium and silicon by Geballe and

Fig. 7 —Seebeck coefficient of n-type Mg_2Si from 7°K to 120°K, showing the effects of impurities, twinning, and chemical purity.

Fig. 8—Temperature dependence of the phonon drag contribution in Mg_2Si , showing that S_p varies as $T^{-3.0}$.

Hull,¹ increased the boundary scattering and decreased the magnitude of the Seebeck coefficient. Samples 31 B-2 and 31 B-3 had approximately the same dimensions and same purity, but 31 B-2 showed considerable twinning. It is not unreasonable to suppose that such twinning would have an effect similar to that obtained by decreasing the thickness.

Sample 34 B-3 was the purest (as shown by Hall data); samples 31 B-2 and 31 B-3 were slightly less pure; the sample 28 B-5, which was doped with aluminum, was very impure. The phonon drag effect was very small in such impure crystals as 28 B-5.

Figure 8 shows the phonon drag contribution to the Seebeck coefficient of Mg_2Si as a function of temperature. The dotted line has a slope of -3.0, showing that S_p varies as T^{-3} . For an ideal semicon-

ductor, according to Herring² S_p varies

¹ Geballe, T. H. and Hull, G. W., Phys. Rev. 94, 1134 (1954); Phys. Rev. 98, 940 (1955).

² Herring, C., Phys. Rev. 96, 1163 (1954).

as $T^{-3.5}$. Geballe and Hull¹ found the exponent to be -3.2 for germanium and -2.3 for silicon; Goldsmid, et al.³ found -3.6 for diamond; and Hutson⁴ found -2.5 for ZnO.

From these calculations of the phonon drag contribution (and from Hall measurements) the effective masses of the charge carriers can be obtained. For the ratio of the effective electron mass in Mg_2Si to the free electron mass we obtained 0.64 for sample 31 B-2, 0.66 for 31 B-3, and 0.58 for 34 B-3. These values are obtained on the assumption that acoustical mode scattering predominated.*

2.1.2 Resistivity and Hall Coefficient of Mg_2Si .

Figure 9 shows new data on the resistivities and Hall coefficients of Mg_2Si . Previous results by Morris et al.⁵ were from 77°K to 1000°K. These new data gave an energy gap ΔE_g in agreement with the energy gap previously reported by Morris et al.⁵ From the extension of the temperature range to 4°K, however, it was possible to obtain also the activation energies arising from the impurities (or defects) present in the crystals; even though, so far, these impurities (or defects) have not been identified. Table I shows these impurity activation

³ Goldsmid, Jenns, and Wright, Proc. Phys. Soc. 73, 393 (1959).

⁴ Hutson, A. R., J. Phys. Chem. Solids, 8, 467 (1959).

⁵ Morris, Redin, and Danielson, Phys. Rev. 109, 1909 (1958).

* If optical mode and impurity scattering predominated (as we believe to be the case) $m_e/m_0 = 0.46$ and $m_n/m_0 = 2.1$ in both the extrinsic and intrinsic temperature range.

energies (ΔE_{DA}) and (ΔE_{DB}) for impurities A and B as well as the energy gap ΔE_G between the filled band and the conduction band.

Fig. 9 — Resistivities and Hall coefficients for Mg_2Si from 4°K to 1000°K .

Table I.

Impurity Activation Energies for n-type Mg_2Si

	$(\Delta E_D)_A$	$(\Delta E_D)_B$	ΔE_G at $T = 0^\circ\text{K}$
Sample 31 B-2	0.006 ev	-----	0.79 ev
Sample 31 B-3	0.006 ev	0.009 ev	0.80 ev
Sample 34 B-3	-----	0.011 ev	0.80 ev
Morris <u>et al.</u> ⁵	-----	-----	0.78 ev

2.1.3 Magnetoresistance Tensor for Mg_2Ge

Report IS-67, entitled "Note on the Determination of the Magnetoresistance Tensor of a Crystal Having the Symmetry O_h or O " by Toshihiro Okada was distributed.

Abstract-- A practical method for the determination of the magnetoresistance tensor is discussed from the viewpoint of the phenomenological theory of the galvanomagnetic effects. This method is convenient for the measurement of the three independent tensor components of a crystal having the point group symmetries O or O_h to which Mg_2Ge belongs.

2.2 Thermal Properties of Metals at High Temperatures

2.2.1 Thermal Diffusivity Measurements

A new technique for measuring the thermal diffusivities of solids has been devised. The new method involves a plot of temperature vs. time at the midpoint of a sample having measured boundary conditions. A suitably chosen thermal diffusivity gives a match of the theoretical curve with the experimental curve. The calculations have been programmed for an IBM 650 computer. A report (IS-137) entitled, "An IBM Computer Program for Determining the Thermal Diffusivity of Finite Length Samples" by W. Leon Kennedy was distributed.

The new method has been applied to nickel from 20°C to 500°C and to armco iron from 20°C to 1000°C. The results are in good agreement with results obtained by our modified angstrom method. The new method is particularly suitable for short samples.

2.2.2 Specific Heat of High Purity Iron by a Pulse Heating Method

A dynamic pulse-heating method has been developed for measuring, with an error of less than 2%, the specific heats of metal wires from room temperature to 1000°C. The method consists essentially of recording the resistance of the sample wire while it is being heated by a pulse of large current and short time duration; then obtaining the temperature of the wire throughout the pulse with the aid of the measured resistance as a function of temperature; and finally computing the specific heat of the sample from the temperature as a function of time during

the pulse, the measured power input to the wire, and the theoretically computed heat loss corrections. Results were obtained for high-purity iron over the temperature range 25°C to 1050°C. Variations of the specific heat near the phase transitions were observed in detail.

2.2.3 Specific Heat of Thorium at High Temperatures

The specific heat and electrical resistivity of high-purity thorium have been measured from room temperature to 1000°C. The specific heat was measured by an electrical pulse-heating method. The results have been analyzed in terms of additive lattice and electronic specific heats. A paper on this subject, by Duane C. Wallace, was submitted for publication in Physical Review.

2.2.4 Specific Heat of Copper

High purity copper (.99999%) has been used in a specific heat determination from 100°C to 950°C. The specific heat was 6.31 cal/mole at 100°C and increased linearly to 7.07 cal/mole at 950°C. These results are within five percent of other published values.

2.3 Hall Mobility of Germanium at Microwave Frequencies

A method of measuring microwave Hall mobilities in semiconductors, which was reported by Nishina and Spry⁶ has been greatly extended by Nishina in our Laboratory. The method uses a bimodal cavity with a sample attached on one wall as shown in Fig. 10. One mode of oscillation is excited externally and when a steady magnetic field

⁶ Y. Nishina and W. J. Spry, J. Appl. Phys. 29, 230 (1958).

MEASUREMENT OF HALL MOBILITY IN A SEMICONDUCTOR WITH MICROWAVE FIELD

Fig. 10 — Measurement of Hall mobility in a semiconductor with microwave field.

is applied the other mode is induced by Faraday rotation inside the sample. The relative intensity of the two modes determines the Hall mobility. The theoretical calculations were carried out to obtain the power ratio of the two modes in terms of the Hall mobility, the magnetic field and the dimensions of the cavity and the sample. The final result of this calculation is given in Fig. 10. The formula was derived on the assumption that only one kind of carriers was present and the magnetic field was weak.

The geometrical dependence of microwave Hall power on sample dimensions is shown in Fig. 11 for n-type germanium at 300°K. The theoretically predicted dependence was obtained experimentally.

The magnetic field dependence of Hall power for n-type Ge is shown in Fig. 12, and for p-type Ge in Fig. 13. In n-type Ge the Hall power relationship followed our formula in weak magnetic fields. Appreciable deviation from our formula was observed at lower temperatures and in large magnetic fields, because the mobility of the elec-

Fig. 11 — Geometrical dependence of microwave Hall power.

Fig. 12—Magnetic field dependence of microwave Hall power for n-type germanium.

Fig. 13—Magnetic field dependence of microwave Hall power for p-type germanium.

trons is larger at low temperatures than at room temperature. Due to the degeneracy of the valence band in Ge, the p-type sample showed a magnetic field dependence on mobility for all temperature ranges. The dependence seems to be in qualitative agreement with the discussions given by Willardson et al.⁷

The dependence of Hall mobility on temperature from 30°K to 300°K is shown in Fig. 14 for n-type Ge and in Fig. 15 for p-type Ge. The discrepancies between the microwave Hall mobility and the D. C. Hall mobility have not yet been explained completely.

2.4 Resistivity of Tungsten Bronzes

The resistivity of sodium tungsten bronze as a function of sodium composition has been obtained down to 4°K. As previously reported (IS-14) there is no conspicuous minimum. The conductivity varied linearly with x in Na_xWO_3 ($\sigma \sim x$) at high temperatures as would be expected, since thermal scattering predominated.

⁷ Willardson, Harmon and Beer, Phys. Rev., 96, 1513 (1954).

Fig. 14—Hall mobility in n-type germanium.

Fig. 15—Hall mobility in p-type germanium.

At low temperatures (4°K), however, $\sigma \sim X^4$. This strange dependence of conductivity on sodium concentration has not been explained as yet. It is not the dependence one would expect from any simple theory of impurity scattering.

A great deal of work has been done on the lithium bronzes. If $x = 0.45$ or 0.48 , a strange reproducible maximum in the resistivity occurred near room temperature in the resistivity vs. temperature curve. A phase change seemed to be a reasonable explanation, but X-ray diffraction has so far shown no phase change. At low lithium concentrations, the lithium bronzes became semiconducting.

2.5 A Quantum Mechanical Law of Corresponding States for Van Der Waals Solids at 0°K

A paper "A Quantum Mechanical Law of Corresponding States for Van Der Waals Solids at 0°K" by Newton Bernardes was submitted for publication in Physical Review.

Abstract--A quantum mechanical variational treatment based on a simple Heitler-London wave function is used to describe the various properties of Van der Waals solids at 0°K. The effects of nuclear motion on the cohesive energy, volume, compressibility, sound velocity, etc. are discussed. These effects can be expressed in the form of a power series in $\hbar$, of which we show the first term, linear in $\hbar$, explicitly. The results are in good agreement with the available experimental data for all solidified inert gases, except for He to which the present method is not applicable.

2.6 Polarization Effects in AgBr (D. W. Lynch)

Studies of the frequency dependence of the resistance and capacitance of samples of AgBr doped with up to 1% CdBr_2 are being undertaken. In these samples conduction is due to the motion of silver ion vacancies instead of silver interstitials and vacancies as in pure AgBr. Preliminary results indicate that the vacancies are not completely blocked at the electrodes as concluded by Friauf,¹ and there is no evidence for recombination of excess vacancies with Cd^{++} ions near the electrodes.

2.7 Preparation of Metal Single Crystals (S. Legvold)

A single crystal of holmium metal was obtained by annealing an arc-melted button at a temperature 150° below its melting point. This crystal was about one cm on an edge. A smaller crystal of terbium was obtained in the same manner. It is believed that this technique will yield single crystals of many metals.

2.8 Magnetic Measurements (S. Legvold and F. H. Spedding)

2.8.1 Holmium

Holmium single crystals have been examined in fields up to 18 kilooersteds. At helium temperatures and in fields above 12 kilooersteds the direction of easy magnetization is in the basal plane of the hexagonal close packed metal and is directed along a line halfway

¹ R. J. Friauf, J. Chem. Phys. 22, 1329 (1954).

between two a_0 axes. The full theoretical moment corresponding to gJ is obtained in a field of 18 kilooersteds.

2.8.2 Erbium

Erbium crystals have been examined magnetically. The easy direction appears to be along the C_0 axis of the hexagonal close packed metal. However, a saturation moment of only eight Bohr magnetons instead of the theoretical nine is obtained in this direction. At helium temperatures and in fields above 15 kilooersteds along an a_0 direction the magnetic moment grows rapidly with increasing fields. This indicates it may be possible to obtain the nine Bohr magnetons in sufficiently strong fields in this direction.

2.8.3 Alloys with Yttrium

Dilute alloys of Gd or Ho in Y have been used for adiabatic demagnetization experiments. With a 0.3% Gd alloy and a field of 12 kilooersteds it has been possible to get a drop in temperature of about 0.4 degree from 1.25°K. A similar drop has been obtained with a 1% Ho in Y sample. Magnetic measurements on a single crystal of the Ho alloy show high magnetic anisotropy which complicate the polycrystalline demagnetization experiments.

2.9 Electrical Measurements (S. Legvold and F. H. Spedding)

The resistivities of nearly all of the rare-earth metals in polycrystalline form were determined down to 1.3°K. The thermo-electric powers of the same samples were measured between helium temperatures

and room temperature. Results showed that magnetic transformations influence the thermo-electric power.

A paper "Electrical Resistivity of the Heavy Rare-Earth Metals" by R. V. Colvin, Sam Legvold and F. H. Spedding was submitted for publication in Physical Review.

Abstract--The electrical resistivities of polycrystalline Gd, Tb, Dy, Ho, Er, Tm, and Lu have been measured between 1.3°K and room temperature. The slope of resistivity curve for Gd changes near the Curie point. The curve for Tb is very much like that for Gd but there is some evidence that two ordering temperatures exist for this metal. Dy, Ho and Tm all show peaks in resistivity near their Neel points, while Er shows only a change in slope at its Neel point. The change from ferromagnetism to antiferromagnetism in Dy is seen as a sharp rise in the resistivity.

2.10 High Pressure Studies (C. A. Swenson and F. H. Spedding)

Our experimental data for sodium metal on its PVT relationship to 20,000 atmos from 20°K to the melting point have been analyzed and the results have been prepared for publication. The results, for the first time, give information which can be used to test the applicability of the simple Mie-Grueneisen theory of the volume dependence of the lattice contributions to the equation of state of a solid. Future investigations will include a solidified inert gas (xenon) and the other

alkali metals, using the same pressure and temperature ranges.

Handbook-type data have been obtained for the column compressions in 20,000 atmos of europium and terbium, and similar data will be obtained for scandium. It is only recently that high purity samples of these substances have become available of sufficient size to make feasible the obtaining of these data.

A paper, "On the Existence of a Critical Point for the Phase Transition in Cerium", by R. I. Beecroft and C. A. Swenson, has been accepted for publication in the Journal of the Physics and Chemistry of Solids.

Abstract--A piston-displacement technique has been used to examine the phase transition in cerium to 20,000 atmos and 575°K. The results are in agreement with previous thermal data, and show that the volume change decreases with increasing temperature, extrapolating to zero somewhere near 630°K and 20,000 atmos. Above roughly 500°K and 15,000 atmos, however, the transition becomes increasingly spread out in pressure at constant temperature, and it becomes quite difficult to assign values to the transition pressures and the volume changes. Although there are definite indications that the nature of the transition is changing at these pressures and temperatures, the possibility that the transition is merely becoming sluggish cannot be ruled out.

2.11 Superconductivity (C. A. Swenson)

2.11.1 Tantalum

Highly degassed samples of high purity tantalum have been produced by heating tantalum wire near the melting point (3000°C) in a high vacuum (better than 10^{-9} mm Hg). The superconducting transitions of these samples have been measured as functions of both magnetic field and 2,000 atmos pressure, using solid helium as the pressure transmitter. The pressure results agree with previous zero field data obtained in this Laboratory, and discrepancies with earlier data seem to be due to lack of high purity in the earlier samples. The contributions of the electrons to the various thermodynamic functions of tantalum have been calculated.

2.11.2 Mercury

One of our major interests has been in the superconducting properties of a new solid phase of mercury (β -mercury) which was first produced at zero pressure in this Laboratory. We have measured the critical field curves of both α - and β -mercury as a function of pressure to 3,000 atmos in the solid helium apparatus. The major objective of this work was to attempt to investigate the influence of crystal structure on the superconducting properties of a metal. It would appear that the effect is small in zero magnetic field, but quite significant at very low temperatures and high fields.

2.11.3 Tin

The effect of pressure on the superconducting critical field curve

of tin also has been measured since this parameter is used as a means for determining the pressure in the solid helium apparatus. The results show an anomalous curvature near 1°K, and there is a need to obtain data below this temperature. We also hope to do this for the mercuries.

2.11.4 Vanadium

Preliminary work has been done on the production of highly degassed vanadium in order to investigate the superconducting properties of this metal. The methods are the same as were used for tantalum. It has not been possible so far to obtain samples with sharp magnetic superconducting transitions, and the difficulty seems to lie in the initial purity of the metal which was used.

2.12 Effect of Pressure on the Curie Temperature of Dysprosium

(C. A. Swenson, S. Legvold, R. Good and F. H. Spedding)

The high pressure equipment which was used in the superconducting experiments has been used without modification to measure the effect of pressure on the Curie temperature (85°K) of dysprosium metal. The effect is small ($dT_c/dP = -10^{-3}$ deg/atmos) and in the opposite direction from that predicted in a recent theory.

2.13 Nuclear Magnetic Resonance Studies

2.13.1 Nuclear Magnetic Resonances in Metallic Tungsten

Bronzes (R. G. Barnes)

We have previously reported on the observation that the Na²³ nuclear

magnetic resonance in the cubic sodium tungsten bronzes shows no conduction electron shift (Knight shift). Inasmuch as the cubic sodium tungsten bronzes possess very good electrical characteristics, the absence of a Knight shift indicates that the conduction electron wavefunction essentially vanishes at the sodium positions. If the character of the conduction band wavefunction is determined mainly by the tungsten atom, then a zero value at the sodium positions could occur if either a radial or angular node in the wavefunction falls at these positions.

In an effort to examine further the metallic tungsten bronzes, we have detected the nuclear magnetic resonances of Li^7 in cubic Li_xWO_3 ($x = 0.45$) and of Tl^{203} and Tl^{205} in tetragonal Tl_xWO_3 ($x = 0.30$). As with the sodium resonances, these also show no Knight shifts. This observation is especially striking in the case of the thallium bronze because of the very large ($\approx 1.5\%$) Knight shift in thallium metal.

Additional information is obtained in the case of thallium tungsten bronze from consideration of the shape of the resonance. The observed second moment of the Tl^{205} resonance, for example, is about ten times the expected value due to nuclear dipole-dipole interaction alone. Because the thallium isotopes have nuclear spin one-half, quadrupole effects are rigorously excluded. The additional line width may be interpreted as arising from a combination of indirect nuclear spin exchange and pseudodipolar interactions. These interactions are known to be especially important when nuclei of heavy elements are involved.

Qualitatively, we may conclude that the Tl^+ ion is appreciably covalently bonded to the WO_3 structure, and that the valence band orbitals possess significant s-character.

2. 13. 2 Knight Shifts in Pure Metals (R. G. Barnes)

A paper entitled, "Knight Shifts in Potassium, Indium, and Yttrium Metals", by W. H. Jones, Jr., T. P. Graham, and R. G. Barnes has been accepted for publication in Acta Metallurgica.

Abstract--Information about the conduction electron wavefunction in a metal or alloy may be obtained from measurements of the Knight shifts of the nuclear magnetic resonance of the constituent nuclei. Although the Knight shifts of many metals have been measured, several shifts have not been reported because of inconveniently low resonance frequencies or nuclear quadrupolar effects. We have measured the shifts in potassium, indium, and yttrium metals, using the dispersion mode of the nuclear magnetic resonance signal. In the case of potassium, sufficient data exists in the literature to permit calculating the electronic probability density at the nucleus in the atom and in the metal from the measured Knight shift. The values obtained are in good agreement with the corresponding values for the other alkali metals.

2. 13. 3 Steady-State Nuclear Induction Signal Shapes in Lithium Metal (R. G. Barnes)

In solids, the behavior of the nuclear magnetic resonance signal shape is in general a complex function of the amplitude of the radio-frequency magnetic field and of the amplitude and frequency of the modulating magnetic field. For most solids, detailed predictions of the dependence of the resonance signal shape on these quantities are not possible. Nuclear magnetic resonance in liquids, however, is more amenable to theoretical treatment, and is generally believed to be described by the so-called Bloch equations.¹ Extension of these equations to include the effects of the modulating field have also been derived in general terms.² At such a temperature that significant self-diffusion can occur, a nucleus in a solid may in effect seem to be in a liquid. For such a solid the Bloch equations might be expected to apply to the nuclear magnetic resonance behavior.

Lithium metal suggests itself as a system to test the predictions of the Bloch theory in detail, since significant self-diffusion occurs at room temperature. Accordingly, we have undertaken a theoretical and experimental study of the absorption and dispersion mode nuclear magnetic resonance signals of Li^7 in solid lithium metal. Resonance signal shapes were calculated for a wide variety of experimental conditions and were compared with the observed signal shapes. Excellent

¹ F. Bloch, Phys. Rev. 70, 460 (1946).

² K. Halbach, Helv. Phys. Acta 27, 259 (1954).

agreement was obtained in the case of some samples, whereas in other cases significant disagreement was found. It is not yet clear what particular property of the lithium metal gives rise to the discrepancy.

2.13.4 Nuclear Quadrupole Resonances in Iron-Group Halides (R. G. Barnes)

A paper entitled, "Pure Nuclear Quadrupole Resonances in Paramagnetic Iron-Group Halides", by R. G. Barnes and L. L. Segel was published (Phys. Rev. Letters 3, 462 (1959)).

Abstract--Nuclear magnetic resonance is a potentially powerful tool for studying magnetic ordering effects in solids. Especially attractive for such study are paramagnetic insulators which undergo antiferromagnetic ordering at low temperatures. Numerous simple transition metal halides fall in this category and offer the advantage that all nuclei in the substance may be resonated (by contrast to oxides, for example). In the case of chlorides and bromides, there exists also the likelihood of nuclear quadrupole interaction with the electric field gradients of bonding electrons. Quadrupole interactions complement information on the magnetic hyperfine interaction derived from magnetic resonance shift studies in that the latter arise principally from the s-electron parts of anti-bonding orbitals whereas the former originate mainly from the p-electron parts of bonding orbitals. The study of the magnetic resonance spectra of both the

cation and anion nuclei in a single crystal of a transition metal chloride ought to be especially fruitful.

In this way, a determination of the electric field gradient and magnetic hyperfine tensors at all nuclei in the crystal would be obtained. A fairly complete analysis of covalent bonding structures and their significance in the light of current theories of the superexchange process could then be made.

As a preliminary step in this direction, we have detected pure nuclear quadrupole resonances in polycrystalline samples of a number of iron-group chlorides and bromides: TiCl_3 , TiCl_2 , VCl_3 , CrCl_3 , CrBr_3 , and CrCl_2 . The quadrupole resonance frequencies provide an estimate of the admixture coefficient α of molecular orbital theory. In those cases in which estimates of α are available from other sources, the agreement with the quadrupole data is good.

2.13.5 Nuclear Quadrupole Resonances in Very Ionic Halides (R. G. Barnes)

In most solid halides, the dominant contribution to the nuclear quadrupole coupling energy of the halogen nuclei has its origin in the p-character of the covalent bond formed between the halogen atoms

and a neighboring atom. A variety of experiments have indicated, however, that polarization of the halogen ion core by external charges greatly enhances the effective nuclear quadrupole moment (the so-called antishielding effect). This suggests that in very ionic compounds halogen nuclei located in sites of less-than-cubic symmetry may possess appreciable nuclear quadrupole coupling energy due to the charge distribution external to the halogen ion itself. This effect ought to be most pronounced in the cases of bromides and iodides because of their relatively large nuclear quadrupole moments.

We have detected the pure nuclear quadrupole resonances of Br^{79} and Br^{81} in CdBr_2 and of I^{127} in CdI_2 . The measured coupling energies are indeed small, roughly one-twentieth of the values in solid Br_2 and I_2 . Preliminary calculations of the ionic contribution to the electric field gradients in the cadmium halides indicates, however, that the extreme smallness of the halogen quadrupole coupling energies may result from partial cancellation of the ionic and covalent contributions, since these have opposite sign. More detailed calculations of the ionic charge gradient need to be made before firm conclusions can be drawn with respect to bond character.

2.14 Rare-Earth Cohesive Energies (D. E. Hudson and F. H. Spedding)

An accurate and sensitive mass-spectrometric method for study of cohesion in the rare-earth metals has been described in previous reports. Thorough measurements on terbium and lutetium were completed during this report period. The results for the enthalpy of sublimation at 298°K were :

Terbium (19 runs) : $H_{298} = 91.8 \pm 0.6$ kcal/M

Lutetium (23 runs) : $H_{298} = 102.7 \pm 0.4$ kcal/M

These results complete the cohesive energy studies on the stable rare earths. Contrary to all expectations, wide variations in the cohesion were discovered by this group. A qualitative explanation of the variations in terms of the energetics of the metallic and gaseous states has been proposed and will appear shortly in J. Chem. Phys.

2.15 Carrier Trapping in Diamond (D. E. Hudson)

The crystal counting properties of diamond have been exploited to study the processes associated with charge carrier trapping. An internal field due to trapped carriers is built up in the crystal. The decay of this field under bombardment by photons in the visible range has been studied in detail. Both the experiment and its interpretation are rather involved so only the results will be treated here.

One interpretation, summarized in IS-14, suggests that a hole trap is located about 3.0 ev above the valence band. On this model, the detrapping cross sections for photon energies between 2.85 ev and 3.45 ev extends from $\sim 0.5 \times 10^{-4} \text{ cm}^{-2}$ to $\sim 2 \times 10^{-4} \text{ cm}^{-2}$.

(These figures have been recalculated and revised since our last report). The large cross sections are consistent with the hypothesis that an aggregate of vacancies is responsible for the trap.

A second interpretation of our results has been analyzed during the current period. This interpretation has some advantages over the previous one and may be more nearly correct. In this second model a normally filled "donor" level is placed about 2.2 ev above the valence band. The incident photons produce photoconductivity by an electron transition (3.2 ev to the conduction band); this induced conductivity accounts for the decay of the internal field. Theoretical calculations of the optical absorption coefficient have been made on this basis and the results agree qualitatively with the known experimental values for many of the photon energies involved.

A startling and important auxiliary result of this experiment is that the true bulk conductivity of diamond at 300°K may be from 100 to 1000 times larger than has been previously reported. (This conclusion is model-independent but must be considered tentative until further studies are completed.) It is suggested that previous measurements on diamond were complicated by surface phenomena, by "apparatus conductivity", or by interfacial effects at the electrodes.

2.16 Sublimation of Indium from Silver (D. E. Hudson)

The vapor pressure of indium above an alloy of 4% In in Ag was studied in the mass spectrometer. The partial enthalpy of sublimation

of the In from the alloy was 62 ± 2 kcal/M at about 1100°K. The data were obtained in connection with an investigation of the diffusion of In from the alloy.

APPENDIX I: LIST OF REPORTS FROM THE AMES LABORATORY

1. Reports for Cooperating Laboratories

- ISC-1076 H. A. Wilhelm. A History of Uranium Metal Production in America.
- ISC-1095 Lawrence Burkhardt and R. W. Fahien. Pulse Column Design.
- ISC-1115 Ames Laboratory Staff. Physics. Semi-Annual Research Report. July-December, 1958.
- ISC-1116 Ames Laboratory Staff. Chemistry. Semi-Annual Research Report. July-December, 1958.
- ISC-1173 William S. Rawls and L. J. Laslett. The Determination of Photoneutron Thresholds.
- IS-1 C. V. Banks, O. N. Carlson, A. H. Daane, V. A. Fassel, R. W. Fisher, E. Olson, J. E. Powell and F. H. Spedding. Studies on the Preparation, Properties and Analysis of High Purity Yttrium Oxide and Yttrium Metal at the Ames Laboratory.
- IS-2 John Walker and Ed Olson. Preparation of Yttrium Fluoride Using Ammonium Bifluoride.
- IS-3 Edwin H. Olson, M. Smutz and Clayton W. Watson. Extraction Equipment and Sampling Technique Used in Semi-Continuous Silver-Uranium Extraction Studies.
- IS-8 G. Burnet and R. Tischer. Preparation of Yttrium Fluoride Using Fluorine.
- IS-14 Ames Laboratory Staff. Physics. Semi-Annual Summary Research Report. January-June, 1959.
- IS-15 Ames Laboratory Staff. Chemistry. Semi-Annual Summary Research Report. January-June, 1959.
- IS-16 Ames Laboratory Staff. Engineering. Semi-Annual Summary Research Report. January-June, 1959.
- IS-17 Ames Laboratory Staff. Metallurgy. Annual Summary Research Report. July, 1958-June, 1959.
- IS-26 Glenn Murphy and Robert E. Uhrig. Observations on Creep of Tantalum.
- IS-47 O. N. Carlson and A. L. Eustice. Vanadium-Chromium Alloy System.

- IS-48 J. R. Bohn, R. E. Uhrig and Glenn Murphy. A Method of Specimen Corrosion Protection for High Temperature Creep Testing.
- IS-50 R. Kniseley, V. A. Fassel and F. Lentz. Misidentifications in the Arc Spectra of the Rare Earths.
- IS-57 D. H. Dennison, F. H. Spedding and A. H. Daane. The Determination of the Melting Point, the Vapor Pressure, and the Decomposition Temperature of Yttrium Tri-Iodide.
- IS-66 Robert L. Hammel and Robert E. Uhrig. An Autographic Elevated Temperature Creep Testing Facility.
- IS-67 Toshihiro Okada. Note on the Determination of the Magnetoresistance Tensor of a Crystal Having the Symmetry O_h or O .
- IS-107 C. D. Wirkus and D. R. Wilder. Uranium Glass I. Fundamental Considerations.
- IS-115 O. N. Carlson, F. A. Schmidt and R. L. Wells. A Study of the High-Temperature Air-Oxidation of Yttrium Metal.
- IS-125 R. L. Hammel. Creep of Tantalum Under Cyclic Elevated Temperatures.
- IS-138 Robert Uhrig. A Proposed Model for High Temperature Creep of Tantalum.

2. Publications

- Atoji, M. and R. C. Medrud, The Structures of Calcium Dicarbide and Uranium Dicarbide by Neutron Diffraction. J. Chem. Phys. 31, 332-337 (1959).
- Atoji, M. and R. E. Rundle, Neutron Diffraction Study on Sodium Tungsten Bronzes Na_xWO_3 ($x=0.9\sim 0.6$). J. Chem. Phys. 32, 627-628 (1960).
- Atoji, M., J. E. Shirber and C. A. Swenson, The Crystal Structure of β -Hg. J. Chem. Phys. 31, 1628-1629 (1959).
- Atoji, M. and D. E. Williams, The Deuterium Positions in Lanthanum Deuterioxide by Neutron Diffraction. J. Chem. Phys. 31, 329-331 (1959).
- Banks, C. V., Analysis of Thorium. United Nations Peaceful Uses of Atomic Energy. Proceedings of the 2nd International Conference. Geneva, 1958. Paper P/918. Anal. Chem., Prog. in Nucl. Energy Series, No. 9, Vol. 1, 33-56 (1959).
- Banks, C. V. and R. I. Bystroff, Stability Orders in Transition Metal-1, 10-Phenanthroline Complexes. J. Am. Chem. Soc. 81, 6153-6158 (1959).
- Banks, C. V. and J. J. Richard, The Determination of vic-Dioximes. Talanta 2, 235-238 (1959).
- Banks, C. V. and R. S. Singh, Composition and Stability of 5-Sulfosalicylate Complexes of Beryllium and Copper. J. Am. Chem. Soc. 81, 6159-6163 (1959).
- Banks, C. V. and R. V. Smith, Spectrophotometric Determination of Palladium Using 4-Methyl-1, 2-Cyclohexanedionedioxime. Anal. Chim. Acta 21, 308-311 (1959).
- Barnes, R. G. and S. L. Segel, Pure Nuclear Quadrupole Resonances in Paramagnetic Iron-Group Halides. Phys. Rev. Letters 3, 462-464 (1959).
- Bartell, L. S., An Electron Diffraction Study of Monomethyl and Dimethylphosphine. J. Chem. Phys. 32, 832-834 (1960).
- Bartell, L. S., Effect of Specimen Delocalization in Electron Diffraction Studies of Gas Molecules. J. Appl. Phys. 31, 252-254 (1960).

- Bartell, L. S. and R. C. Hirst, An Electron Diffraction Study of the Structure of Phosphine. J. Chem. Phys. 31, 449-451 (1959).
- Beecroft, R. I. and C. A. Swenson, The Behavior of Polytetrafluorethylene (Teflon) Under High Pressures. J. Appl. Phys. 30, 1793-1798 (1959).
- Carlson, B. C., Fields of an Accelerated Point Charge. Am. J. Phys. 27, 669-670 (1959).
- Carlson, O. N., D. W. Bare, E. N. Gibson and F. A. Schmidt, Survey of the Mechanical Properties of Yttrium and Yttrium Alloys. Am. Soc. for Test Mat. (Symposium on Newer Metals) 272, 144-159 (1959).
- Carlson, O. N., D. T. Eash and A. L. Eustice, Vanadium-Tantalum and Vanadium-Chromium Alloy Systems. Metallurgical Society Conferences, "Reactive Metals" 2, 277-295 (1959).
- Carlson, O. N., J. A. Haeffling, F. A. Schmidt and F. H. Spedding, Preparation and Refining of Yttrium Metal by Y-Mg Intermediate Alloy Process. J. Electrochem. Soc. 107, 504-545 (1960).
- Carlson, O. N. and B. A. Loomis, Investigation of the Brittle-Ductile Transition in Vanadium. Metallurgical Society Conferences. "Reactive Metals" 2, 227-243 (1959).
- Chiotti, P. and G. R. Kilp, Vapor Pressure and Thermodynamic Properties of Zn-Zr and Zn-U Alloys. Trans. AIME 218, 41-44 (1960).
- Chiotti, P. and G. R. Kilp, Zinc-Zirconium System. Trans. AIME 215, 892-898 (1959).
- Clikeman, F. M. and M. G. Stewart, The Influence of ℓ -Forbiddenness on the 82-keV Transition in Cs¹³³. Phys. Rev. 117, 1052-1055 (1960).
- Corbett, J. D. and F. C. Albers, An Electromotive Force Investigation of the Product of the Solution of Antimony in Liquid Antimony Triiodide. J. Am. Chem. Soc. 82, 533 (1960).
- Curry, M. A., S. Legvold and F. H. Spedding, Electrical Resistivity of Europium and Ytterbium. Phys. Rev. 117, 953-954 (1960).

- Daniel, H., Theory of A High-Resolution Beta-Ray Spectrometer with High Luminosity. Rev. Sci. Instr. 31, 249-252, (1960).
- Daniel, H. and G. W. Eakins, Beta-Gamma Directional Correlation in the Decay of Co^{60} and Na^{22} . Phys. Rev. 117, 1565-1567 (1960).
- Daniel, H., G. Schupp and E. N. Jensen, Continuous Electron Spectrum Accompanying K-Capture. Phys. Rev. 117, 823-827 (1960).
- Druding, L. F. and J. D. Corbett, Rare Earth Metal-Metal Halide Systems. The Preparation of Neodymium(II) Halides. J. Am. Chem. Soc. 81, 5512 (1959).
- Duke, F. R., Mechanisms of Oxidation-Reduction Reactions. Treatise on Anal. Chem. 1, Chap. 15, 629-660 (1959).
- Duke, F. R., Oxidation-Reduction Equilibria and Titration Curves. Treatise on Anal. Chem. 1, Chap. 16, 661-673 (1959).
- Duke, F. R. and A. L. Bowman, Transport Numbers in Pure Fused Salts. The Alkali Metal Chlorides. J. Electrochem. Soc. 106, 626-627 (1959).
- Duke, F. R., A. L. Bowman, E. Wolf and H. Garfinkel, Ion Mobilities in Pure Fused Silver Chloride. New York Acad. of Sci. Symposium 79, 1023-1024 (1960).
- Duke, F. R. and M. L. Iverson, Kinetics of the Oxidation of Bromide Ion in Fused Alkali Nitrate Solutions of Dichromate. Anal. Chem. 31, 1233-1234 (1959).
- Duke, F. R. and W. W. Lawrence, Complex Formation Constants of Lead and Cadmium Ions with Chloride in Fused Lithium Perchlorate. J. Phys. Chem. 63, 2087 (1959).
- Duke, F. R. and N. C. Peterson, The Sn(II) Reduction of Methyl Orange. J. Phys. Chem. 63, 2076-2077 (1959).
- Duke, F. R. and E. Wolf, The Effect of Some Organic Compounds on the Rate of the Fe(II) , Fe(III) Exchange. Iowa State J. Sci. 34, 157-162 (1959).
- Duke, F. R. and S. Yamamoto, Acid-Base Reactions in Fused Salts II. The Absolute Concentration of NO_2^+ Ion in Fused Nitrate. J. Am. Chem. Soc. 81, 6378-6379 (1959).

- Dunning, W. W. and D. S. Martin, Jr., Mixed Tetra(chlorobromo) platينات(II) Equilibrium Constants for Formation in Aqueous Solution. J. Am. Chem. Soc. 81, 5566-5570 (1959).
- Eash, D. T. and O. N. Carlson, Investigation of the Thorium-Yttrium System. Trans. ASM 52, 1097-1114 (1960).
- Fassel, V. A. and L. L. Altpeter, Emission Spectrometric Determination of the Gaseous Elements in Metals VI. Oxygen in Vanadium. Spectrochim. Acta 16, 443-449 (1959).
- Fassel, V. A., W. A. Gordon and R. J. Jasinski, Spectrographic Determination of Oxygen, Nitrogen and Hydrogen in Metals. Anal. Chem., Prog. in Nucl. Energy Series, No. 9, Vol. 1, 230-243 (1959).
- Fitzwater, D. R. and R. E. Rundle, Crystal Structure of Hydrated Erbium, Yttrium and Praseodymium Ethyl Sulfates. Z. Krist. 12, 362-374 (1959).
- Fritz, J. S., Acid Base Titrations in Nonaqueous Solvents. Rec. Chem. Prog. 21, 94-106 (1960).
- Fritz, J. S. and D. F. Pietrzyk, Photometric Titration of Scandium. Anal. Chem. 31, 1157-1159 (1959).
- Fritz, J. S. and G. H. Schenk, Acid Catalyzed Acetylation of Organic Hydroxyl Groups. Anal. Chem. 31, 1808-1812 (1959).
- Gibson, E. D. and O. N. Carlson, The Yttrium-Magnesium Alloy System. Trans. ASM 52, 1084-1096 (1960).
- Gray, L. S. Jr., V. A. Fassel and Richard N. Kniseley, The Use of Nitrogen-15 for the Characterization of Infrared Bands Arising from Nitrogen Vibrations. Spectrochim. Acta 16, 514-517 (1960).
- Guter, G. A. and G. S. Hammond, Chelates of β -Diketones. III. Steric Effects in the Formation Constants of Metal Chelates. J. Am. Chem. Soc. 81, 4682-4689 (1959).
- Hall, P. M., S. Legvold and F. H. Spedding, Electrical Resistivity of Dysprosium Single Crystals. Phys. Rev. 117, 971-973 (1960).
- Hall, P. M., S. Legvold and F. H. Spedding, Electrical Resistivity of Yttrium Single Crystals. Phys. Rev. 116, 1446-1447 (1960).

- Hammer, C. L. and R. H. Good, Jr., Four-Fermion Interactions with Spin $3/2$ Neutrino. Phys. Rev. 117, 889-890 (1960).
- Hammond, G. S., W. G. Borduin and G. A. Guter, Chelates of β -Diketones. I. Enolization, Ionization and Spectra. J. Am. Chem. Soc. 81, 4682-4689 (1959).
- Hansen, R. S., R. E. Minturn and B. H. Clampitt, Some Studies of Aqueous Uranium Oxide Slurries. Nucl. Sci. and Eng. 6, 458-460 (1959).
- Hansen, R. S. and T. C. Wallace, The Kinetics of Adsorption of Organic Acids at the Water-Air Interface. J. Phys. Chem. 63, 1085-1091 (1959).
- Holloway, J. T., D. C. Lu and D. J. Zaffarano, Large Proportional Counter Spectrometer for the Study of Radioactive Samples with Low Specific Activity. Rev. Sci. Instr. 31, 91-95 (1960).
- Horrigan, V. M., V. A. Fassel and J. W. Goetzinger, Determination of Oxygen in Yttrium Fluoride By a Vacuum Distillation Technique. Anal. Chem. 32, 787-789 (1960).
- Jennings, L. D., E. Hill and F. H. Spedding, The Heat Capacity of Samarium from 130 to 350°K. J. Chem. Phys. 31, 1240-1243 (1959).
- Kniseley, R. N., V. A. Fassel and E. E. Conrad, Observations on the Silicon-Hydrogen Vibrational Bands in Alkyl and Aryl Substituted Silanes. Spectrochim. Acta 14, 651-655 (1959).
- Liu, S. H., D. R. Behrendt, S. Legvold and R. H. Good, Jr., Interpretation of Magnetic Properties of Dysprosium. Phys. Rev. 116, 1464-1468 (1959).
- Lynch, D. W., Midwest Solid-State Physics Conference. Phys. Today 13, No. 4, 40-42 (1960).
- McCarley, R. E. and J. W. Roddy, The Preparation of High Purity Vanadium Pentoxide by a Chlorination Procedure. J. of Less Common Metals 2, 29 (1960).
- Mahmoud, Hormoz, Angular Distribution of Polarized Electrons Emitted from Oriented Nuclei. Annals Phys. 7, 429-439 (1959).
- Niira, Kazuo, The Temperature Dependence of the Magnetization of Dysprosium Metal. Phys. Rev. 117, 129-133 (1960).

- Peterson, D. T. and D. J. Beernsten, The Uranium-Hafnium Equilibrium System. Trans. ASM 52, 763-780 (1960).
- Peterson, D. T. and J. A. Hinkebein, Equilibria in the Reaction of Barium with Calcium Chloride. J. Phys. Chem. 63, 1360 (1959).
- Peterson, D. T. and R. Kontrimas, Distribution of Silver Between Liquid Lead and Zinc. J. Phys. Chem. 64, 362 (1960).
- Peterson, D. T. and D. G. Westlake, Diffusion of Hydrogen in Thorium. J. Phys. Chem. 64, 649-651 (1960).
- Peterson, D. T. and D. G. Westlake, The Rate of Reaction of Hydrogen with Thorium. J. Phys. Chem. 63, 1514 (1959).
- Peterson, D. T., D. G. Westlake and J. Rexer, The Effect of Thorium Oxide on Thorium-Hydrogen Equilibrium. J. Am. Chem. Soc. 81, 4443-4445 (1959).
- Powell, J. E. and F. H. Spedding, The Separation of Rare Earths by Ion Exchange. Trans. of Met. Soc. of AIME 215, 457-463 (1959).
- Ruch, R. J. and L. S. Bartell, Wetting of Solids by Solutions as a Function of Solute Adsorption. J. Phys. Chem. 64, 513-519 (1960).
- Ruedenberg, K., Boulder Conference on Molecular Quantum Mechanics. Phys. Today 13, 34-36 (1960).
- Sidles, P. H. and G. C. Danielson, Thermal Diffusivity Measurements at High Temperatures. Paul H. Egli, Ed. Thermoelectricity p. 270-287. New York, N. Y. John Wiley and Sons, Inc., (1960).
- Smith, J. F. and C. L. Arbogast, The Elastic Constants of Single Crystal Beryllium. J. Appl. Phys. 31, 99-102 (1960).
- Smith, J. F. and J. L. Christian, Thermodynamics of Formation of Copper-Magnesium and Nickel-Magnesium Compounds from Vapor Pressure Measurements. Acta Metallurgica 8, 249-255 (1960).
- Smith, J. F. and J. A. Gjevre, The Elastic Constants of Yttrium Single Crystals in the Temperature Range, 4.2-400°K. J. Appl. Phys. 31, 645-647 (1960).
- Smith, J. F. and J. D. Greiner, The Magnetic Susceptibility of Thorium Metal in the Range 130-300°K. Phys. Rev. 115, 884-885 (1959).

Spedding, F. H., J. J. McKeown and A. H. Daane, The High Temperature Thermodynamic Functions of Cerium, Neodymium and Samarium. J. Phys. Chem. 64, 289-294 (1960).

Staley, H. G. and H. J. Svec, The Determination of Nitrogen in Metals by Isotope Dilution. Anal. Chim. Acta 21, 289-295 (1959).

Stanton, R. M., L. D. Jennings and F. H. Spedding, The Heat Capacity of Terbium from 1.4° to 4.0° Kelvin. J. Chem. Phys. 32, 630-631 (1960).

Stewart, M. G. and D. C. Lu, Nuclear Levels of Cs¹³³. Phys. Rev. 117, 1044-1051 (1960).

Utterback, N. G. and G. H. Miller, Ionization Yields for Fission Fragments. Phys. Rev. 116, 976-980 (1959).

Vossos, P. H., L. D. Jennings and R. E. Rundle, On the Structure and Magnetic Properties of LiCuCl₃·2H₂O. J. Chem. Phys. 32, 1590-1591 (1960).

Wallace, D. C., P. H. Sidles and G. C. Danielson, Specific Heat of High Purity Iron by a Pulse Heating Method. J. Appl. Phys. 31, 168-176 (1960).

Wilhelm, H. A., A History of Uranium Metal Production in America J. Chem. Educ. 37, 56-68 (1960).

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APPENDIX II: LIST OF SHIPMENTS

<u>Destination</u>	<u>Item</u>
University of Arizona General Stores Building Fifth Street and Mountain Avenue Tucson, Arizona	5 gm ytterbium oxide
Monsanto Chemical Company Mound Laboratory Miamisburg, Ohio	1 lb cerium metal
University of California Los Alamos Scientific Laboratory Los Alamos, New Mexico	2 metal cylinders lanthanum and cerium 50 gm lanthanum metal 50 gm neodymium metal
Michigan State University P. O. 39530 East Lansing, Michigan	20 gm cerium metal
H. B. Nicholas B-11 Research Building Iowa State University Ames, Iowa	10 gm yttrium oxide 10 gm lanthanum oxide 10 gm cerium oxide 10 gm neodymium oxide 10 gm dysprosium oxide 4 gm samarium oxide 2 gm gadolinium oxide 2 gm erbium oxide 2 gm ytterbium oxide 1 gm praseodymium oxide 1 gm holmium oxide 1 gm thulium oxide 1 gm terbium oxide 1 gm lutetium oxide
Mr. Sebastian Amer Box 122, Station A Ames, Iowa	20 gm Er_2O_3
Dr. Milton Burton Department of Chemistry University of Notre Dame Notre Dame, Indiana	10 gm Dy_2O_3 25 gm La_2O_3 25 gm Gd_2O_3 25 gm Y_2O_3 4 gm Lu_2O_3
Mr. Pierre Pelen French Embassy 2535 Belmont Road N. W. Washington, D. C.	samples of uranium metal (natural)

<u>Destination</u>	<u>Item</u>
University of California Receiving Department 2000 Carleton Street Berkeley 4, California	25 gm ytterbium metal 25 gm thulium metal 50 gm samarium metal
Dr. Masao Atoji Oak Ridge National Laboratory Oak Ridge, Tennessee	30 gm lutetium metal 30 gm ytterbium metal 30 gm terbium metal 2 glass vials of thorium carbide-thorium deuteride x-ray powder samples 46 gm lutetium carbide 110 gm thorium carbide 42 gm ytterbium dicarbide 30 gm Lu_2O_3 30 gm Yb_2O_3
Dr. Richard J. Weiss Materials Research Laboratory Ordnance Materials Research Office Watertown 72, Massachusetts	1 pc gadolinium metal appx. 10cm x 5cm x 0.1cm
Iowa State University Room 142 Research Building Ames, Iowa	200 ml 5% rare-earth chloride solutions: YCl_3 , NdCl_3 , GdCl_3 , DyCl_3 and YbCl_3 1500 ml 5% gadolinium chloride solution
J. C. Jamieson R. 21, 5641 S. Ingleside Avenue Chicago 37, Illinois	100 gm cylinder cerium metal
Mr. Warren DeSorbo General Electric Company Schenectady, New York	50 gm crystal bar vanadium
Dr. Glenn A. Crosby University of New Mexico Albuquerque, New Mexico	10 gm Sm_2O_3 10 gm Dy_2O_3
Mr. Dave Drennen Battelle Memorial Institute Columbus 1, Ohio	50 gm crystal bar hafnium metal
Mrs. Mary E. White Massachusetts Institute of Technology Cambridge 39, Massachusetts	1 gm yttrium metal

<u>Destination</u>	<u>Item</u>
Professor Paul A. Beck University of Illinois Urbana, Illinois	100 gm crystal bar wire appx. 1/16" diameter vanadium
Phillips Petroleum Company Atomic Energy Division Idaho Falls, Idaho	18 pc. 1" x 1/2" x 1/8" yttrium metal
Argonne National Laboratory Bailey Road Lemont, Illinois	250 gm distilled yttrium metal
Acct. Prop. Affr. Warehouse 335 Fort Belvoir, Virginia	5 gm praseodymium metal 5 gm samarium metal 5 gm neodymium metal 5 gm dysprosium metal 5 gm terbium metal 5 gm gadolinium metal 5 gm holmium metal
Veterinary Physiology & Pharmacology Room 100, Vet Physiology Ames, Iowa	1200 ml 5% dysprosium chloride solution 0.5 gm gadolinium oxide 0.5 gm dysprosium oxide 0.5 gm ytterbium oxide 0.5 gm yttrium oxide
Brookhaven National Laboratory Warehouse 100 Upton, L. I., New York	3 pc. thulium metal
Mr. W. E. Jardner Atomic Energy Research Establishment Harwell, Didcot Berks, England	5 gm crystal bar vanadium
Dr. Alvin Boltax Nuclear Metals Inc. Concord, Massachusetts	1 - 1" x 0.35" x 0.03" thorium metal