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Semi-annual summary research report in physics for January–June 1959

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SEMI-ANNUAL SUMMARY
RESEARCH REPORT IN PHYSICS
for
January-June 1959
by
Ames Laboratory Staff

AMES LABORATORY
RESEARCH AND DEVELOPMENT REPORT
U.S.A.E.C.
UNCLASSIFIED

Physics and Mathematics (UC-34)
TID 4500, August 1, 1959

UNITED STATES ATOMIC ENERGY COMMISSION

Research and Development Report

SEMI-ANNUAL SUMMARY
RESEARCH REPORT IN PHYSICS
for
January-June 1959
by
Ames Laboratory Staff

October 1959

Ames Laboratory
at
Iowa State University of Science and Technology
F. H. Spedding, Director
Contract W-7405 eng-82

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For the period January-June 1959

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

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Theoretical Physics

1. Interpretation of Magnetic Properties of Dysprosium (R. H. Good, Jr. and S. Legvold)

A paper "Interpretation of Magnetic Properties of Dysprosium" by S. H. Liu, D. R. Behrendt, S. Legvold and R. H. Good, Jr. was submitted for publication in Phys. Rev.

Abstract—Dysprosium is ferromagnetic below 85°K, antiferromagnetic between 85 and 179°K, and paramagnetic above 179°K. The spontaneous magnetic moment lies always in the basal plane, and there is anisotropy in this plane below 110°K.

In the present paper it is shown that the magnetic properties can be interpreted in terms of a two-sublattice model and a phenomenological theory proposed by Neel. Detailed agreement for the magnetization curves in the ferromagnetic and antiferromagnetic regions is obtained.
2. **Four-Fermion Interactions with Spin 3/2 Neutrino (C. L. Hammer and R. H. Good, Jr.)**

The possibility of a spin 3/2 value for the neutrino emitted in beta decay was considered by Kusaka\(^1\) and Ono\(^2\) using a parity conserving interaction. This idea was discarded because the theory permits only Gamow-Teller transitions and because it predicts relatively more electrons at low energy than are observed.

Recently Lanter, et al.\(^3, 4\) observed deviations from the theoretical shape in the Fermi-Kurie plots of Na\(^{22}\), In\(^{114}\), Y\(^{90}\) and P\(^{32}\), all of which decay by pure Gamow-Teller transitions. They find that a factor of \((1 + b/w)\), where \(.2 < b < .4\), must be applied to the theoretical curve to produce agreement with the experiments.

This is a larger discrepancy than has been previously observed.\(^5\)

Also Langer finds that these deviations cannot be attributed to the effects of finite de Broglie wavelength, screening contributions from second forbidden matrix elements, or Fierz interference because

the deviations are so large and of the same sign for the positron emitter Na\textsuperscript{22} as for the negatron emitters.

The facts that the deviations are for Gamow-Teller transitions and increase the low energy end of the spectrum suggest that the idea of beta decay with a spin 3/2 neutrino should be examined as a less probable mode of the decay. There are two possible interactions as long as parity need not be conserved and, with the proper choice of coupling constants, one can fit Langer's observations with either of them. However, if the same branching interaction is applied to the decay of the $\mu$ meson, a Michel parameter in disagreement with experiment is obtained.


In analyzing measurements of high-energy electron scattering by atomic nuclei, it would be advantageous to have methods of calculation more accurate than the Born approximation and less laborious than a partial-wave analysis. A promising step in this direction was made by Schiff and Saxon\textsuperscript{1} for the case of a high-energy Schrödinger particle scattered by a possibly non-central potential. They expressed the exact wave function as the solution of an integral equation of which the inhomogeneous term is a semi-clasical wave function (modified plane wave). From the first

\textsuperscript{1} Nuovo Cimento 6, 614 (1957).
iteration they obtained a scattered amplitude that can be put in a
moderately simple form in the cases of small or of large scattering
angles.

A quicker and simpler method of deriving the Schiff approxi-
mation has been found. The exact wave function is expressed in
terms of the semi-classical wave function by an equation of the
Chew-Goldberger type that involves the exact Green's function.
The scattered amplitude is very quickly obtained from this equation
and has a form different from that given by Saxon and Schiff,
although the two are readily shown to be equivalent. The new form
has been used to reproduce the small-angle and large-angle
approximations; it also has a transparent relation to Lippmann's
two-potential theory ¹ although the splitting of the potential into
two parts is different from that used by Lippmann.

4. **Self-Energy and Potential of an Ellipsoidal Charge Distribution**

(B. C. Carlson)

Previously reported work on the potential of a homogeneous
ellipsoid has been extended to apply to any distribution in which the
surfaces of constant density are a family of similar ellipsoids. In
other words, the density is \( \rho(R) \), where \( R^2 = (x/a)^2 + (y/b)^2 + (z/c)^2 \).

¹ Annals of Physics 1, 113 (1957).
Density functions of this kind provide reasonable approximations to the charge distributions of many atomic nuclei and to the mass distributions of planets.

The self-energy of such a distribution is found to be a product of two factors, one of which depends only on the functional form of \( \varrho(R) \) and is just the self-energy of a spherical distribution \( \varrho(r) \) having \( a = b = c = 1 \). The other factor depends only on \( a, b, \) and \( c \), and can be evaluated easily with the help of a table of elliptic integrals.

The series expansion of the potential given in an earlier report for the special case of a homogeneous ellipsoid is valid also for general \( \varrho(R) \). The radial functions \( f_1(R) \) are defined by:

\[
\int_{\mu R}^{\infty} \varrho(t) t \, dt = \sum_{n=0}^{\infty} \frac{(4n + 1)}{(4n + 2)} f_{2n}(R) P_{2n}(\mu) \quad (0 \leq \mu \leq 1)
\]

where \( P_{2n} \) is a Legendre polynomial. For a distribution of the form \( \varrho(R) = \exp(-R^2) \), the radial functions are Toronto functions (confluent hypergeometric functions).

For the exterior potential of a homogeneous ellipsoid, a second approximation formula has been developed that is also a purely algebraic function of Cartesian coordinates. At the surface
of the ellipsoid it gives exact values of the potential and of its first
and second derivatives, and at large distances it has improved accuracy.

5. Temperature Dependence of the Magnetization of Dysprosium
Metal (R. H. Good)

A paper entitled "The Temperature dependence of the Magnetization of Dysprosium Metal" by Kazuo Niira was submitted for
publication in Phys. Rev.

Abstract - In this paper the experimental fact that the
temperature dependence of the saturation magnetic moment of
dysprosium metal shows a marked departure from the Bloch
T3/2 law at low temperatures is interpreted as due to magnetic
anisotropy. The calculation is in the spin wave approximation
and gives a result which agrees well with the observed
temperature dependence of the magnetization if the magnitude
of the magnetic anisotropy is suitably chosen. A discussion on
the atomic origin of the magnetic anisotropy is given.

Experimental Physics

1. Nuclear Studies (E. N. Jensen)

1.1 High Resolution Beta-Ray Spectrometer

A paper "Theory of a High Resolution Beta-Ray Spectrometer
with High Luminosity" by H. Daniel was submitted to Phys. Rev.
Abstract - Second order perturbation theory has been used to calculate the electron orbits in a "flat" beta-ray spectrometer with an azimuth-independent magnetic field having a symmetry plane. Abandoning first order z-focusing, it is possible to obtain a much higher resolution at a given transmission compared with the usual $\pi\sqrt{2}$-instrument. The resolution depends, in the lowest power, only on fourth-order terms of the radial and axial emission angles. The resolution does not depend on the first power of the source height. The focusing principle is applicable for a set of angles $\theta$ and the dispersion increases strongly with increasing angle. Several examples are discussed.

1.2 Shape of Beta Spectra

The shape of beta spectra are being examined carefully with the intermediate-image spectrometer. The beta spectra of Pm$^{147}$, In$^{114}$ and P$^{32}$ have been examined.

The data on Pm$^{147}$ were fitted with a shape factor of the form $(1 + aW)$. The data yielded a value for $''a''$ of $0.057 \pm 0.008$ $1/mc^2$. In a similar manner the In$^{114}$ data were analyzed and yielded a value of $a = 0.0073 \pm 0.009$ $1/mc^2$ for the shape factor
The data on $\text{P}^{32}$ were fitted to the same shape factor $(1 + aW)$ and gave a value for "$a$" of $0.0028 \pm 0.0017 \text{ l/mc}^2$. The above are preliminary results. Further work is being done on all of the spectra.

The above results appear to be in contradiction to those of Johnson et al. $^1$ and Hamilton et al. $^2$ Their data were fitted to a shape factor $(1 + \frac{b}{W})$ with $b$ essentially zero for Pm$^{147}$. For In$^{114}$ their data indicated $0.2 < b < 0.3$ and for $\text{P}^{32}$ $0.2 < b < 0.4$.

1.3 Moderately Intense Sources Made in an Electron Synchrotron

(C. L. Hammer and A. J. Bureau)

The usual method for irradiating samples internal to a synchrotron or betatron vacuum chamber is to place the sample in a thin-walled thimble that projects into the chamber and then to cause the electron beam to "peel off" adiabatically onto the sample. This procedure is difficult because the thimble must be placed at a radius near the edge of the guide field where the "Fall off" index, $\eta$, approaches unity and where the radial motion of the electron beam is unstable so that the beam can miss the end of the thimble and strike

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the sample. However, the thimble cannot be at a radius larger than the injector since then, in an adiabatic expansion, the electron beam will strike the injector instead of the sample. Because the injector must be placed close to or in the stable region of the guide field to insure capture of the injected beam, a very small radial region which critically depends upon the fringing field of the synchrotron magnet is available for placement of the thimble.

In the Iowa State Synchrotron the extent of this region is approximately 1/16 inch. In addition, because of the close proximity to the stable region of the guide field, the growth of the radial oscillations is small so that the beam fails to penetrate more than a few mils of radial extent of the sample, a large fraction of the beam being lost on the end of the thimble.

These difficulties can be avoided if excitation of the one-half integral resonance, in the manner proposed earlier, is used to increase the amplitude of the betatron oscillations instead of the instability which occurs near the edge of the guide field. With this technique the beam can be preferentially placed onto the thimble even

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if it is at a larger radius than the injector because of the azimuthal
dependence of the growth of the betatron oscillations. Therefore,
placement of the thimble is no longer critical. Furthermore, because
of the rapid growth of the betatron oscillations, a much larger radial
extent of the sample can be irradiated. Uniform radiation of
approximately 1/5 inch of radial extent has been obtained with this
technique with a source strength of one millicurie.

1.4 Large Proportional Counter Spectrometer (D. C. Lu and
D. J. Zaffarano)

A paper "Large Proportional Counter Spectrometer for the Study
of Radioactive Samples with Specific Activity" by J. T. Holloway,
D. C. Lu and D. J. Zaffarano was submitted for publication in Rev.

Abstract - The design and construction of a cylindrical
proportional counter 36" long, 12" i.d. is described, and
its performance as a spectrometer for studying soft radiations
from radioactive samples of low specific activity is given.
The counter tank is operated in an axial magnetic field of 2500
gauss to constrain beta rays to helical paths. A line width of
3.4% (ΔE/E) is obtained from 625 kev electrons from a Cs\textsuperscript{137}
source mounted on a thin film placed within the tank. Simple theory would predict 2.2%. Beta spectra are readily obtained with sources having total activities less than 10 millimicrocuries.

1.5 **Photo-nuclear Cross-section Measurements (D. J. Zaffarano)**

Measurements have been completed on the variation of the argon \((\gamma, p)\) cross-section with photon energy from threshold to 40 Mev. A significant difference has been observed in the response of the previously used Victoreen roentgen dosimeter and the newly constructed standard ionization chamber based on the National Bureau of Standards design. Cross-section curves are being calculated from data on the production of \(\text{Cl}^{39}, \text{Cl}^{38}, \text{C}^{11}\), and \(\text{Cu}^{62}\).

1.6 **Nuclear Levels of \(\text{Cs}^{133}\) (M. G. Stewart and D. C. Lu)**

A paper "Nuclear Levels of \(\text{Cs}^{133}\)" by M. G. Stewart and D. C. Lu was submitted for publication in *Phys. Rev.*

**Abstract** - The gamma-rays of \(\text{Cs}^{133}\) following the electron-capture decay of \(\text{Ba}^{133}\) were studied using a coincidence scintillation spectrometer. Gamma-rays with the following energies (in kev) were observed: 386, 356, 301, 276, (220), 162, 82, 80 and 54. The energies (in kev) of the nuclear levels of \(\text{Cs}^{133}\) with their spins and parities are: ground state \((\frac{7}{2}^+)\) 82 \((\frac{5}{2}^+)\), 162 \((\frac{3}{2}^+)\), 383 \((\frac{3}{2}^+)\), and 438 \((\frac{1}{2}^+)\). The electron-capture transitions
and their relative intensities are as follows: (a) to the 438 kev level, 76% (b) to the 383 kev level, 11% (c) to the 162 kev level, 13%. In the decay of Xe$^{133}$, 1.5 ± 1.0% of the beta transitions was observed to go to the 162 kev level in Cs$^{133}$ and the remaining goes to the 82 kev level.

1.7 The Influence of $I$-forbiddenness on the 82 kev Transition in Cs$^{133}$ (M. G. Stewart)

A paper "The Influence of $I$-forbiddenness on the 82-kev Transition in Cs$^{133}$" by F. M. Clikeman and M. G. Stewart was submitted for publication in Phys. Rev.

Abstract- The gamma-gamma directional correlation of the 356-82 kev cascade in Cs$^{133}$ was measured. The directional correlation coefficients were $\frac{A_2}{A_0} = 0.031 \pm 0.006$ and $\frac{A_4}{A_0} = -0.006 \pm 0.010$. This is consistent with a spin assignment $\frac{1}{2}(Q)\frac{5}{2}(D+Q)\frac{7}{2}$. The ratio of the E2 to M1 matrix elements for the 82 kev transition is $\delta = -0.139 \pm 0.007$. The M1 transition is retarded by a factor of $\sim 700$ and the E2 transition is enhanced by a factor of $\sim 20$, compared to single particle transitions. The retardation of the M1 transition is consistent with the assignment $d\frac{5}{2}$ for the 82 kev state and $g\frac{7}{2}$ for the ground state which would
make the M1 transition \( f \)-forbidden. The enhancement of the E2 transition indicates there is a cooperative phenomenon present.

1.8 Transitions in Mirror Nuclei (M. G. Stewart and D. J. Zaffarano)

A search has been made for nuclear gamma-rays following the positron decays of several of the mirror nuclei. The method employed was to use two scintillation counters in fast coincidence (2 \( \tau \approx 3 \times 10^{-8} \) seconds) that were placed at 90° with respect to each other. One counter was used as a gate for a multichannel analyzer and was set to accept only pulses due to the 511-kev annihilation radiation. The output of the other counter was fed into the multichannel analyzer. The results of the search are tabulated below:

<table>
<thead>
<tr>
<th>Parent Nucleus</th>
<th>Half-life</th>
<th>Energy of Gamma-ray</th>
<th>Percent of Transitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na(^{21})</td>
<td>23 seconds</td>
<td>0.347 Mev</td>
<td>&gt;0</td>
</tr>
<tr>
<td>Mg(^{23})</td>
<td>11.9 seconds</td>
<td>0.440 Mev</td>
<td>9.1</td>
</tr>
<tr>
<td>Al(^{25})</td>
<td>7.6 seconds</td>
<td>0.98 Mev</td>
<td>&lt;0.7</td>
</tr>
<tr>
<td>Si(^{27})</td>
<td>4.1 seconds</td>
<td>1.01 Mev</td>
<td>&lt;0.15</td>
</tr>
<tr>
<td>S(^{31})</td>
<td>2.7 seconds</td>
<td>1.28 Mev</td>
<td>1.1</td>
</tr>
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</table>
Accurate Method for Measuring Internal Conversion Coefficients of Nuclear Transitions (D. C. Lu)

The development of an accurate method for measuring internal conversion coefficients, described in the last report, has been continued. As a test case, the internal conversion coefficients of the 149 kev E\textsubscript{3} transition in Cd\textsuperscript{111m} was carefully measured to be 2.280 ± 0.011, in good agreement with theoretical computations. This represents an accuracy of 0.5% as compared with ± 5% ± 10% usually associated with other methods. A further test is being carried out on the 159 kev transition in Hg\textsuperscript{199m}. This transition has a multipolarity assignment of E\textsubscript{2}, and has been carefully studied by previous investigators. It should offer a good comparison between the results from the new method with theoretical computations as well as other experimental results.

High-Energy Accelerator Studies

Resonant Knock-Out from an A-G Synchrotron

(L. J. Laslett and C. L. Hammer)

The use of gradient-perturbations to effect an instability leading to a marked growth of radial betatron oscillations has been found to have a useful application in knocking the beam out from a conventional
synchrotron. The previous analysis\(^1,2\) of this method has now been extended to A-G synchrotrons in view of the considerable current interest in accelerators of this latter type. The results of this analysis, and corroborative illustrative numerical examples have been described previously. \(^3,4\)

1.10.2 Injection Studies

Following a suggestion made by Dr. Symon, of the MURA Group, attention has been given to an injection method in which the inherent non-linearity of equations governing particle motion in fixed-field accelerators is explicitly employed. Similar considerations may apply to ejection, as in the methods discussed by Dr. Blosser in connection with extraction from a 3-sector AVG cyclotron, the essential feature which is desired being to effect an orderly transfer of "betatron phase space" between regions internal and external to the accelerator.

Basically, the proposed arrangement may be described in terms of a structure for which, in the absence of a field perturbation, the

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\(^3\) L. Jackson Laslett and Charles L. Hammer, MURA-445 (February 2, 1959).

limiting-amplitudes of stable motion fall within a roughly-triangular boundary in the phase-plane for radial betatron motion. By application of a suitably-phased field perturbation, with a spatial wavelength three times that of the unperturbed magnet structure, one corner of this separatrix can be opened up so that a smaller stable region results, around which pass flow-lines defined by the so-called "invariant curves" for slightly unstable particles.

If the perturbation just described is initially made sufficiently great as to suppress the stable region completely and then is caused to decrease to zero, the stable phase-area which is thereby created will be filled with particles efficiently if concurrently the region about this area is flooded with particles from the injector. It is of interest, therefore, to determine the region of phase-space which must be covered by the injector during this process and to note to what extent the boundary of this latter region remains orderly throughout the time that this injection process is in effect. Analytic methods of estimating the nature of the phase plots which prevail, in the absence of the perturbation or with the presence of a static field bump of arbitrary strength, are also of interest in providing useful orientation concerning the method.
Work on the problem outlined above is in progress, having been initiated with a study of somewhat simplified 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 $\sigma = 2 \pi/3$ resonance. Analytic work to describe the character of the phase plots for radial motion has been carried out, by a variational or harmonic balance method and by application of the Moser procedure. The work just mentioned has been guided by a parallel computational investigation with the MURA IBM-704 computer and the results summarized in a series of MURA reports. Computational work has also been performed for the secularly-changing bump which would be employed in the application of this method, considering in this work a perturbation whose strength falls linearly to zero during

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1 The corresponding change of phase for the betatron motion in an interval equal to one period of the perturbation of course would then be $2\pi$, suggesting that an integral resonance with the perturbation is approached.


3 L. Jackson Laslett, MURA-452 (April, 1959), -459 (May, 1959), -461 (May, 1959), -463 (June, 1959), et seq.
Beyond the success of the analytic investigation, the work at this point can only be said to suggest the potential utility of the method—at least for accelerators with a sector number equal to three or to a small multiple of three—but further study is required and the present lines of investigation well may suggest modified procedures which will prove of greater practicality.

2. Solid State Studies

2.1 High Temperature Properties of Metals (G. C. Danielson)

2.1.1 Specific Heat of High Purity Iron


Abstract - 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 are given for high-purity iron over the temperature range 25°C to 1000°C. Variations of the specific heat near the phase transitions are shown in detail.

2.1.2 Specific Heat and Electrical Resistivity of Thorium

The specific heat and electrical resistivity of high purity thorium have been measured from room temperature to 1000°C. Both of these measurements were made on the same sample of crystal bar thorium, which was prepared in this laboratory by the deBoer-van Arkel process. The specific heat data were obtained by a pulse heating method; the electrical resistivity data were obtained by measuring the sample resistance with a Kelvin bridge and calculating resistivities from these data and accurately measured sample dimensions. The results of these measurements are tabulated below.

The specific heat results are accurate to within 2% over the entire temperature range.
Table II. Electrical Resistivity and Specific Heat of Thorium as a Function of Temperature

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Apparent Resistivity (μ ohm-cm)</th>
<th>Specific Heat (cal/mole deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>16.95</td>
<td>6.56</td>
</tr>
<tr>
<td>50</td>
<td>18.45</td>
<td>6.63</td>
</tr>
<tr>
<td>100</td>
<td>21.45</td>
<td>6.75</td>
</tr>
<tr>
<td>150</td>
<td>24.40</td>
<td>6.87</td>
</tr>
<tr>
<td>200</td>
<td>27.35</td>
<td>6.99</td>
</tr>
<tr>
<td>250</td>
<td>30.30</td>
<td>7.12</td>
</tr>
<tr>
<td>300</td>
<td>33.20</td>
<td>7.24</td>
</tr>
<tr>
<td>350</td>
<td>36.10</td>
<td>7.36</td>
</tr>
<tr>
<td>400</td>
<td>38.85</td>
<td>7.49</td>
</tr>
<tr>
<td>450</td>
<td>41.60</td>
<td>7.61</td>
</tr>
<tr>
<td>500</td>
<td>44.20</td>
<td>7.73</td>
</tr>
<tr>
<td>550</td>
<td>46.75</td>
<td>7.85</td>
</tr>
<tr>
<td>600</td>
<td>49.20</td>
<td>7.99</td>
</tr>
<tr>
<td>650</td>
<td>51.55</td>
<td>8.13</td>
</tr>
<tr>
<td>700</td>
<td>53.80</td>
<td>8.28</td>
</tr>
</tbody>
</table>
Table II (continued)

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Electrical Conductivity</th>
<th>Electrical Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>750</td>
<td>55.95</td>
<td>8.44</td>
</tr>
<tr>
<td>800</td>
<td>58.05</td>
<td>8.62</td>
</tr>
<tr>
<td>850</td>
<td>60.05</td>
<td>8.81</td>
</tr>
<tr>
<td>900</td>
<td>62.00</td>
<td>9.02</td>
</tr>
<tr>
<td>950</td>
<td>63.90</td>
<td>9.26</td>
</tr>
<tr>
<td>1000</td>
<td>65.75</td>
<td>9.54</td>
</tr>
</tbody>
</table>

2.2 II - IV Intermetallic Compounds (G. C. Danielson)

2.2.1 Electrical Properties of Mg$_2$Si

Hall effect and electrical resistivity measurements have been made on n-type, single crystal Mg$_2$Si (room temperature carrier concentration approximately $3.5 \times 10^{17}$ cm$^{-3}$) from 5°K to 300°K. The electrical resistivity decreased from 1.5 ohm-cm at 5°K to a minimum of about 0.02 ohm-cm at 100°K, then increased to a value of 0.1 ohm-cm at 300°K. The Hall coefficient had a peak value of 220 cm$^3$/coulomb at 17°K and a saturation value of 76 cm$^3$/coulomb at 5°K. Impurity band conduction appeared to dominate below 20°K. The Hall mobility appeared to have a $T^3$ temperature dependence between 15°K and 20°K.

Electrical resistivity was also measured on p-type crystal samples of Mg$_2$Si. The resistivity of these samples was found to decrease from a very high value at 4°K to about 12.5 ohm-cm at 25°K and to about
4 ohm-cm at 300°K. All of the Mg$_2$Si single crystals were prepared by modified Bridgman techniques. If no impurities are added, the samples are normally n-type. The mechanisms by which n-type material can be converted to p-type material are not fully understood at present and will be the subject of further investigations.

2.2.2 Seebeck Coefficients of Mg$_2$Si and Mg$_2$Ge

Measurements of the Seebeck coefficients of Mg$_2$Si and Mg$_2$Ge have been continued in the temperature range from 300°K to 1000°K. As-grown, n-type samples of Mg$_2$Si were found to be sufficiently thermally stable at temperatures less than 1000°K to yield reliable data if the samples were not heated more than a few hours. These data which are in the intrinsic temperature range can be analyzed to determine $b$, the ratio of electron-to-hole mobilities. By a method of analysis described previously, the following results for $b$ have been obtained for several single crystals of Mg$_2$Si. Morris determined,

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature Range (°K)</th>
<th>$b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg$_2$Si 27B-9</td>
<td>650 - 1000</td>
<td>3.0</td>
</tr>
<tr>
<td>Mg$_2$Si 28B-2</td>
<td>800 - 1000</td>
<td>2.8</td>
</tr>
<tr>
<td>Mg$_2$Si B5-1</td>
<td>700 - 1000</td>
<td>3.0</td>
</tr>
<tr>
<td>Mg$_2$Si B6-5</td>
<td>600 - 1000</td>
<td>3.3</td>
</tr>
</tbody>
</table>

---

$^1$ ISC-975, p 31 (1957).

entirely from Hall effect data by two different methods, the mobility ratio for two p-type (Ag doped) Mg$_2$Si samples. The first method follows Breckenridge; the second is similar to a method outlined by Shockley and is discussed by Morris. These results are tabulated below for comparison purposes.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature (°K)</th>
<th>b (Method 1)</th>
<th>b (Method 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg$_2$Si 25B-2</td>
<td>600</td>
<td>4.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Mg$_2$Si 26B-1</td>
<td>580</td>
<td>5.0</td>
<td>5.2</td>
</tr>
</tbody>
</table>

We have also analyzed, by a method used by Hunter, the electrical resistivity data that was taken simultaneously with the previously cited Hall data of Morris. The results of this analysis are also tabulated.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature (°K)</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg$_2$Si 25B-2</td>
<td>500</td>
<td>3.2</td>
</tr>
<tr>
<td>Mg$_2$Si 26B-1</td>
<td>500</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Winkler has calculated a value for b of 5.7 for polycrystalline

His calculation, however, is based on only a limited amount of Seebeck coefficient data and his result, therefore, is somewhat open to question.

The above results on Mg$_2$Si seem to indicate that values of $b$ obtained from Hall data do not agree with those obtained from either Seebeck coefficient or electrical resistivity data. This disagreement may arise from the unreliability of the Hall data at the temperature at which the analysis must necessarily be made (near the zero of Hall coefficient). Further data are needed to clarify this point.

The results of Seebeck coefficient measurements on three samples of single crystal Mg$_2$Ge indicated that this compound was not thermally stable at elevated temperatures, especially if the measurements (and heating) were done several months after the crystals were grown. These samples, which were prepared by the same techniques employed for Mg$_2$Si, became intrinsic at about 500°K, but experimental values of the Seebeck coefficient at temperatures greater than 700°K tended to deviate from values characteristic of intrinsic behavior toward more positive values. After the crystals had been heated above 700°K, Seebeck coefficients at lower temperatures were more positive than the values which prevailed prior to heating. This effect was sufficiently large, on one
occasion, to cause an n-type sample change to a p-type sample during a data run which extended above 700°K. Because of this instability, the following mobility ratios for Mg$_2$Ge are somewhat less reliable than those for Mg$_2$Si.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature (°K)</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg$_2$Ge</td>
<td>550 - 715</td>
<td>2.8</td>
</tr>
<tr>
<td>Mg$_2$Ge</td>
<td>500 - 715</td>
<td>3.4</td>
</tr>
<tr>
<td>Mg$_2$Ge</td>
<td>570 - 715</td>
<td>3.3</td>
</tr>
</tbody>
</table>

The Hall effect and electrical resistivity data of Redin$^1$ and two p-type Mg$_2$Ge samples were analyzed by the same methods that were used to analyze similar Mg$_2$Si data with the following results. Winkler$^2$

<table>
<thead>
<tr>
<th>Sample</th>
<th>Temperature (°K)</th>
<th>Method</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mg$_2$Ge</td>
<td>445</td>
<td>Hunter(resistivity)</td>
<td>3.6</td>
</tr>
<tr>
<td>Mg$_2$Ge</td>
<td>500</td>
<td>Breckenridge(Hall effect)</td>
<td>3.1</td>
</tr>
<tr>
<td>Mg$_2$Ge</td>
<td>588</td>
<td>Hunter(resistivity)</td>
<td>3.0</td>
</tr>
<tr>
<td>Mg$_2$Ge</td>
<td>800</td>
<td>Breckenridge(Hall effect)</td>
<td>3.1</td>
</tr>
</tbody>
</table>

has reported a value of $b = 5.0$ for polycrystalline Mg$_2$Ge. The

---


$^2$ Loc. cit.
The criticism made above regarding his values for $\text{Mg}_2\text{Si}$ would apply also to this result. In the case of $\text{Mg}_2\text{Ge}$ the agreement between the mobility ratios obtained from Hall data and those obtained from resistivity and Seebeck coefficient data are in sharp contrast to the situation outlined above for $\text{Mg}_2\text{Si}$.

### 2.2.3 Temperature Dependence of Infrared Absorption in Magnesium Silicide


**Abstract** - Infrared spectra of n-type $\text{Mg}_2\text{Si}$ single crystals have been observed in the wavelength region 1 micron to 13 microns over the temperature range $85^\circ\text{K}$ to $370^\circ\text{K}$. The shift in wavelength of the absorption edge varied linearly with temperature, and the optical energy gap ($E_g$) at any temperature ($T$) was given by the equation

$$E_g = E_o + \beta T$$

where

$$E_o = 0.78 \pm 0.02 \text{ ev and}$$

$$\beta = -(3.6 \pm 0.3) \times 10^{-4} \text{ ev/}^\circ\text{K.}$$
This value of $E_0$ is comparable to the thermal energy gap at 0°K of 0.77 ev obtained by Winkler$^1$ and 0.78 ev obtained by Morris, Redin and Danielson.$^2$ The absorption at wavelengths beyond 8 microns was proportional to the square of the wavelength, as predicted by classical Drude theory. A large absorption peak at 0.40 ev, which decreased in height and width as the temperature decreased, indicated a trapping level 0.40 ev below the conduction band.

2.2.4 Elastic Constants of Mg$_2$Sn

An analysis of the lattice vibration of crystals of the fluorite structure has been undertaken, based on a harmonic force law model. Although a general solution of the secular equation has not yet been found, it has been evaluated in the limit of long wavelengths. Calculations, in this limit, were made for calcium fluoride, using two central force constants. These calculations yielded transverse optic mode frequencies of $5.86(10^{13})$ sec$^{-1}$ and $7.59(10^{13})$ sec$^{-1}$, corresponding to wavelengths of light of 32.2 and 24.8 microns. These values can be compared with the experimentally determined Restrahl maxima for calcium fluoride of 32.8 and 22.9 microns.

$^1$ Loc. cit.

In connection with this theoretical study, the elastic constants of \( \text{Mg}_2\text{Sn} \) and \( \text{Mg}_2\text{Pb} \) are being measured in the temperature range from 4°K to 300°K. Both of these compounds have the fluorite structure. These measurements have been completed for \( \text{Mg}_2\text{Sn} \) in the temperature range from 100°K to 300°K. At 300°K, \( C_{11} = 7.81 \pm 0.09 \left(10^{11}\right) \text{ dynes/cm}^2 \), \( C_{44} = 3.61 \pm 0.03 \left(10^{11}\right) \text{ dynes/cm}^2 \) and 
\( C_{12} = 1.72 \pm 0.35 \left(10^{11}\right) \text{ dynes/cm}^2 \).

2.3 Non-stoichiometric Tungsten Bronzes (G. C. Danielson)

2.3.1 Electrical Resistivity of \( \text{Na}_x\text{WO}_3 \)

The electrical resistivity of the cubic sodium tungsten bronzes \( \text{Na}_x\text{WO}_3 \) as a function of sodium concentration \( x \) has been reported to exhibit a minimum in resistivity at \( x = 0.75 \). In a previous report \(^1\) several possible explanations of this minimum were discussed together with a new proposal that the observed minimum is the result of non-homogeneity of the samples, this non-homogeneity being most pronounced at the limits of the range in \( x \) for which \( \text{Na}_x\text{WO}_3 \) has a cubic crystal structure.

To determine the validity of this proposal, electrical resistivity measurements have been made on 12 rectangular, single crystal

\(^1\) ISC-1048, page 25 (1958).
samples with $x$ values ranging from 0.48 to 0.92. Each sample was carefully selected so that differences in resistivity from face to face and from end to end were less than 5%. The results of these measurements show that, in the temperature range from room temperature to 600°C, the maximum resistivity occurs at $x = 0.48$ and the minimum resistivity occurs at $x = 0.92$. Thus, there is no minimum in electrical resistivity at $x = 0.75$ when samples are carefully selected for homogeneity. However, the dependence of the electrical resistivity on $x$ is not linear and the exact dependence will be the subject of further investigation. A preliminary analysis of the electrical resistivity as a function of temperature indicates that $Na_xWO_3$ has the positive temperature coefficient and the quadratic temperature dependence typical of simple metals.

2.3.2 Determination of Precise Lattice Constants of the Tungsten Bronzes

Chemical determinations of the concentration of a metal $M$ in a compound such as $M_xWO_3$ is often difficult and requires relatively large amount of sample material for precise determinations. It is convenient to determine the relationship between the concentration of $M$ and the lattice constants and then to subsequently use determinations of lattice constants as measures of the $M$ concentrations. A modified Cohen method\(^1\) of least squares has been devised in order to obtain

\(^1\) M. V. Cohen, Rev. Sci. Inst. 6, 68 (1935).
precision lattice constants from x-ray powder patterns.

The original Cohen method has been modified in three ways. First, a weight function devised by Hess\(^1\) was added to properly weight the diffraction lines occurring at different angles. This function takes into account the random errors encountered during the process of measuring the x-ray film. The second modification was made by setting the systematic error proportional to the Nelson-Riley function\(^2\) rather than to \(\cos^2\theta\). This function permits the use of reflections occurring at quite low Bragg angles as long as the systematic error is mainly due to absorption. The third modification is concerned with the manner in which the wavelengths are handled. With this third modification it is no longer necessary to refer different wavelengths to a single wavelength.

This work has been programmed for the IBM 650 computer. Programs for the cubic, hexagonal and tetragonal crystal systems have been written in both the Bell Lab interpretive system and in basic machine language.

This new method has been compared with Cohen's original method in a limited number of cases. There is little difference in

\[\begin{align*}
1 \quad & J. B. Hess, \textbf{Acta Cryst.} \textbf{4}, \text{209 (1951)}. \\
\end{align*}\]
lattice constants obtained by the two methods. However, the modified method consistently gives lower values for the estimate of standard error. An experiment is being devised to rigorously compare these two methods of analysis.

2.4 Electrical Resistivity of Rare Earth Single Crystals

(S. Legvold and F. H. Spedding)

Yttrium

A paper entitled "Electrical Resistivity of Yttrium Single Crystals" by P. Hall, S. Legvold and F. H. Spedding was submitted for publication in Phys. Rev.

Abstract - Two samples of yttrium cut from the same single crystal were used to determine the electrical resistivity parallel and perpendicular to the c-axis of the h.c.p. metal. Measurements were made over the temperature range from 1.3 to 300°K. A large anisotropy was observed, with $\rho_\perp / \rho_\parallel = 2.1$ at room temperature. Values for the polycrystalline resistivity over the temperature range indicated were computed from these data and were found to fit a Gruneisen law with $\theta = 187.5°K$. The computed polycrystalline values were also in good agreement with the measured resistivity of a polycrystalline sample.
Dysprosium

A paper entitled "Electrical Resistivity of Dysprosium Single Crystals" by P. Hall, S. Legvold and F. H. Spedding was submitted for publication in Phys. Rev.

Abstract - Resistivity measurements are reported on two single crystals of h.c.p. Dy metal in the temperature range 1.3°K to 400°K. The two magnetic transitions at 90°K and 175°K are very evident in the resistivity. Significant anisotropy is observed only above 175°K, which is the paramagnetic range; at 400°K, $\rho_1/\rho_\parallel = 1.5$. A prediction for the resistivity of polycrystalline dysprosium based on these measurements is seen to be in good agreement with the resistivity of a polycrystalline sample.

Erbium

A single crystal of erbium 1 cm in diameter and about 0.5 cm long was obtained by the Bridgman method. Magnetic measurements on a sample cut from the crystal show that the direction of easy magnetization is along the c-axis. This verifies a neutron diffraction observation by Kohler at Oak Ridge. In the near future erbium samples cut parallel and perpendicular to the c-axis of the hexagonal metal will be used for electrical resistivity measurements.

Attempts to grow other single crystals will be continued.
Europium and Ytterbium

A paper entitled "Electrical Resistivity of Europium and Ytterbium" by M. A. Curry, S. Legvold and F. H. Spedding was submitted to Phys. Rev.

Abstract - Electrical resistivity measurements on europium and ytterbium metals from 1.3° to 300°K are reported. Europium exhibits a sharp peak in its resistivity at 90°K which must correspond to its magnetic ordering temperature. The shape of the peak indicates antiferromagnetic ordering below 90°K. Ytterbium has no sharp anomalies in its resistivity.

2.5 Superconductivity (C. A. Swenson)

Previous work in this group has involved the development of a technique for measuring the change with 10,000 atmos pressure of the zero field superconducting transition temperatures of various metals. These techniques have been applied further to two tin-indium alloys (1.5 and 3.0 percent indium) and to two high purity tantalum samples, in order to determine the influence of sample purity on the pressure effect in superconductors. The results were identical with those which had been found previously for very pure tin and impure tantalum, in direct contradiction with a poorly grounded theoretical prediction by Morel that the impurity influence should be quite large.
The above experiments will conclude our work with this apparatus. The high pressure work on superconductors will be extended to include measurements in a magnetic field in a new moderate pressure (2000 atmos) apparatus which is under construction. This new apparatus will allow the application of truly hydrostatic pressures, and, therefore, will permit the use of single crystal samples. Our interest will be in the cubic metals (such as Va, Ta, Nb), and in order to obtain well-degassed single crystals of these substances a high vacuum ($10^{-8}$ mm Hg) floating zone crystal growing furnace has been constructed and is currently being tested.

A preliminary paper has been published on the superconducting properties of the $\beta$ phase of mercury. This work is being continued, and will be extended to measurements of superconducting pressure effect in $\beta$ mercury. A powder x-ray cryostat has also been built (in collaboration with Dr. M. Atoji of this Laboratory) and the crystal structure of $\beta$ mercury determined as body-centered tetragonal.

2.6 Polytetrafluoroethylene (C. A. Swenson)

A paper entitled "The Behavior of Polytetrafluoroethylene (Teflon) Under High Pressure" by R. I. Beecroft and C. A. Swenson has been accepted for publication in *J. Appl. Phys.*

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Abstract - The presence of polymorphic phase transitions, apparently unique among high polymers, enhances interest in polytetrafluoroethylene, while its potentialities for cryogenic applications make low temperature data particularly valuable. Compression measurements have been made on samples of Teflon at various temperatures between 75°C and 380°C and at pressures up to 21,000 atmos. The phase diagram found for the region above the ice point is in qualitative agreement with previously published results, with a possible additional transition appearing above room temperature at pressures of over 11,000 atmos. Time effects and a large pressure hysteresis make the transition parameters quite ambiguous, and the hysteresis becomes so broad at low temperatures that the phase diagram cannot be extended below the ice point. An apparent negative thermal expansion indicated by the isothermal compression measurements is shown to result from an incomplete high pressure transition. From an engineering standpoint, the measurements indicate that a Teflon gasket loaded to 3000 atmos at room temperature should maintain a seal at any lower temperature.

Further work has been done on the cubic-condensed cubic transition in cerium at both high pressures (20,000 atmos) and high temperature.
(300°C) to investigate the suggestion of Russian workers that a critical point exists for this transition. Both the temperatures and pressures needed are near the limits of the apparatus, and considerable experimental difficulties have been encountered, although preliminary results confirm the Russian data.

2.7 Nuclear Magnetic Resonance in Sodium Tungsten Bronzes

(R. G. Barnes)

A more thorough investigation of the Knight shift of the sodium Na\(^{23}\) nuclear magnetic resonance in the sodium tungsten bronzes, Na\(_x\)WO\(_3\), has been completed. Preliminary results were reported ISC-1115. Relative to aqueous sodium chloride solution, the shift of the bronze resonance is \(-0.002 \pm 0.002\%\) for \(x\)-values of 0.56, 0.65, 0.73, 0.75, 0.78, 0.81, and 0.89. For comparison, the value of the shift for metallic sodium is \(+0.1133 \pm 0.003\%\). The shift of the bronze resonance is therefore essentially zero, and its slight negative value probably reflects a small chemical shift.

Careful and extensive searching has failed to reveal the tungsten W\(^{183}\) and oxygen O\(^{17}\) resonance in the bronzes. This is especially surprising since a very good signal was obtained from pure metallic tungsten. It is quite probable that the isotropic exchange interaction between tungsten and sodium nuclei broadens the tungsten resonance sufficiently to prevent its detection.
2.8 Activation Volume for Self-Diffusion in Metals (R. G. Barnes)


Abstract - It is shown that the activation volume for self-diffusion in a metal may be determined from the pressure dependence of the nuclear spin-spin relaxation time in the temperature range in which narrowing due to diffusional motion occurs. The line width of the Li$^7$ resonance in lithium metal dispersed in mineral oil has been measured as a function of pressure to approximately 3000 atmospheres at room temperature. An activation volume of $5.15 \pm 0.25 \text{ cm}^3$ results, corresponding to 40% of the molar volume.

2.9 Nuclear Quadrupole Resonance Spectra of Group III Halides (R. G. Barnes)

Abstract - The $^{27}$Al pure quadrupole resonances in AlBr$_3$ are reported. With the addition of these data, the quadrupole coupling constants of all the atoms in the structure of five group III halides are known. For these cases it has been possible to determine complete self-consistent electron distributions for the molecules. In addition, for two of the compounds it has been possible to determine bond angles and establish the existence of bent bonds in the molecules.

2.10 Mass Spectrometric Studies of Rare Earth Cohesive Energies

(D. E. Hudson and F. H. Spedding)

An accurate, sensitive, and rapid method of measuring metallic cohesive energies has been described in previous reports.$^{1,2}$ Further work has been done on europium, gadolinium, holmium, and erbium. The results given below are our final values for these metals, using $\Delta H_T$ for the heat of sublimation from the crystal at $T^\circ K$ and $\Delta H_{298}$ for the value reduced to 298$^\circ K$ by thermodynamic procedures.

The results for europium are in fair agreement with the value of

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1 ISC-293
2 ISC-854
41.10 ± 0.08 kcal/M reported by Spedding, Hanak and Daane of this Laboratory. The results quoted above are the first direct measurements on the other three metals.

<table>
<thead>
<tr>
<th>Metal</th>
<th>$H_T$ kcal/M</th>
<th>$H_{298}$ kcal/M</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europium</td>
<td>727</td>
<td>42.0 ± 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>43.1 ± 0.4</td>
</tr>
<tr>
<td>Gadolinium</td>
<td>1370</td>
<td>78.2 ± 0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>81.3 ± 0.3</td>
</tr>
<tr>
<td>Holmium</td>
<td>1248</td>
<td>72.8 ± 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75.0 ± 0.4</td>
</tr>
<tr>
<td>Erbium</td>
<td>1207</td>
<td>73.0 ± 0.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75.3 ± 0.4</td>
</tr>
</tbody>
</table>

In addition, we have been able to estimate the vapor pressure (P) of all of the rare earths by calculation based on statistical thermodynamics. These estimates are relative since they involve J, the total angular momentum quantum number of ground state of the neutral atom. Typical results are expressed in terms of $P/(2J+1)$:

<table>
<thead>
<tr>
<th>Metal</th>
<th>$T^*K$</th>
<th>$P/(2J+1)$ in mm Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europium</td>
<td>727</td>
<td>$4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Gadolinium</td>
<td>1370</td>
<td>$1 \times 10^{-5}$</td>
</tr>
<tr>
<td>Holmium</td>
<td>1248</td>
<td>$4 \times 10^{-6}$</td>
</tr>
<tr>
<td>Erbium</td>
<td>1207</td>
<td>$1 \times 10^{-6}$</td>
</tr>
</tbody>
</table>

Since $2J+1$ is likely to be between 1 and 6, the values given may be used as order-of-magnitude estimates of the pressures themselves. (Unfortunately, $J$ is not definitely known.) These are the only pressure values available for these metals, and as such, are valuable in spite of the uncertainty regarding $J$.

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

The counting properties of diamond are being exploited to study the trapping levels responsible for carrier capture in diamond. Past results and details appear in previous reports.

Further studies of the decay of the internal electric field in the dark have been carried out. This dark decay may be attributed to thermal liberation of trapped charges.

An analysis of the data gives a shallow trap depth of 0.6 electron volts. The value is in good agreement with results obtained by others.

The average cross sections for the liberation of electrons and holes from charge traps has been calculated from our results on detrapping by photons. Some typical results are:

<table>
<thead>
<tr>
<th>Photon energy (e. v.)</th>
<th>Cross section (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.14</td>
<td>$0.2 \times 10^{-14}$</td>
</tr>
<tr>
<td>2.61</td>
<td>$0.5 \times 10^{-14}$</td>
</tr>
<tr>
<td>2.85</td>
<td>$4 \times 10^{-14}$</td>
</tr>
<tr>
<td>3.46</td>
<td>$26 \times 10^{-14}$</td>
</tr>
</tbody>
</table>
These and other data have been used to substantiate the hypothesis that a hole trapping level is to be found about 3.2 e.v. above the valence band. It has been postulated that lattice vacancies give rise to this trap.

It should be pointed out that our cross section values show that the effective geometrical extent of a trap is much larger than a single atom site. This could mean that the trap has a long-range coulomb field or that it is due to a neutral defect of larger extent than a vacancy.

2.12 A Study of Surface Ionization (D. E. Hudson)

The work on this project was extended and re-analyzed. We have reached the conclusion that the effective work function of hot tungsten and iridium surfaces for surface ionization is considerably higher than the electronic work function. Our final results are:

<table>
<thead>
<tr>
<th>Surface</th>
<th>Atom being ionized</th>
<th>Work Function Difference (Effective minus electronic) electron volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tungsten</td>
<td>Dy</td>
<td>1.3</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Er</td>
<td>1.2</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Ho</td>
<td>0.9</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Eu</td>
<td>0.6</td>
</tr>
<tr>
<td>Tungsten</td>
<td>Gd</td>
<td>0.3</td>
</tr>
<tr>
<td>Iridium</td>
<td>Dy</td>
<td>0.8</td>
</tr>
<tr>
<td>Iridium</td>
<td>Ho</td>
<td>0.7</td>
</tr>
</tbody>
</table>
The data are interpreted to mean that the surface contains patches of higher work function. These patches give the predominant contribution to surface ionization.
APPENDIX I: LIST OF REPORTS FROM THE AMES LABORATORY

1. Reports for Cooperating Laboratories


ISC-1038  Charles V. Banks, Nelson J. Fowlkes, Peter A. Beak and Michael J. Maximovich. Annotated Bibliography of Alpha-Benzildioxime.


ISC-1058  Donald R. Saxton and Glenn Murphy. Creep of Uranium.


ISC-1069  R. W. Johnson and E. H. Olson. Separation of Cerium from Other Rare Earths by Ignition of the Nitrates.


2. Publications

Armstrong, P. E., O. N. Carlson and J. F. Smith
The Elastic Constants of Thorium Single Crystals in the

Atoji, Masao

Atoji, Masao
(1959).

Banks, C. V. and Roger E. Yerick
Chelating Properties of N,N,N',N'-Tetrakis(phosphonomethyl) -

Barnes, R. G., R. D. Engardt and R. A. Hultsch
Nuclear Magnetic Resonance Determination of Activation Volume
(1959).

Baroch, Charles J., Morton Smutz and Edwin H. Olson
Processing of California Bastnasite Ore. Mining Eng. 214,

Beaudry, B. J. and A. H. Daane
The Antimony-Uranium Alloy System. Trans. AIME 215, 199-

Capellen, Jennings and Harry J. Svec
Correction of the Observed Ratio for Errors Associated with
Ion Current Collection and Amplification in Dual Collector
Mass Spectrometers. Iowa State Coll. J. Sci. 33, 427-430
(1959).

Dorweiler, V. P. and R. W. Fahien
Mass Transfer at Low Flow Rates in a Packed Column. A.I.Ch.E.
Journal 2, 139-144 (1959).

Duke, Frederick R.

Duke, Frederick R. and Richard A. Fleming
Transport Numbers and Ionic Mobilities in the System Potassium
(1959).
Elleman, Thomas S., John W. Reishus and Don S. Martin, Jr.

Flesch, Gerald D. and Harry J. Svec

Fritz, James S. and Shirley K. Karraker

Fritz, James S. and Marlene Johnson Richard

Fritz, James S., Stanley S. Yamamura and Evelin Carlston Bradford

Haeffling, J. F. and A. H. Daane
The Immiscibility Limits of Uranium with the Rare Earth Metals. Trans. AIME 215, 336-338 (1959).

Hansen, Robert S.

Hansen, Robert S.

Hansen, Wilford N.

Hansen, Wilford N. and Maurice Griffel

Holloway, J. T. and L. Jackson Laslett

Johnson, Russell W. and Don S. Martin, Jr.

Knapp, Lester, Roman Schoenherr, John Barghusen and Morton Smutz
Kniseley, Richard N., Velmer A. Fassel, Raymond A. Tabeling, E. George Hurd and Beverly B. Quinney

Laslett, L. Jackson

Powell, J. E. and M. A. Hiller

Powell, J. E. and F. H. Spedding

Savage, William R., Donald E. Hudson and Frank H. Spedding

Sawada, S. and G. C. Danielson

Sawada, S. and G. C. Danielson

Sawada, S. and G. C. Danielson

Schirber, J. E. and C. A. Swenson

Schupp, Fritz D., Clifford B. Colvin and Don S. Martin, Jr.

Smith, J. F. and B. T. Bernstein
Smith, J. F. and R. L. Smythe

Spedding, F. H., K. Gschneidner, Jr. and A. H. Daane

Spedding, F. H., A. W. Naumann and R. E. Eberts

Wilhelm, Harley A. and Raymond A. Foos

Williams, Donald E., Gabriele Wohlauer and R. E. Rundle
<table>
<thead>
<tr>
<th>Destination</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Armour Research Foundation</td>
<td>200 gm crystal bar vanadium</td>
</tr>
<tr>
<td>Illinois Institute of Technology</td>
<td></td>
</tr>
<tr>
<td>Chicago, Illinois</td>
<td></td>
</tr>
<tr>
<td>Physikalisches Institut der Technischen</td>
<td>3 rods cerium metal</td>
</tr>
<tr>
<td>Munich, Germany</td>
<td></td>
</tr>
<tr>
<td>Argonne National Laboratory</td>
<td>23 yttrium fluoride samples</td>
</tr>
<tr>
<td>Lemont, Illinois</td>
<td></td>
</tr>
<tr>
<td>Karl S. Vorres</td>
<td></td>
</tr>
<tr>
<td>State University of Iowa</td>
<td></td>
</tr>
<tr>
<td>Iowa City, Iowa</td>
<td></td>
</tr>
<tr>
<td>Biophysics Research Laboratory</td>
<td>5 gm praseodymium oxide</td>
</tr>
<tr>
<td>Peter Bent Brigham Hospital</td>
<td>5 gm neodymium oxide</td>
</tr>
<tr>
<td>Boston, Massachusetts</td>
<td>5 gm samarium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm lanthanum oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm cerium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm gadolinium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm yttrium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm dysprosium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm holmium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm erbium oxide</td>
</tr>
<tr>
<td></td>
<td>1 gm ytterbium oxide</td>
</tr>
<tr>
<td></td>
<td>200 mg ytterbium oxide</td>
</tr>
<tr>
<td></td>
<td>200 mg thulium oxide</td>
</tr>
<tr>
<td></td>
<td>200 mg lutetium oxide</td>
</tr>
<tr>
<td></td>
<td>27 gm yttrium metal</td>
</tr>
<tr>
<td>U. S. Bureau of Mines</td>
<td></td>
</tr>
<tr>
<td>Boulder City, Nevada</td>
<td></td>
</tr>
<tr>
<td>University of California</td>
<td>200 gm cerium metal</td>
</tr>
<tr>
<td>Los Alamos Scientific Laboratory</td>
<td>200 gm lanthanum metal</td>
</tr>
<tr>
<td>Los Alamos, New Mexico</td>
<td></td>
</tr>
<tr>
<td></td>
<td>sample of octasodium salt of N,N,N',N'-tetrakis-</td>
</tr>
<tr>
<td></td>
<td>(phosphonomethyl)-1,2-cyclohexanediamine</td>
</tr>
</tbody>
</table>
Destination

University of Arizona
Tucson, Arizona

20 gm Gd$_2$O$_3$
20 gm Dy$_2$O$_3$
20 gm Ho$_2$O$_3$
20 gm Pr$_6$O$_11$
20 gm Er$_2$O$_3$
20 gm Yb$_2$O$_3$
20 gm La$_2$O$_3$
20 gm Ce$_2$O$_3$

5 gm ytterbium oxide

University of New Mexico
Albuquerque, New Mexico

5 gm holmium oxide
5 gm thulium oxide
10 gm erbium oxide

Dr. Torgen Huus
Universitetets Institut for Teoretisk
Copenhagen, Denmark

1 gm yttrium metal
1 gm lanthanum metal
1 gm cerium metal
1 gm neodymium metal
1 gm praseodymium metal
1 gm gadolinium metal
1 gm lutetium metal
1 gm erbium metal
1 gm ytterbium metal
1 gm samarium metal
1 gm terbium metal
1 gm dysprosium metal
1 gm holmium metal
1 gm thulium metal

5 gm praseodymium oxide
5 gm neodymium oxide
5 gm samarium oxide

1 gm lanthanum oxide
1 gm cerium oxide
1 gm gadolinium oxide
1 gm yttrium oxide
1 gm dysprosium oxide
1 gm holmium oxide
1 gm erbium oxide
1 gm ytterbium oxide

200 mg terbium oxide
200 mg thulium oxide
200 mg lutetium oxide

Atomic Energy Research Establishment
Harwell, Berkshire, England

1 gm lutetium metal
<table>
<thead>
<tr>
<th>Destination</th>
<th>Item</th>
</tr>
</thead>
</table>
| Carnegie Institute of Technology  
Pittsburgh, Pennsylvania | 4 gm cerium metal |
| Michigan Chemical Corporation  
St. Louis, Michigan | 3 10-gm samples yttrium metal |
| California Institute of Technology  
Pasadena, California | 1 gm N\textsuperscript{15} salt |
| | 2 gm ammonium sulfate |
| Professor Yngve Ohman  
Stazione Astrofisica Svedese  
Isola Di Capri, Italy | 2 disks gadolinium metal |