U N C L A S S I F I E D

ISC-707

UNITED STATES ATOMIC ENERGY COMMISSION

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SEMI-ANNUAL SUMMARY RESEARCH REPORT IN PHYSICS

For July through December, 1955

by

Ames Laboratory Staff

March 8, 1956

Ames Laboratory
at
Iowa State College
F. H. Spedding, Director
Contract W-7405 eng-82

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Printed in USA. Price 25 cents. Available from the

Office of Technical Services
U. S. Department of Commerce
Washington 25, D. C.

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SEMI-ANNUAL SUMMARY RESEARCH REPORT IN PHYSICS

For the Period July through December, 1955

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

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ISC-645

PHYSICS

Under the direction of F. H. Spedding, G. W. Fox, G. C.
Danielson, D. E. Hudson, E. N. Jensen, J. M.
Keller, J. K. Knipp, S. Legvold and
D. J. Zaffarano
C. A. Swenson

Theoretical Physics1. Magnetic properties of dysprosium (J. M. Keller)*

We have continued a study of the magnetic properties of dysprosium metal, based on a molecular field model. The apparent existence of a ferromagnetic-antiferromagnetic (F-A) transition at 85°K requires that the molecular field coefficients are themselves slowly varying functions of the temperature. Such a model predicts that in a single crystal for a magnetic field applied in the direction of spin orientation, the susceptibility decreases slowly and monotonely as temperature decreases from the Néel point to the F-A transition temperature. For a magnetic field perpendicular to the direction of spin orientation, the susceptibility increases continuously as the temperature is lowered, becoming essentially infinite at the F-A transition. (See ISC-645).

According to this theory, the reduction in susceptibility (found experimentally in polycrystalline samples) [F. Trombe, Compt. rend. 236, 591 (1953); J. F. Elliott, S. Legvold and F. H. Spedding, Phys. Rev. 94, 1143 (1954)]⁷, as the temperature is decreased immediately below the Néel point is attributed to the parallel susceptibility. This points up the importance of magnetic anisotropy, since if the material were isotropic, the spins would always instantaneously rotate into an orientation (nearly) perpendicular to a weak applied magnetic field.

We have explored the nature of the magnetic orientations produced by external magnetic fields of arbitrary magnitude and direction, using the molecular field model and including an anisotropy energy proportional to the square of the component of atomic angular momentum in the preferred direction. Competition between the ferro- and antiferromagnetic couplings makes interesting effects occur at magnetic field strengths considerably lower than is the case for simple antiferromagnetics.

For a field applied perpendicular to the preferred direction, the large perpendicular susceptibility is due to the progressive reorientation of the angular momenta of the different sublattices without change of magnitude, as the external field is made stronger.

* Names indicate group leaders in charge of work.

At a certain critical field, the angular momenta all become parallel to the applied field, and the crystal becomes essentially a ferromagnetic (or a saturated paramagnet).

For a field applied nearly parallel to the preferred direction, the initial (parallel) susceptibility is small, and due primarily to change in magnitude of the angular momenta of the atoms on the different sublattices. But when the applied field becomes strong enough to overcome the effects of anisotropy, the angular momenta suddenly rearrange themselves to be nearly perpendicular to the applied field (this phenomenon is known as "spin flop"), and in stronger fields behave essentially the same as for fields applied perpendicular to the preferred direction. There is again a change to a ferromagnetic (or saturated paramagnetic) state at still greater applied fields.

The theory explains qualitatively the magnetization curves of Elliott et al. as follows. In weak external magnetic fields, the magnetization is small because some of the crystallites are oriented with their preferred spin direction parallel to the applied field. When the field strength becomes strong enough to overcome the anisotropy effects, the angular momenta rotate into more effective directions, with a consequent rapid increase in magnetization. The initial susceptibility predicted by the theory is somewhat larger, and the rapid increase in magnetization smaller than the experimental observations. This may be due to the known limitation in any molecular field theory. It may also indicate that the form of anisotropy assumed is inadequate.

2. Electron scattering in transition metals (J. M. Keller)

A report (ISC-687) entitled "Multiband Electrical Conductivity" by John Gibson and J. M. Keller is being distributed.

Abstract

Scattering amplitudes arising from lattice vibrations are calculated for electrons in a transition metal, with special reference to nickel. The potential in the crystal is treated as a deformable potential, with corrections to adjust the zero of potential and to include effects of the redistribution of charge during lattice vibration.

The distinction between normal and Umklapp processes is not a sharp one when a deformable potential is assumed. Rather, the scattering gradually takes on more of an Umklapp character as the wave length of the phonon decreases.

The 4s electrons are treated in the weak binding and 3p electrons in the strong binding approximation. For s-s scattering, the Umklapp amplitude is larger than normal amplitude by roughly the ratio

(kinetic energy at the bottom of the band)/(Fermi energy), or about 8. This makes back-scattering unreasonably likely, and indicates that the method is probably not accurate for large angle scattering. Scattering amplitudes for s-d scattering are of the same order as for s-s scattering in the forward direction. The dependence of s-d amplitude on the various angles is explored.

Experimental Physics

1. Nuclear Studies

1.1 The decay scheme of Sc^{47} (E. N. Jensen)

A paper entitled "Decay Scheme of Sc^{47} " by R. T. Nichols and E. N. Jensen, was published. [*Phys. Rev.*, 100, 1407 (1955)]7

Abstract

The radiations of Sc^{47} have been examined with a scintillation spectrometer and with an intermediate image spectrometer operated in conjunction with a scintillation spectrometer for coincidence spectra. Two beta groups were observed with maximum energy values of 0.596 ± 0.010 Mev and 0.430 ± 0.005 Mev and relative intensities of 36% and 64% respectively. The log ft values of the beta groups were found to be 6.0 and 5.3, respectively. One gamma ray was observed having an energy of 0.167 ± 0.002 Mev. The coincidence beta spectrum contained only the lower energy group. The decay scheme for Sc^{47} is discussed.

1.2 The decay scheme of Br^{82} (E. N. Jensen)

The radiations from Br^{82} have been studied using an intermediate-image coincidence spectrometer, a gamma-gamma coincidence scintillation spectrometer, and gamma-gamma directional correlation equipment. One allowed beta-ray group, having a maximum energy of $444 \pm$ kev, and eight gamma rays were observed. The gamma-ray energies were found to be 545 ± 2 , 610 ± 2 , 688 ± 2 , 766 ± 3 , 817 ± 7 , $1,029 \pm 5$, $1,305 \pm 5$, and $1,469 \pm 7$ kev. Determinations were made of the relative intensities of the internal conversion electrons, the relative intensities of the gamma rays and the internal conversion coefficients. Five directional correlation measurements have been performed between various gamma-ray combinations. Unambiguous assignments for the spins and parities of four of the first five excited levels have been made, while the assignment for the remaining level is restricted to two possible values. The proposed decay scheme is shown in Fig. 1. Multipole mixing ratios were determined for three of the transitions. The E2 intensity of the 1.30-Mev transition is 15.8

Fig. 1 - Proposed energy level diagram for Br^{82} . The energy levels are given in Mev. Radiations represented by dashed lines have been reported by Easterday [UCRL-2172 (1953)] and Huddleston and Mitchell [Phys. Rev., 88, 1350 (1952)].

times that of the M1 component, the E2 intensity of the 0.61-Mev transition is 5.29 times that of the M1 component, and the M2 intensity of the 0.55-Mev transition is 2.37 per cent of the E1 component. It appears probable that levels I and II are vibrational levels.

Further details of this study are given in ISC-704.

1.3 Some measurements of beta-gamma directional correlations (E. N. Jensen)

Beta-gamma directional correlation measurements have been made on Re^{186} , Pr^{142} , and La^{140} . The beta detector consisted of a $1\frac{1}{8}$ " x $1\frac{1}{8}$ " anthracene crystal mounted on a Lucite pipe sealed to a type 6292 phototube. The gamma detector was a NaI crystal. The source and detectors were mounted in a thin aluminum vacuum chamber.

Re^{186}

The gamma channel was set to window on the 137 kev photopeak and three measurements of the anisotropy

$$A = \frac{W(180^\circ) - W(90^\circ)}{W(90^\circ)}$$

were made with the beta channel set to window as indicated in the tabulated results. All probable errors are statistical.

The Anisotropy A of Re^{186}

Energy Range	A
600 - 1100 kev	0.131 ± 0.017
600 - 980 kev	0.131 ± 0.014
400 - 600 kev	0.070 ± 0.006
Integral above 400 kev	0.055 ± 0.005

The above results have been corrected for the finite detector geometry. These results are in agreement with the results of Freedman [private communication and Phys. Rev., 98, 214 (1955)]. The source was prepared by evaporating the water from a drop of solution.

Pr^{142}

Beta-gamma directional correlation measurements were made by setting the gamma analyzer integrally to pass all radiation above 1 Mev and the beta analyzer was set to window in the region of 400 - 500 kev. The anisotropy of the directional distribution,

corrected for detector geometry, was found to be -0.058 ± 0.014 . The source was prepared by evaporating the water from a solution of praseodymium chloride.

La¹⁴⁰

Measurements of the beta-gamma directional correlation between the 1.6-Mev gamma-ray and the 2.15-Mev beta group were made by setting the gamma analyzer to pass radiation above 900 kev and the beta analyzer to pass betas above 1670 kev. The anisotropy of this distribution, corrected for detector geometry, was found to be 0.133 ± 0.016 .

1.4 Small order effects of beta spectra (E. N. Jensen)

A paper (ISC-658) entitled "Small Order Effects of Beta Spectra", by A. V. Pohm, R. C. Waddell and E. N. Jensen was submitted to Physical Review for publication.

Abstract

An intermediate-image spectrometer and a thin-lens spectrometer were used to carefully examine the beta spectra of P³², K⁴², and As⁷⁶. The P³² beta spectrum was examined for a Fierz type deviation and within the experimental error none was found. The value of "r" describing the magnitude of the Fierz deviation as defined by Davidson and Peaslee was found to be 0.00 ± 0.03 . The first forbidden transitions with $\Delta I = 0$, "yes" of K⁴² and As⁷⁶ were examined for deviations from a linear Kurie plot. Within experimental error no deviations were found. From the shape factors calculated by Mahmoud and Konopinski on the basis of an STP combination one would expect deviations for these first forbidden transitions if the best previous estimate of certain parameters are correct. A deviation of the K⁴² Kurie plot below 500 kev was attributed to an additional beta group.

1.5 Ionization yields for fission fragments (C. L. Hammer)

Measurements of the kinetic energy of fission fragments in gas ionization chambers have usually been made under the assumption that the average energy per ion pair for fission fragments is the same as that for alpha particles. This assumption has resulted in an energy discrepancy of several per cent for the fission energy. Theoretical work by Knipp and Ling [J. K. Knipp and R. C. Ling, Phys. Rev., 82, 30 (1951)] predicted that the magnitude of the discrepancy should be dependent on the gas used in the ionization chamber. Specifically, the energy should be several per cent higher if the measurements were made in helium rather than in argon. An attempt [L. O. Herwig and G. H. Miller, Phys. Rev., 95, 413 (1954)] to verify this prediction failed to show any

difference between helium and argon, although wide variations were found among other gases. An effort has been made to find the theoretically predicted difference in helium and argon, and to discover any other effects which might account for the remaining discrepancy (if any). The gases helium, argon, and a one-tenth per cent argon in helium mixture have been examined.

Natural uranium was fissioned by D-D neutrons and the ionization was collected in a gridded parallel-plate electron collection chamber. The pulses were sorted and probability versus ionization plots were made. The ionization corresponding to the most probable light fragment and to the most probable heavy fragment were read from these plots. A similar procedure was followed in finding the ionization produced by alpha particles of known energy from the uranium. The fission energies quoted in Table 1 were found by multiplying the ratio of fission ionization to alpha ionization by the alpha energy. The gases were continuously purified by a convection purifier containing a calcium-magnesium alloy at 500°C.

Saturation curves (ionization versus collecting field) were taken for the alpha particles and fission fragments. Although the fields were twice those used in the original attempt, a completely flat plateau could not be achieved. Reducing the fields by one-third lowered the alpha ionization by three-tenths per cent and the fission ionization (light fragment) by eight-tenths per cent. These slopes were about the same for all three gases. Table 1

Table 1

Gas	Energy (mev)	
	Light	Heavy
Argon	94.2	61.1
Helium	96.6	65.3
Helium + Argon	98.1	66.4

gives the measured energy values (uncorrected for source thickness).

The differences in energy found between helium and argon are in line with those expected from theory. It is probable that the original attempt to find a difference failed because sufficient saturation could not be achieved under the fields obtainable in the chamber at that time.

The possibility of an effect in helium due to metastable states was also examined. One-tenth per cent of argon is

sufficient to discharge most of the metastable states in helium. As the results show, this addition of argon increased the energy significantly. It therefore appears that fission fragments are more efficient in producing metastable states in helium than are alpha particles, thus decreasing the ionization ratio and therefore the measured energy. A pulse rise-time correction, the magnitude of which is now being investigated, should be applied to the energy measured in the mixtures.

1.6 Excitation of isomers by high energy x-rays (C. L. Hammer)

A search for isomeric transitions with half-lives in the microsecond region, which was previously reported, has been extended to include most of the rare earth nuclei. Six of the rare earth nuclei have been found to have long lived states. The results of preliminary measurements are shown in Table 2.

Table 2

Element	Energy (kev)	Half-life (μ sec)
W	352 $\pm$ 4	14.3 $\pm$ 0.5
Lu	120	40 - 80
Er	210	millisecond region
Ho	300	millisecond region
Tb	only 45 kev x-ray observed	millisecond region
Nd	120	5 - 15
Pr	70	5 - 15

In addition to the rare earth nuclei, further information concerning the isomeric transition in tungsten (ISC-645) has been obtained. Preliminary measurements of the threshold of this reaction, about 10 Mev, indicate that the isomeric state is obtained by the emission of a neutron from the parent nucleus. Since only natural tungsten has been used for target material, this means that the isomeric state can be in either W¹⁸¹ or W¹⁸⁵. W¹⁸³ has been eliminated because the decay scheme is well known [Dumond et al., Phys. Rev., 97, 1007 (1955)] and is not in agreement with the observations reported here. The energy and half-life of this transition, also shown in Table 2, are consistent with that expected from a magnetic quadrupole transition. [S. A. Moszkowski, Ch. XIII, Beta and Gamma-ray Spectroscopy, Siegbahn]. Rough measurements of the K shell conversion coefficient

are in agreement with this assignment [Rose, Goertzel, Perry, ORNL-1023]. An extensive search for other γ -rays following this decay has yielded negative results thereby determining that the transition goes primarily to the ground state.

Since no 100 kev γ -ray is observed, the transition from the isomeric state to the first rotational level of the nucleus must be more highly forbidden than the transition to the ground state. This observation coupled with the fact that the transition is of the magnetic quadrupole type is not in agreement with the level scheme predicted by Motteleson and Nilsson [B. R. Motteleson and S. G. Nilsson, Phys. Rev., 99, 1615 (1955)].

1.7 Synchrotron development (D. J. Zaffarano)

1.7.1 Energy control

Accurate energy control for the synchrotron has been developed and tested. This control utilizes two concentric pickup loops of wire placed above the donut, connected so that the difference voltage is proportional to the time flux change in the vicinity of the equilibrium orbit. This voltage is integrated by means of a chopper stabilized amplifier in a Miller circuit and compared with an absolute D.C. reference. When the signal and reference are equal, a sharp pulse triggers the beam expander circuit [C. L. Hammer and A. J. Bureau, Rev. Sci. Instr., 26, 594-598 (1955); C. L. Hammer and A. J. Bureau, Rev. Sci. Instr., 26, 598-600 (1955)] and the x-ray beam is ejected from the donut. In principle, if the area of the pickup coil is known, the R.F. frequency monitored, and the RC of the integrating circuit and bias are known, an absolute calibration of the energy of the machine should be possible.

1.7.2 Beam extraction

Equipment has been installed to allow the use of a larger donut with electrostatic beam deflection for the purpose of extraction of the internal electron beam of the synchrotron. The external electron beam will provide certain advantages in monitoring, and will permit electron scattering experiments at energies up to 90 Mev. Quadrupole lenses have been fabricated for focusing the electron beam.

1.8 Photographic pulse height analysis (D. J. Zaffarano)

A multichannel pulse-height analyzer [Hunt, Rhinehart, Weber and Zaffarano, Rev. Sci. Instr., 25, 268 (1954)] in use at this Laboratory has been simplified and a version of the new design has been fabricated. A special, simplified oscilloscope has been constructed for the purpose of presenting information in the form of intensified pulses which may be recorded photographically. Pulse amplitudes may be recorded at a rate of 10^4 to 10^5 per second and analyzed into 200 channels with about 1% accuracy. This speed, consistent with good accuracy, makes this analysis system particularly useful with pulsed machines, such as the synchrotron.

2. Solid State Studies

2.1 Thermal properties of metals at high temperatures

(G. C. Danielson)

2.1.1 Thermal conductivity

For any metal at any specified temperature (T), the thermal conductivity (K), the thermal diffusivity (k), the specific heat per unit mass (c) and the density (d) are related by the equation $K = kcd$. The object of this experimental program is to determine each of these four quantities to an accuracy of two per cent in the temperature range 20°C to 1000°C .

The thermal conductivity (K) of any metal at any temperature between 100°C to 600°C can be measured by the apparatus described in ISC-518. The thermal conductivities from 100°C to 600°C have been measured and reported for nickel (ISC-518), uranium (ISC-533), and zirconium (ISC-577). This static method, which involves the comparison of the temperature gradient in an unknown material to that in a standard material such as Armco iron, gives good results at temperatures under 600°C . If the temperature range is to be extended above 600°C , however, major modifications seem to be necessary in order to eliminate electrical leakage between thermocouples.

2.1.2 Thermal diffusivity

The thermal diffusivity (k) of any metal at any temperature between 20°C and 1000°C can be measured by the modified Angstrom method [P. H. Sidles and G. C. Danielson, J. App. Phys., 25, 58-66 (1954)] described in ISC-198. The numerous difficulties encountered in attempting to extend the range from 600°C to 1000°C have been completely overcome. Hence, our objective (to determine the thermal properties to an accuracy of two per cent in the temperature range 20°C to 1000°C) has been attained in the case of thermal diffusivity. An example of the data now possible is shown in Fig. 2. The changes in thermal diffusivity of Armco iron at the Curie temperature ($760^{\circ}\text{--}780^{\circ}\text{C}$) and at the α - δ phase transformation (910°C) are clearly measurable. The complicated effects which take place in uranium [P. H. Sidles, Phys. Rev., 100, 1256 (1955)] at high temperatures are shown in Fig. 3. The possibility of investigating the detailed behavior of thermal diffusivity at phase transformations opens up a new field of research. The success of the modified Angstrom method depends upon its ability (1) to measure thermal diffusivity at a point in temperature, (rather than determine some average value over a range in temperature), (2) to measure thermal diffusivity with a high degree of reliability and accuracy, and (3) to measure thermal diffusivity at exceptionally high temperatures.

2.1.3 Specific heat

The specific heat (c) of any metal at any temperature between 20°C and 600°C can be measured by the electrical pulse heating method described previously (ISC-645). The method requires considerable modification in order to reduce the error to ± 2 per cent and to extend the temperature range to 1000°C . These

Fig. 2 Thermal diffusivity of Armco iron.

Fig. 3 - Thermal diffusivity of uranium.

modifications, which seem to be entirely feasible, are nearing completion and include the following: (1) construction of a vacuum furnace in order to adjust the ambient temperature, (2) design of a bridge circuit so that voltage changes during the pulse can be measured more accurately, and (3) calculation of the heat loss by conduction from the ends of the sample to the electrodes. A report entitled "Measurement of Specific Heat by a Pulse Method", by R. Strittmater and G. C. Danielson is being distributed.

Abstract

A pulse heating method for measuring the specific heat of metals at all temperatures has been developed. The apparatus will deliver a current pulse of sufficient magnitude to heat a fine wire sample to its melting temperature in a short time, for example 0.1 second. Under these conditions, the energy losses from the wire are negligibly small compared with the energy input. By recording simultaneously with a dual beam cathode ray oscilloscope the current through and the potential across a sample, one can determine at any instant the power input and the resistance of the wire. From the resistance of the wire and the results of a preliminary experiment on the resistance-temperature relationship, the temperature can be found. By a single heating pulse a plot of the temperature as a function of time can be made. Since the power input and the mass of the sample are known, the specific heat, at any temperature within the range of the test, can be calculated. Preliminary results are given for platinum and nickel over the temperature range 25°C to 500°C.

2.1.4 Density

The density (d) of any metal at any temperature between 20°C and 600°C can be obtained with an error much less than + 2 per cent from a measurement of the density at room temperature and a measurement of the volume expansion coefficients. The expansion coefficients can be obtained from changes in the unit cell dimensions as determined by x-ray diffraction. The high temperature x-ray diffraction equipment designed by P. Chiotti [P. Chiotti, Rev. Sci. Instr., 25, 683-688 (1954)] could be used for this purpose.

2.2 Semiconducting metallic compounds (G. C. Danielson)

2.2.1 Magnesium silicide (Mg₂Si)

The electrical resistivities and Hall coefficients of single crystals of Mg₂Si have been measured in the temperature range 60°K to 1000°K. [C. R. Whitsett and G. C. Danielson, Phys. Rev., 100, 1261 (1955); C. R. Whitsett and G. C. Danielson, ISC-714, (1955)]. Since the Hall coefficients were always negative, electron conduction always predominated over hole conduction

in these particular single crystals. At 300°K the density of electrons from impurity levels was 10^{17} to 10^{18} per cm^3 and the Hall mobility was about $200 \text{ cm}^2/\text{volt-second}$. Above 300°K the temperature dependence of the mobility in Mg_2Si was given by $9(105)T^{-3/2} \text{ cm}^2/\text{volt-second}$. In the intrinsic region ($T > 500^\circ\text{K}$) the resistivity (ρ) was given by the equation $\rho = A \exp(\Delta E/2kT)$ where $A = 3.2 (10^{-4}) \text{ ohm-cm}$ and $\Delta E = 0.48 \text{ ev}$. The ratio of the electron mobility to the hole mobility was estimated to be about 1.3. The effective masses of the electrons and holes were estimated to be 1.8 and 2.0 times the free electron mass.

Since the value for ΔE is less rather than greater than ΔE for Mg_2Ge (one would expect the order of activation energies to be greatest for Mg_2Si and least for Mg_2Pb), these tentative results will be checked with additional experimental data.

2.2.2 Magnesium germanide (Mg_2Ge)

The electrical resistivities and Hall coefficients of single crystals of Mg_2Ge have also been measured in the temperature range 60°K to 1000°K. Again, electron conduction always predominated over hole conduction in these particular single crystals. The density and mobility of the electrons were about 10^{17} to 10^{18} per cm^3 and $200 \text{ cm}^2/\text{volt-second}$ as for Mg_2Si . In the intrinsic region ($T > 500^\circ\text{K}$) the resistivity (ρ) was given by the equation $\rho = A \exp(\Delta E/2kT)$ where $A = 1.2(10^{-4}) \text{ ohm-cm}$ and $\Delta E = 0.64 \text{ ev}$.

These tentative results have recently been confirmed by additional data on an additional crystal (3B) cut from the same ingot. (see Figs. 4, 5 and 6).

2.3 Measurement of magnetic field gradient by the Hall effect (G. C. Danielson)

A report entitled "Measurement of Magnetic Field Gradient by the Hall Effect" by R. D. Redin and G. C. Danielson is being distributed as ISC-685/R. D. Redin and G. C. Danielson, Phys. Rev., 100, 1252 (1955).

Abstract

A magnetic field gradient measuring device, which uses the Hall effect in germanium, has been constructed. The field sensitive element is a bar of germanium 1 mm by 1 mm by 12 mm with two sets of Hall leads attached 2 mm either side of its center. One hundred cycle alternating current flows in the long direction of the bar. In a magnetic field two 100 cycle Hall voltages are obtained. These voltages, which are proportional to the magnetic field strength at two points of the field 4 mm apart, are subtracted to give an output directly proportional to the magnetic field gradient.

19 Fig. 4 - Resistivity of $\text{Mg}_2\text{Ge}-3\text{B}$.

20

Fig. 5 - Hall coefficient of $\text{Mg}_2\text{Ge-3B}$.

21

Fig. 6 - Hall mobility of $\text{Mg}_2\text{Ge}-3\text{B}$.

The instrument will also measure field strengths and relative gradients. The instrument was tested in a calculable magnetic field produced by step pole pieces. Gradients from 5 gauss/inch to 500 gauss/inch in magnetic fields below 5000 gauss were measured. The usefulness of the instrument is still uncertain owing to errors caused by excessive field dependence of the gradient voltage.

2.4 Electrical conductivity of thin sodium films (G. C. Danielson)

The purpose of this project is to measure the conductivities of thin sodium films as a function of thickness and temperature. Such information would, in principle, determine the density, mean free path, and mobility of the carriers as a function of temperature.

A film of sodium was deposited on a substrate at 102°K and in vacuo by emission of sodium atoms from a small hole in an oven. The resistivity was measured as the deposition took place, starting when the film was 177 Å thick and continued until it was 446 Å thick. (The number of atoms evaporated was calculated by kinetic theory). The final resistivity at 102°K was $3.60(10^{-6})$ ohm-cm. After being warmed to 236°K and then cooled again to 102°K, the resistivity was $2.82(10^{-6})$ ohm-cm. The resistivity of bulk sodium at 102°K was $1.04(10^{-6})$ ohm-cm.

It was found that no single bulk resistivity and electronic mean free path could be used to fit the data to a Sondheimer plot over the entire range of thicknesses. There is some indication that the film was annealing during deposition. This would explain the observed results. It is hoped that this difficulty can be avoided.

2.5 Mass spectrometric studies of metallic phase transitions (D. E. Hudson)

2.5.1 Latent heat studies

Previous work in this Laboratory on determination of the heat of vaporization of aluminum has given results for ΔH which were very precise (i.e. high internal consistency) but which were somewhat higher than those quoted in the literature. Our current value for the heat of vaporization for aluminum, which is believed to be more accurate than any previously reported, is 73.6 ± 0.5 kcal/mole at 1300°K. This reduces to a heat of sublimation of 78.1 ± 0.5 kcal/mole at 298°K compared to the best previous value of 77.5 ± 1.5 kcal/mole [Brewer and Searly, J. Am. Chem. Soc., 73, 5308 (1951)].

2.6 Superconductivity in rare earth alloys (S. Legvold and F. H. Spedding)

It has been known for some time that pure La is a superconductor with a transition temperature of about 5.8°K. Alloys of La with small amounts of Lu, Yb, and Y are under study to

determine the shift in the transition temperature caused by the foreign atoms. A mixture of 10% Lu and 90% La has been investigated. The transition temperature of this mixture is 3.6°K showing that the Lu has a marked effect. It is hoped that a study of a sequence of alloys will permit the determination of the transition temperatures of the pure Lu, Yb, and Y metals. Critical field data (the magnetic field required to destroy superconductivity) will also be determined.

2.7 Magnetic properties of Ho, Tm and Sm (S. Legvold and F. H. Spedding)

Holmium metal has been studied and the magnetic susceptibility as a function of temperature exhibits a cusp at 133°K, which indicates that the metal is apparently antiferromagnetic below this temperature. The magnetization curves below 133°K and down to 20.4°K are similar to those below 175°K for dysprosium and it appears that holmium will become ferromagnetic just below 20°K.

In the case of thulium metal there is a cusp in the susceptibility versus temperature curve at 51°K with the metal apparently antiferromagnetic in the region 20°K to 51°K. From the field dependence of the magnetic moment below 40°K there is evidence that Tm will become ferromagnetic, but not until the temperature is considerably below 20°K.

Thulium metal is non-magnetic down to 20.4°K.

2.8 Magnetic properties of alloys of Gd and La (S. Legvold and F. H. Spedding)

Studies of the magnetic properties of alloys of Gd with La were initiated. The addition of La to Gd lowered the paramagnetic Curie temperature. A mixture of 10% La in Gd was ferromagnetic below 254°K. Mixtures of 25% La in Gd and 54% La in Gd did not become ferromagnetic down to 20.4°K. The magnetic behavior of the latter two alloys was certainly not normal. X-ray examinations of the alloys by others in this Laboratory showed the 10% La in Gd had the Gd structure (hex close-packed) and that the 25% and 54% alloys did not have the Gd structure.

2.9 Remanent magnetism in toroids (S. Legvold) and P. H. Spedding

A report entitled "Remanent Magnetism in Toroids" by P. Hall and S. Legvold was distributed as ISC-630.

Abstract

The Brookhaven Laboratories have reported that the remanent magnetism in the Cosmotron magnet decreases with increasing pulse height, and increasing pulse length (BNL-1447). A group at Iowa State College has attempted to duplicate these effects with the simple geometry of a virtually complete toroid. It was found in this case that B_{rem} is independent of the pulse length, rises and

approaches a constant value as the pulse height is increased. These results confirm a previous hypothesis that the unusual behavior of the Cosmotron remanent field is due to the particular configuration of the copper and iron used in that case, and is not due to inherent properties of iron.

APPENDIX I: LIST OF REPORTS FROM THE AMES LABORATORY

1. Reports for Cooperating Laboratories

- ISC-575 Ames Laboratory Staff. Metallurgy. Quarterly Summary Research Report. October, November, December, 1954.
- ISC-604 F. H. Spedding, J. E. Powell and E. J. Wheelwright. The Stability of the Rare Earth Complexes with N-Hydroxyethylethylenediaminetriacetic Acid.
- ISC-605 Ames Laboratory Staff. Engineering. Quarterly Summary Research Report. January, February, March, 1955.
- ISC-606 Ames Laboratory Staff. Chemistry. Quarterly Summary Research Report. January, February, March, 1955.
- ISC-607 Ames Laboratory Staff. Metallurgy. Quarterly Summary Research Report. January, February, March, 1955.
- ISC-608 Ames Laboratory Staff. Physics. Quarterly Summary Research Report. January, February, March, 1955.
- ISC-609 Compiled by P. Chiotti and O. N. Carlson. Hanford Slug Program. Quarterly Summary Research Report. January, February, March, 1955.
- ISC-611 F. H. Spedding and J. E. Powell. A Laboratory Method for Separating Nitrogen Isotopes by Ion-Exchange.
- ISC-612 A. W. Andresen and G. L. Bridger. Recovery of Uranium from Superphosphates.
- ISC-617 J. E. Powell and F. H. Spedding. Basic Principles Involved in the Macroseparation of Adjacent Rare Earths from Each Other by Means of Ion-Exchange.
- ISC-620 R. D. Kross and V. A. Fassel. The Infrared Spectra of Aromatic Compounds. III: The 1045-1185 cm^{-1} Vibration in Monosubstituted Benzenes.
- ISC-621 R. D. Kross and V. A. Fassel. An Infrared Study of Picric Acid Molecular Complexes.

- ISC-623 L. S. Gray and V. A. Fassel. Emission Spectrometric Determination of Low Percentages of Zirconium in Hafnium.
- ISC-625 R. D. Kross, V. A. Fassel and M. Margoshes. The Infrared Spectra of Aromatic Compounds. II. Evidence Concerning the Interaction of π -Electrons and σ -Bond Orbitals in C-H Out-of-Plane Bending Vibrations.
- ISC-629 R. T. Nichols and E. N. Jensen. The Decay Scheme of Sc^{147} .
- ISC-630 P. Hall and S. Legvold. Remanent Magnetism in Toroids.
- ISC-632 J. T. Jones, Jr. and J. K. Knipp. Notes on Hyperfragments.
- ISC-633 E. M. Layton, Jr., R. D. Kross and V. A. Fassel. A Correlation of Bond Length with Stretching Frequency for C-O and C-N Systems.
- ISC-634 G. H. Beyer, E. L. Koerner and E. H. Olson. Conversion of Zirconium Sulfates to Anhydrous Zirconium Tetrafluoride.
- ISC-637 E. Wheelwright and F. H. Spedding. The Use of Chelating Agents in the Separating of the Rare Earths Elements by Ion-Exchange Method.
- ISC-640 P. Chiotti, P. F. Woerner, H. H. Klepfer, K. J. Gill and R. E. Cutrell. Application of Metal Coatings on Uranium-Summary Report.
- ISC-641 Compiled by P. Chiotti and O. N. Carlson. Hanford Slug Program. Quarterly Summary Research Report. April, May, June, 1955.
- ISC-642 Ames Laboratory Staff. Engineering. Quarterly Summary Research Report. April, May, June, 1955.
- ISC-643 Ames Laboratory Staff. Chemistry. Quarterly Summary Research Report. April, May, June, 1955.
- ISC-645 Ames Laboratory Staff. Physics. Quarterly Summary Research Report. April, May, June, 1955.

- ISC-656 P. Chiotti, H. H. Klepfer and K. J. Gill. Uranium-Zinc System.
- ISC-661 J. S. Fritz and S. A. Sutton. Titration of Mercury with Bis(2-Hydroxyethyl) Dithiocarbamate.
- ISC-665 M. C. Day and A. F. Voigt. The Molecular Chemistry of Antimony and Tellurium.

2. Papers Published in Scientific Journals

- Corbett, J. D. and R. K. McMullan
The Lower Oxidation States of Gallium. I. The GaI_3 -GaI System. J. Am. Chem. Soc. 77, 4217-19 (August, 1955).
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- Day, M. C., G. W. Eakins and A. F. Voigt
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- Freeland, M. Q. and J. S. Fritz
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- Fritz, J. S. and M. Johnson
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- Fritz, J. S. and S. S. Yamamura
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- Hansen, R. S.
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- Happe, J. A. and D. S. Martin, Jr.
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- Herwig, L. O., G. H. Miller and N. G. Utterback
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- Hettel, H. J. and V. A. Fassel
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- Jones, J. T., Jr. and J. K. Knipp
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The Infrared Spectra of Aromatic Compounds. III. The 1045-1185 cm^{-1} Vibration in Monosubstituted Benzenes. J. Am. Chem. Soc. 77, 5858-9 (November, 1955).
- Laslett, L. J. and D. J. Zaffarano
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- Ring, L. S., Jr.
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- Simmons, C. R. and R. S. Hansen
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- Skochdopole, R. E., M. Griffel, and F. H. Spedding
The Heat Capacity of Erbium from 15-320°K. J. Chem. Phys. 23, 12, 2258-63 (December, 1955).
- Spedding, F. H. and J. L. Dye
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