UNCLASSIFIED

ISC-135

**AMES
LABORATORY
IOWA STATE
COLLEGE**

UNCLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

W0 4100

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

ISC-135

U N I T E D S T A T E S A T O M I C E N E R G Y C O M M I S S I O N

PROGRESS REPORT IN PHYSICS FOR THE PERIOD

July 1, 1950 to December 31, 1950

By

G. W. Fox
W. C. Caldwell
J. F. Carlson
G. C. Danielson
E. N. Jensen
J. K. Knipp

J. M. Keller
L. J. Laslett
S. Legvold
G. Miller
D. Zaffarano

March 15, 1951

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

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

This report is distributed according to the category "Physics" as listed in the "Distribution List for United States Atomic Energy Commission Non-Classified Research and Development Reports" November 15, 1950.

TABLE OF CONTENTS

	Page
I. SUMMARY	5
II. RADIATION STUDIES	6
2.1 The Low-Energy Beta-Spectrum of Rb ⁸⁶	6
2.2 The Beta-Spectra of Ag ¹¹² and Ag ¹¹³	7
2.3 Energy of the Cs ¹³⁷ Gamma-Radiation	8
2.4 Beta-Spectrum of P ³²	8
2.5 Induced Activity in Argon	9
2.6 X-ray Induced Activities in Rare Earths	10
2.7 Proportional Counter Spectrometer	10
2.8 Double Lens Beta-Ray Spectrometer	10
III. STUDIES OF NUCLEI	12
3.1 Fission Fragment Experiment	12
3.2 Study of Nuclear Processes with Photographic Emulsions	13
a. Photofission of Uranium	13
b. Photodisintegration of the Deuteron	14
c. Study of X-ray Induced Nuclear Processes Leading to the Emission of Heavy Charged Particles	14
d. Use of Electron Sensitive Emulsions	14
3.3 Excitation Functions for X-ray Induced Nuclear Reactions	14
3.4 Examination of Synchrotron Radiation Spectrum	15
3.5 Observation of Nuclear Disintegrations Leading to Heavy-Particle Emission	15
3.6 Proportional Counter Experiments	16
3.7 Magnetic Analyzer	16
3.8 Secondary Electron Emission from Slow Ion Bombardment	16
3.9 Scintillation Counter Response to Low Velocity Ions	17
3.10 Application of Scintillation Counters to β Ray Spectrometry	17
3.11 Scintillation-Spectrometer Program	18
3.12 Counter Window Transmission Experiment	19
IV. THEORETICAL PHYSICS	19
4.1 Ionization Studies	19
4.2 Specific Heat of Rare Earth Metals	20
4.3 Miscellaneous Problems	20

TABLE OF CONTENTS (continued)

	Page
V. SOLID STATE PHYSICS	21
5.1 Diamond Conduction Counters	21
a. Mobilities of charge carriers (wide-band preamplifier)	21
b. Polarization effects and secondary conduction	23
c. Decay of space charge field	25
d. Absorption spectra of counting diamonds . .	29
e. Proportional counting	29
f. Thermal effects	32
5.2 Sodium Wolfram Bronze	32
a. Crystal growth	32
b. Electrical conductivity	34
c. Hall coefficient	34
d. Density of charge carriers	37
e. Magnetic susceptibility	37
f. Electron mobility and mean free path	37
g. Thermal conductivity and electronic specific heat	38
5.3 Piezoelectricity at Liquid Helium Temperature .	38
5.4 Apparatus for Growing Single Crystals of High Melting Point Metal	38
5.5 Synchrotron Service Work	39
VI. SYNCHROTRON DEVELOPMENT	39
VII. PAPERS PUBLISHED	41
VIII. LITERATURE CITED	42

Previous reports in this series are: 5, 20, 27, 46, 73, 104

I. SUMMARY

Radiation studies of variously activated nuclides are continuing by means of the thin lens beta ray spectrometer, augmented by proportional counter techniques. Further observations on the ionization defect of fission fragments are in process with equipment sufficiently refined to determine the magnitude of the effect with considerable precision. Photographic emulsion techniques are being applied to studies of uranium photo-fission, the photo-disintegration of the deuteron and to X-ray induced nuclear processes which lead to the emission of heavy charged particles. Electron sensitive photographic plates are being used to record the tracks of beta particles in special cases where their continuously sensitive character represents a great advantage.

The excitation functions of various gamma-ray induced radio-nuclides produced by the synchrotron are being determined. Work is nearly complete on the analysis of approximately 1000 stereophotographs of electron pairs, produced under suitable magnetic field conditions by synchrotron radiation which will permit a determination of the X-ray spectrum of the machine.

The magnetic analyzer for use with the kevatron is almost finished, and auxiliary apparatus is in the test stage. In connection with experimental work on the kevatron arc source, it is proposed to investigate some problems concerning secondary emission of electrons from metals bombarded by positive ions.

The response of scintillation counters to low velocity ions in beta ray spectroscopy is being investigated. Such counters have also been found especially useful in connection with studies of very short half life nuclides produced by synchrotron radiation.

Theoretical studies of the ionization produced by atomic particles are continuing. It has been shown that ionization defects of several Mev should be exhibited by fission fragments. Marked progress has been made in the statistical study of ionization by application of the Smoluchowski-Kalmogoroff equation.

Intensive study of the low temperature specific heat anomalies in the rare earths indicate that the previous conclusion of the predominance of the second degree harmonic may be incorrect. A new calculation based on Madelung's method gives a definite but false result. Under investigation is the difference in lattice vibration specific heats between hexagonal close packed and face-centered cubic crystals. Additional theoretical problems

include an investigation of nearly adiabatic collisions and an investigation of the problem of determining the gamma-ray spectrum produced by electrons from the synchrotron through study of the energies of the positrons produced.

An extensive study of diamond conduction counters has led to a fairly well established understanding of why some diamonds count and others do not. Irradiation with ultra violet light has been shown to improve the counting abilities of some diamonds markedly. A preliminary understanding of this phenomenon has been reached.

Further development work on ceramic donuts for the synchrotron has resulted in successful casting and assembling of the first unit. The construction of cathode structures for such donuts is making good progress.

II. RADIATION STUDIES

2.1 The Low-Energy Beta-Spectrum of Rb^{86}

A source* of purified Rb^{86} was examined with a coincidence scintillation spectrometer in an effort to determine the spectrum of the low-energy component (1) alone. Based upon a calibration of the instrument by the 0.63 Mev conversion line from Cs^{137} (Ba^{137}), an upper limit of approximately 0.67 Mev was obtained for the low-energy Rb^{86} beta-ray which appears in coincidence with the gamma-ray. The relatively poor statistical character of the present data imposes limits of error estimated as ± 15 per cent, but a measurement of the rather similar beta-ray from a (gamma-free) Sr^{90} source led under similar geometrical conditions to an end point of 0.56₂ Mev for the Sr^{90} beta-ray, in excellent agreement with previously reported values. (2,3) The shapes of the Sr^{90} and the low-energy Rb^{86} beta-spectra appeared closely similar, but it is believed that the precision of the present work does not permit a definitive comparison of spectral form.

Following the completion of the above measurements in this Laboratory, Muether and Ridgway (4) reported the results of measurement on Rb^{86} , performed with a coincidence magnetic spectrometer, which indicate upper limits of 1.80 and 0.714 Mev for the beta-spectra and 1.076 Mev for the gamma-ray energy.

*We are indebted to Mr. E. Dewell, of the Radiochemistry Group for preparation of the sources used in much of this work.

Even more recently Macklin, Likofsky, and Wu (5) reported the low energy group as indistinguishable from the allowed shape and as having an upper-limit of 670 ± 5 Kev.

2.2 The Beta-Spectra of Ag^{112} and Ag^{113}

The radioactivity ascribed to Ag^{112} was considered of interest since there appeared to be a considerable disparity between the beta-ray energy determined by cloud-chamber methods in the original work of Pool (6) and the comparatively recent absorption measurements of Seiler. (7) An investigation of both Ag^{112} and Ag^{113} was undertaken with the scintillation spectrometer, since these activities were readily obtainable by synchrotron irradiation and the comparatively high-energy beta-particles obtained from each made their study especially suitable.

Cadmium nitrate was irradiated by X-rays whose spectrum extended nominally to 70 Mev. The radio-silver produced was separated chemically from the irradiated material and deposited in metallic form upon aluminum foil 0.001 inch thick. Such samples contained, in addition to the Ag^{112} and Ag^{113} activities of interest, the longer-lived beta-emitter Ag^{111} , whose spectrum, however, did not extend significantly above 1.0 Mev.

One such radio-silver source was used, in conjunction with the pulse-height selector of the spectrometer, to measure the periods of the activities of interest. When only pulses of energy greater than 3.2 Mev were counted, a half-life close to 3.2 hrs. was obtained. Subsequently, approximately 20 hrs. following the end of the irradiation when it appeared that the greater part of the high-energy activity had vanished, the discriminator was set to count pulses above 0.70 Mev and a half-life of 5.3 hrs. observed. The values so found for the periods of Ag^{112} and Ag^{113} were in good agreement with those previously reported (6 - 9) for these activities and definitely confirmed that the energy of the 3.2 hr. activity was substantially greater than that of the material with a 5.3 hr. half-life.

A second radio-silver source was used to permit examination of the Ag^{112} and Ag^{113} beta-spectra, which could be separated on the basis of their unequal half-lives. Kurie plots of the results led to upper-limits of 4.2 and 2.0 Mev for these respective activities. The accuracy of these measurements is estimated as ± 8 per cent. The energy thus obtained for the Ag^{112} beta-ray favors distinctly the value reported by Seiler (7) and that found for Ag^{113} is in good agreement with the values reported by Duffield and Knight (8) and by Turkevich. (9).

The yield of Ag^{112} activity relative to that of Ag^{113} at the end of a 3.5 hr. irradiation of natural cadmium was estimated as very close to unity and, on the assumption that these nuclides

are produced exclusively by (γ ,p) reactions from Cd^{113} and Cd^{114} respectively, suggests that the nuclear cross-section for the Cd^{113} (γ ,p) Ag^{112} process is approximately 1.5 times that for the Cd^{114} (γ ,p) Ag^{113} reaction. The relative yield stated for the Ag^{112} and Ag^{113} activities appears consistent with that estimated from G-M counter data obtained with silver separated from from synchrotron-irradiated cadmium.

The Ag^{111} , Ag^{112} , and Ag^{113} activities have also been obtained, in considerably lower intensity, by irradiation of indium and suggest the possibility of interesting future work on the relative probabilities of (γ ,2p) and similar processes.

2.3 Energy of the Cs^{137} Gamma-Radiation

The thin lens spectrometer has been recalibrated using the internal conversion line of Cs^{137} . The energy of the Cs^{137} internal conversion line was determined by a comparison with the internal conversion line of Au^{198} arising from the gamma-ray having an energy of 0.4112 ± 0.0001 Mev. This gamma-ray energy has been measured very accurately by DuMond, Lind and Watson. (10) A comparison of the two internal conversion lines was made by placing a composite source of Cs^{137} and Au^{198} on a thin Formvar-polystyrene film and then determining the positions of the lines with the spectrometer.

Using 0.08305 and 0.03740 Mev for the binding energies of mercury and barium, as calculated from the critical absorption wavelengths given by Compton and Allison, (11) the energy of the Cs^{137} gamma-ray was found to be 0.6605 ± 0.001 Mev. This value is in good agreement with the value 0.6614 ± 0.0007 Mev reported by Langer and Moffat (12) using the same technique as that described above.

2.4 Beta-Spectrum of P^{32}

It was reported in ISC-73 that a weak low energy beta component was observed in the beta-spectrum of P^{32} in addition to the main component. This low energy beta group appears to have a maximum energy of about 0.3 Mev and a half-life of about 26 days. This low energy group was first observed in December 1948 in a P^{32} sample received from Dr. C. W. Sherwin of the University of Illinois; it has also been observed in two different samples of P^{32} received from Oak Ridge. One sample was received in July 1949 and the other in April 1950. The sample received in April 1950 was followed in the thin lens spectrometer for approximately 10 half-lives. During this time seven spectra were obtained and in each succeeding spectrum the low energy

group was more prominent in comparison with the main beta group which has a half-life of 14.3 days. All of the P^{32} samples referred to above were prepared by irradiating sulfur with neutrons in the Oak Ridge pile.

The above results are in contradiction with the results reported by Agnew (13) and Warsaw, Chen, and Appleton. (14) They also report a weak low energy component, with a maximum energy of about 0.330 Mev, but found that the shape of the beta-spectrum did not change when followed for several half-lives.

One possible explanation of the low energy group is that it is due to an impurity. In order to check on this possibility a fraction removed in the purification process of P^{32} was obtained from Oak Ridge. The spectrum of this sample, as obtained with the spectrometer, did not show an excessive amount of the low energy group as would be expected if the group were due to an impurity that was not completely removed by chemical purification, particularly so if it were due to sulfur.

In September 1950 a sample of P^{32} was received from Oak Ridge which was prepared by neutron irradiation of P_2O_5 . The sample was followed in the spectrometer for a little more than three half-lives and three spectra were obtained. The low energy group again made its appearance. The maximum energy of the beta group was about the same as that obtained with the other samples of P^{32} . The specific activity of the sample was too low to permit a calculation of the half-life, but it was apparent that the half-life was longer than 14.3 days. Hence it appears that the low energy beta group is in some way related to phosphorous. Work is continuing on this problem.*

In another effort to identify this 26 day activity in P^{32} , lithium chloride was bombarded for about 10 hours with synchrotron X-rays. This should yield phosphorous isotopes by $Cl(\gamma, 2p)P$ reactions. A chemical separation and subsequent decay curve showed that only the 14 day half-life of phosphorous 32 could be identified, this being formed by $Cl^{35}(\gamma, 2pn)P^{32}$.

2.5 Induced Activity in Argon

Consideration has been given to the possible applicability of the cloud-chamber to a study of a synchrotron-induced radioactivity in argon. The character of the supposed radioactivity

*The authors express their appreciation to Dr. A. F. Rupp, Superintendent, Radioisotope Development Department and Mr. J. A. Cox, Superintendent, Radioisotope Control Department of the Oak Ridge National Laboratory for their generous cooperation on this problem.

is currently being studied, by preparation, with a Geiger-Mueller counter situated near the synchrotron and to which the argon may be quickly transferred following an irradiation period.

2.6 X-ray Induced Activities in Rare Earths

Irradiation of praseodymium 141 with the 70 Mev. X-ray beam of the I.S.C. synchrotron results in strongly activated Pr^{140} with an observed half-life of $3\frac{1}{2}$ minutes. Preliminary scintillation spectrometer data yield a beta-endpoint of 2.5 Mev.

Erbium 166 (γ, n) erbium 165 has been reported to yield a 1.1 minute activity. No evidence of this was found, but a 10 hour activity was measured. This was corroborated while these measurements were in progress by Butement. (15)

2.7 Proportional Counter Spectrometer

A cylindrical proportional counter $7\frac{1}{2}$ " ID, 24" long has been used to obtain beta-spectra from radioactive samples prepared by evaporating salts on thin foils. The foils are mounted near the wall of the counter, and about 25% of the total solid angle subtended by the source is useful for particle collection. The results for a tellurium 125 sample are shown in Fig. 1. This material is known (16,17) to consist of a 109 Kev. gamma-ray highly converted in the K and L shells, and a 35 Kev. gamma-ray more weakly converted. The electron energies expected are therefore 104, 78, and 30 Kev., and it may be seen from the figure that these are indeed observed. The amplified pulses have been displayed on an oscilloscope and photographed, using a technique developed at Oak Ridge.

The beta spectrum of cesium 137 has also been observed, under the following conditions: pressure, 105 lbs/in² absolute; wire diameter, 0.002", 4720 volts. The internal conversion line at 623 Kev. is well resolved. The source strengths in both cases were approximately 0.01 microcurie. It is planned to use this instrument to investigate beta-spectra of weak activities induced by synchrotron X-ray bombardment.

2.8 Double Lens Beta-Ray Spectrometer

The main components of the double lens beta-ray spectrometer have been completed, including the winding of the coils. The main task now is to complete construction of minor parts, assemble the spectrometer and make adjustments for optimum operating conditions.

Fig. 1. Pulse spectrum from Tellurium 125 obtained with proportional counter spectrometer.

III. STUDIES OF NUCLEI

3.1 Fission Fragment Experiment

A continuation of the study of the ionization defect for fission fragments is in progress. This effect was discussed previously (18) and consists of an increase in the energy required to create an ion pair, on the average, as the velocity of the bombarding ion decreases. The main reason for its existence is the transfer of energy in elastic nuclear collisions between the bombarding particle and the target nucleus. The target nucleus will then recoil with some energy and it is quite possible that its ionization efficiency may be quite low, which would then mean that the average energy per ion pair for the primary particle has been increased. This effect becomes prominent at lower velocities since the probability of an ionizing interaction between the primary particle and an electron of the target atom falls off rapidly as the velocity of the primary particle decreases.

The present investigation is aimed at determining the magnitude of this effect for fission fragments. It involves measuring the pulse height distribution for fission fragments in an ionization chamber for fillings of a heavy gas, such as argon, and a light gas, such as helium. By the mechanics of the collision, it is found that for the heavy gas more energy, on the average, will be transferred to the recoil atom than for the light gas. On the other hand, the light particle may recoil with as much velocity as the heavy one. It is quite likely, then that its ionization efficiency will be greater and one would expect that there would be a significantly greater ionization defect in the heavy gas than in the light gas. To calibrate the chamber, an alpha particle of known energy will be used in each case.

The electronic equipment for this experiment has been carefully checked. The amplifier to be used is a Los Alamos model 100, since a fast rise time is not essential. This amplifier is followed by a model 1000 amplifier to drive the oscilloscope. The sweep for the scope is a model 260 and is triggered by a Bell-Jordan amplifier. The chamber which is being used for preliminary work is the same as discussed in ISC-104. It is quite likely that a new chamber will be built later. A Frisch grid has been constructed and inserted in the chamber, minimizing the pulse height variation due to such effects as obliquity and variations in the ionization distribution along the track. The addition of the grid permits the introduction of a rather novel feature. If the voltage to the source plate is supplied through a rather large resistor, then a pulse may be obtained from this electrode just

as it is from the collector. However, since the charges originate between the source and grid, and then drift through the grid to the collector, the pulse from the source will occur several microseconds in advance of the one from the collector. The source pulse is then amplified by means of the Bell-Jordan amplifier and triggers the sweep, and the pulse from the collector is then viewed on this sweep. Thus the entire pulse may be seen without the introduction of a delay line in the collector amplifier system, which has always been a bad feature from the standpoint of signal-to-noise. A collimator has been constructed and placed in front of the source to prevent the possibility of a fragment coming out at such an angle that it would pass out of the region in which the field is sufficiently uniform. This collimator is constructed by drilling a large number of one-thirty-second inch diameter holes in a plate of aluminum one-thirty-second inch in thickness.

Pictures have been taken with the above system using the alphas from U^{238} and U^{234} . The distribution in pulse height gives two peaks which differ in voltage by an amount which corresponds quite nicely to the energy difference. As yet, an insufficient number of fission pictures have been taken to form any conclusions.

It was pointed out in the previous report that in many cases one would like to have a chamber with rather large spacing between plates. This, however, leads to an inconveniently large plate diameter in order to have a sufficiently large region in which the field is uniform. A possible means of avoiding this difficulty is being investigated. If the potential gradient at the edges of a plate along a line perpendicular to the plate over to the other plate could be maintained as a constant, then within the space between the plates it would appear that the plates extend to infinity. It should be possible to set up such a gradient by having, between the plates along this line, a surface which is slightly conducting and which has uniform distribution of resistance. Present work is directed toward the use of glass cylinders which will be coated with a material such as stannous chloride for this purpose.

3.2 Study of Nuclear Processes with Photographic Emulsions

a. Photofission of Uranium

A study has been completed of the angular distribution of fission tracks obtained in Eastman NTC nuclear plates in contact with a foil of (natural) uranium exposed to radiation from the 70 Mev synchrotron. Measurement of 500 fission events indicated no angular correlation between the direction of emission of the fission particles and that of the incident X-ray beam.

b. Photodisintegration of the Deuteron

Preliminary work has been done to implement a study of the photodisintegration of the deuteron by the radiation from the 70 Mev synchrotron. This work so far has consisted chiefly of comparing the merits of possible shielding arrangements, studying the preparation of the target material, and becoming familiar with the permissible exposure times for the nuclear plates to be used for recording the high-energy protons produced.

c. Study of X-ray Induced Nuclear Processes Leading to the Emission of Heavy Charged Particles

Recently, exploratory work has been initiated to investigate the extent to which the use of nuclear photographic emulsions can contribute to a study of X-ray induced nuclear reactions, in which a variety of heavy charged particles may be emitted. Initial work has involved the use of thallium and indium foils, but the present status of the work does not permit a definitive judgment of the utility of emulsion work in these specific problems.

d. Use of Electron-Sensitive Emulsions

Some interest has been devoted to the techniques involved in the use of electron-sensitive emulsions to record the tracks of beta-particles. It is felt that this technique may be of value in special problems where the intensity or certain questions concerning correlation make the continuously-sensitive feature of the photographic medium particularly attractive.

3.3 Excitation Functions for X-ray Induced Nuclear Reactions

The ease with which the (maximum) X-ray energy of the synchrotron may be controlled electronically has been exploited in constructing equipment for the determination of the excitation functions of various X-ray induced radionuclides. The equipment will provide for rapid alternative irradiation of the sample of interest and of a monitor sample of the same material, with the latter subjected to the full-energy synchrotron beam. The relative strengths of the induced radioactivities can then be determined, with G-M counters or similar equipment, without critical dependence upon constancy of the electron beam in the synchrotron orbit.

The necessary equipment for the foregoing experiment has been assembled and preliminary tests have begun.

Experience is being acquired concerning the production, through synchrotron-irradiation, of various nuclides which may be of interest for further investigation. Among these may be mentioned those produced by irradiating S, Cl, A, Fe, Ag, Cd, In, and Pt. Some of this work was undertaken in an effort to cast further light on the anomalous low-energy electron group found in radiophosphorous samples described in section 2.4 of this report; in this connection an attempt was also made, with a negative result, to find electron coincidences with an old spectrometer source of radiophosphorous.

3.4 Examination of Synchrotron Radiation Spectrum

As reported previously, (19) the 12-inch cloud-chamber has been arranged so that it may be used in conjunction with the synchrotron, with the synchrotron operated for one or a prescribed small number of pulses suitably timed in relation to the expansion of the chamber.

To permit determination of the X-ray spectrum from the synchrotron, stereoscopic photographs have been taken of electron pairs produced in the chamber while the chamber was traversed by a suitable magnetic field. The use of pairs produced in the chamber-gas (air and alcohol) has appeared to be preferable to attempting the measurement of pairs produced in a thin foil near the wall of the chamber, since the former arrangement reduces the danger of erroneous association of unrelated positron- and negatron-tracks. The X-ray beam from an external lead collimator has, accordingly, been admitted to the chamber through a thin (coated) beryllium window in the wall to permit photography of the desired pairs with a minimum of interference from unuseable tracks. In addition to pairs formed in the nuclear fields, some produced in the field of the electrons have been recorded (triplets).

It is believed that sufficient data have been recorded to permit the measurement of nearly one thousand electron-pairs; these measurements are at present in progress.

3.5 Observation of Nuclear Disintegrations Leading to Heavy-Particle Emission

In the course of the foregoing work, a number of nuclear disintegrations involving the emission of heavy charged particles (coincident with the X-ray beam) have been recorded. The most common of these disintegrations involve a single track of a heavy ion, with a recoil nucleus at one end. Multiple-prong stars were also noted, however. It is planned, when the study of electron-pairs is completed, to obtain further data concerning

these disintegrations in which heavy charged particles are emitted, so that some statistical correlation may be attempted; such data can be obtained more efficiently at higher X-ray intensities than were suitable for the observation of electron pairs. Furthermore, observation of particle emission from target foils of specific materials, subjected in the cloud-chamber to the X-ray beam from the synchrotron, may be of value in special problems.

3.6 Proportional Counter Experiments

A proportional counter, which was described in the last report, has been constructed and is very nearly complete. The only remaining difficulty is in locating adequate seals to support the center conductor. At present a trial seal has been made up using a porcelain insulator, a brass tube, and a small Stupakoff seal which have been put together with Araldite in such a manner as to provide a guard ring. It appears that this seal may be satisfactory provided the dimensions can be increased.

3.7 Magnetic Analyzer

The magnetic analyzer (19) for use in low energy proton experiments is now very nearly complete. The pieces were machined, then annealed at about 700°C and then "pickled" by bathing in a weak sulphuric acid solution. At present the analyzer is assembled in the electronics shop of the Laboratory, where the control circuit is being tested. The support for the magnet has been completed and part of the vacuum system has been assembled and tested. Pressures less than one millimicron can be obtained at the mouth of the diffusion pump. The deflecting chamber for the magnetic analyzer has also been built and vacuum tested.

3.8 Secondary Electron Emission from Slow Ion Bombardment

A search of the literature has been made concerning the emission of secondary electrons from metals as a result of bombardment by slow positive ions. It appears that the data available are rather incomplete. All of the measurements reported are for bombarding energies either below 1.6 Kev or above 50 Kev. Since this problem has a bearing on practical applications of secondary emission it should be very profitable to attempt to verify and supplement the present data. It is proposed to use the magnetic analyzer to select a monoenergetic homogeneous beam, which will then be allowed to impinge on targets of various materials which have been very carefully

cleaned. The secondary electrons themselves will be collected on an electrode which surrounds the target but which is itself shielded from the beam. By varying the potential on the collector, the scattered positive ion beam may be measured and corrected for. The energy distribution of the secondary electrons as well as the total yield may be obtained from this set of measurements. The equipment for this experiment is now being constructed.

3.9 Scintillation Counter Response to Low Velocity Ions

The pulses from a photomultiplier tube used in connection with various phosphors will be studied for monoenergetic ions obtained from the accelerator. It is proposed to study particle energies varying from 10 Kev up to 300 Kev to determine if the pulse height is proportional to the energy of the particle. For the purpose of examining the pulse shape in some detail a fast amplifier has been built and a sweep is being constructed.

3.10 Application of Scintillation Counters to β -Ray Spectrometry

The scintillation counting equipment previously reported (19) has been applied to the examination of beta-spectra of certain radioactive nuclides.

A statistical analysis suggests that the relative variance in the output of the photomultiplier tube, when mono-kinetic electrons strike the scintillation crystal, will be inversely proportional to the electron energy, E ; thus the standard deviation of the pulse height distribution will be proportional to $E^{\frac{1}{2}}$. (20) The transmission curve of the instrument, assumed for convenience to be approximately of Gaussian form, is accordingly written as

$$T(V, E_0) = A(2\pi kE_0)^{-\frac{1}{2}} \exp \left[-(V - E_0/K)^2 / 2kE_0 \right],$$

where $T(V, E_0)$ represents the probability of recording a pulse of height V from an electron of energy E_0 and where A , K , and k are proportionality constants.

The foregoing transmission function, if used to analyze the instrumental distortion introduced into the body of a continuous energy distribution, leads to the following (approximate) expression for the true spectrum expressed in terms of the observed energy distribution.

$$n_t(E) \approx (1/KA) \int N_e(V) - kK N'_e(V) - (kK/2)V N''_e(V) dV,$$

with $E \approx KV$. Near the end-point of a beta-distribution the foregoing result would not, of course, be applicable and a special derivation of the appropriate corrections would be required; by noting the predominately parabolic character of a beta-spectrum near its end-point and by assuming, for convenience, a transmission curve of triangular form, approximate corrections to be applied near the end-point of a beta-spectrum have also been evaluated.

The instrumental corrections discussed in the preceding paragraphs have been applied to data obtained with beta-sources of known spectral form and have been found to bring the data into better, but not complete, agreement with the true distributions. The failure to obtain complete agreement appears particularly in the low-energy portions of these spectra and may be attributable to a possible departure of the transmission curve from the simple form considered in the analysis; such an effect might arise from scattering or other processes in the crystal which would cause less than the full electron-energy to be expended in the crystal itself (see section 3.11 below).

3.11 Scintillation-Spectrometer Program

The scintillation spectrometer appears to be a particularly well-suited tool for the study of synchrotron-produced radio-activities and it is planned to continue the use of such equipment for work of this character. In an effort to locate the source of the impaired quality of the low energy portions of the Kurie plots currently being obtained from the scintillation spectrometer, the transmission curve for the instrument is being examined for any prominent low-energy tail which may form a part of that curve. To further this effort it is desirable (i) to measure the transmission curves revealed by various mono-kinetic electron sources and (ii) to continue efforts directed toward increasing the sharpness of such curves.

In the pursuance of the foregoing objectives an effort has been made to find convenient sources of simple conversion lines, free from interfering continuous beta distributions. An examination of the quite low energy radiations from Te^{125} may ultimately be of value, but the present status of the developmental work indicates the particular desirability of a source to provide mono-kinetic electrons with an energy in the neighborhood of 250 Kev. Through the cooperation of one of the Radio-chemistry Groups, it was proven practicable to separate useful sources of Pt^{196m} from a synchrotron irradiated platinum complex; the conversion electrons from the 337 Kev excited level (21) of this nuclide (K-electron energy, 259 Kev) are currently being utilized to examine the performance of the scintillation counter equipment and to monitor attempts at improving the instrument.

Equipment is also being readied to permit, by means of a high-speed pneumatic tube apparatus, the examination of the beta- and gamma-spectra of short-lived synchrotron-produced radioactivities. These spectra are being recorded by registration of pulse heights from a scintillation counter on a moving photographic film, which may later be examined visually or photoelectrically.

3.12 Counter Window Transmission Experiment

Progress has been made on the apparatus for determination of the electron transmission characteristics of thin foils, such as those used for low energy Geiger counters. A precision resistor composed of 24 "Nobeloy" 5 megohm resistors wired in series and vacuum cast in a polystyrene type matrix will be used to accurately measure the potential accelerating the electron beam. A vacuum chamber housing an electron gun, foil holder, and Faraday cup has been assembled.

IV. THEORETICAL PHYSICS

4.1 Ionization Studies

The ionization produced by electrons, protons, alpha particles, and other atomic particles including fission fragments and recoiling atoms from alpha decay has been studied theoretically. It is possible to account for the observed ionization of recoil particles by reasonable assumptions regarding the ratio of electronic to atomic stopping cross sections. It is found that fission fragments should show ionization defects of the order of several Mev. Such defects are adequate to explain the large dispersion of ionization measurements as compared to mass measurements.

The Smoluchowski-Kolmogoroff equation for the composition of probabilities has been found to be a proper basis for the study of the statistics of ionization produced by particles stopped in a gas. The fundamental process is the single atomic or molecular collision, for which there are certain probabilities for elastic scattering, excitation, and ionization. First and second moments as calculated from the basic equations give integral equations for the average ionization, excitation, and mean square fluctuations of ionization and excitation. These are of the form of continuity equations in which the probabilities for the fundamental process enter as coefficients. Work is continuing on ionization by heavy particles.

4.2 Specific Heat Of Rare Earth Metals

In pursuing the idea that low temperature specific heat anomalies are largely due to crystalline splitting of free ion energy levels, attempts have been made to calculate the relative strengths of different components of the crystal field. In a hexagonal close packed crystal, principal interest lies in the parts of the field with angular dependences corresponding to spherical harmonics of degree 2 and 4 about atomic positions. The previous statement (19) of the predominance of the 2nd degree harmonic may be incorrect. Based on a simplified model of positive point charges at atomic positions, and a uniform smear of valence electrons, calculations of the contributions to the potential due to successive neighbors failed to converge sufficiently rapidly. A second calculation, based on Madelung's method of energy calculation, (22) gives a definite, but apparently false result. It is believed that convergence of this method to the correct value (at least in the form used here) is only guaranteed for ionic crystals.

Also under investigation is the difference in lattice-vibration specific heats between hexagonal close packed and face-centered cubic crystals. The usual difficulties of determining the distribution of vibration frequencies can be avoided if one makes an expansion in powers of T^{-2} , where T is absolute temperature. This type of calculation will not give directly information at very low temperatures, but it does serve to establish the differences in the lattice contributions to specific heat in the two types of crystal. Assuming identical central forces (and the "ideal" ratio of lattice parameters for the hexagonal crystal), the lattice-vibration specific heats for the two crystals agree in the T^{-2} and T^{-4} terms, but differ in the T^{-6} term. The group acknowledges the assistance of Mr. Tom Hendrickson of the Physics Department in making these calculations.

4.3 Miscellaneous Problems

An investigation of nearly adiabatic collisions has been started. The formal theory has been developed, but the resulting expressions have been so complicated in all definite problems attempted thus far that no concrete results have been obtained.

A study of the problem of determining the δ -ray spectrum produced by electrons from the synchrotron through a study of the energies of the positrons produced has been initiated. This involves the solution of an integral equation of the first kind. Methods of approximating the integral equation by a set of linear equations have been investigated. Also the form of the positron spectrum has been calculated approximately for an assumed δ -ray distribution.

The problem of determining the cross section for photo-disintegration from the yield as a function of the synchrotron electron energy, assuming the γ -ray spectrum to be known has been studied. This also leads to an integral equation of the first kind which may be approximated by a set of linear equations. The converse problem of assuming a cross section and γ -ray spectrum and calculating the shape of the yield curve is being investigated.

V. SOLID STATE PHYSICS

5.1 Diamond Conduction Counters

a. Mobilities of charge carriers (wide-band preamplifier)

When an electron is raised from the filled band to the conduction band by a high energy particle, the size of the conduction pulse depends upon the distances the electron and hole travel before being trapped. These distances (or mean ranges) are the products of time of travel and drift velocity of the carrier. The time of travel, which is determined by the density of traps and the thermal velocity, has been discussed in detail by Willardson. (23) Infrared absorption spectra is useful in estimating the density of shallow traps and the thermal velocity can be calculated from the temperature. The greatest unknown is the drift velocity which is the product of the mobility and field strength. Many attempts have been made to determine the mobilities of the electrons and holes in diamond but these fundamental quantities cannot yet be considered well established. Klick and Maurer, (24) from the product of the Hall coefficient and conductivity, gives an electron mobility of about $900 \text{ cm}^2/\text{volt-sec}$. The polarization effects make the reliability of this result questionable and the method cannot be used for determining the mobility of holes.

The mobilities of both electrons and holes can be found from measurements of the rise time of the pulses under suitable conditions. This method has been tried at other laboratories but the results must be rejected owing to the use of inadequate band-width of the preamplifier. It is believed that this particular difficulty has been solved.

In Fig. 2 is shown the preamplifier which has been built for use in conjunction with a chain of six Hewlett-Packard 460A and 460B wide-band amplifiers. By using a 6J6 cathode follower and exercising great care in construction to eliminate stray capacitance, this preamplifier will match the diamond to the amplifiers, retain the requisite bandwidth, and have reasonably good gain. The present bread-board model, when

operating into a 200 ohm load, has a voltage gain of 0.385 and is flat from 100 kc/sec to 200 Mc/sec. Filtering, decoupling and shielding of the high voltage and filament supplies have reduced noise from the environment.

b. Polarization effects and secondary conduction

When electrons and holes are separated and move toward the electrodes they may become trapped. A negative charge is built up near the positive electrode and a positive charge is built up near the negative electrode. The resulting polarization reduces the effective field and hence the pulse height and counting rate for γ -rays.

At the same time electrons are removed from a normally filled impurity level at 2.98 ev below the conduction band (corresponding to the absorption line at 4152 Å). The resulting positive space charge will become concentrated near the negative electrode and induce a negative charge on this electrode. The drop in potential will then be largely across the double layer formed by this induced negative charge on the cathode and the positive space charge from ionized impurities. It is evident, therefore, that the distribution of positive charge results in a reduction of the effective field over most of the diamond and hence reduces the number of γ -rays counted.

At the same time, however the positive charge lowers the energy of the conduction band until electrons can enter the diamond from the negative electrode. The resulting increase in the number of carriers increases the pulse height and hence the counting rate. The characteristics of a positively charged diamond are, therefore, a low initial counting rate, which becomes still lower during γ -ray bombardment owing to the polarization by trapped carriers, followed by a large increase in counting rate as the conduction band becomes low enough to allow an appreciable influx of electrons from the negative electrode.

Most diamonds are in this condition owing to retention of the positive charge for long periods of time. A good example is shown in Fig. 3. The initial behavior is similar to that of diamond Q described in progress report ISC-104. The counting rate increases initially, which is accounted for on the basis of smoothing out of energy band boundaries. When violet light is used the diamond is put into an activated condition in which the increase in number of carriers entering from the negative electrode fully compensates for loss in pulse height due to polarization by trapped charges. If one attempts to repeat this curve it is found that the counting rate is initially low, decreases for a short time, and then returns to the high counting rate characteristic of the activated condition. A substantial

Fig. 3. A plot showing the permanent change in initial counting rate for diamond HC-1.

part of the positive charge remained in this diamond for months. This charged condition can usually be removed by subjecting the diamond to many hours of ultraviolet irradiation with the field removed.

Figure 4 shows diamond D to be in a partially charged condition. The γ -rays remove sufficient electrons from the impurity levels to produce the necessary space charge for activation. The initial counting rate indicated a poor counter but activation revealed diamond D to be a very superior counter. Diamond K (also shown in Fig. 4) is spectacular in that the counting rate was zero for six hours and one would ordinarily classify the diamond as a non-counter. However, after six hours the counting rate began to increase, owing to activation by accumulation of positive charge, and in thirty hours of gamma bombardment had reached a counting rate of 3000 counts per minute.

c. Decay of Space charge field

Figure 5 shows the decay of space charge field before activation by removing the applied field and counting pulses of opposite polarity. Curve A shows the normal decay, curve B shows the effect of reducing the gamma source strength, curve C shows the effect of irradiation with violet light, curve D shows the effect of irradiation with red light, and curve E shows the effect of removing the source for 30 minutes before measuring the decay. It is clear from these diagrams that the traps are so deep that time alone is not very effective in removing charge carriers from traps but so shallow that red light removes the charge carriers readily. This indicates a probable trap depth of the order of one electron volt. Since the gamma rays add electrons (or holes) to traps faster than they remove them; the complete decay of the space charge (no net polarization) is not a state in which the traps are empty but merely a state in which the center of negative charge is at the same point as the center of positive charge.

Figure 6 shows the decay of space charge field after activation. The counting rate increases before decreasing when the applied field is removed. The tentative explanation for this phenomenon assumes that the positive charge becomes uniformly distributed in the time required for the counting rate to reach a maximum. The original concentration of positive space charge (ionized impurities) in the vicinity of the cathode would result in the major drop in potential being near the cathode. As this charge becomes uniformly distributed the drop in potential is determined by the displaced trapped carriers; a larger portion of the diamond contributes to the counting; and the counting rate increases. The final decrease (as before) is due to the neutralization of the polarization by trapped carriers displaced in a direction opposite to that of the original displacement.

Fig. 4. The increase of counting rate with time observed in diamonds which initially show very low counting rates.

Fig. 5. Decay of space charge field before activation and under several different conditions.

Fig. 6. A semilogarithmic plot showing the decay of the space charge field which is present in diamond Q after activation. A saturation field strength of 10,000 volts/cm and Co^{60} gamma rays were used.

d. Absorption spectra of counting diamonds

The ultraviolet and infrared absorption spectra of more than thirty counting diamonds have been taken. It appears that ultraviolet absorption spectra is not a useful criterion in selecting counting diamonds but the absence of large absorption peaks in the infrared is usually a necessary condition for good counting properties.

Many diamonds are a mixture of type I and type II or a type in between these two, as is shown in Fig. 7. The ultraviolet transmission patterns were taken by mounting the diamond on the surface of the photographic plate of a medium quartz spectrograph. By slightly defocusing the final lens and opening the slit, the mercury line 2399 Å or 2653 Å could be used to cover the diamond completely. Observations were made on fifty diamonds. Twenty-two showed complete absorption before 2653 Å and could be classified type I; three showed several small areas (less than half the area of the diamond) transmitting 2399 Å light and could be classified as mixtures of type I and II; the remaining twenty five completely absorbed the 2399 Å radiation but gave transmission patterns similar to those shown in Fig. 7 when using mixture of type I with a small amount of type II. Diamond D-1 (mostly type I) shows a poorer initial counting rate than diamond FSC-5 (mostly type II). Good counters appear to have a substantial portion of the diamond type II. However a type II diamond is not necessarily a good counter.

Figure 8 shows the infrared absorption spectra of diamond B which is a poor counter and diamond Q which is a good counter. Many poor counters show the newly discovered peak at 21 microns much more conspicuously. In general, for good counting properties, the peaks at 8 and 21 microns must not be large compared to the 5 micron peak. Good counters appear to have the 8 micron peak smaller than the 5 micron peak. However, one of our best counters (B-2) has the 8 micron peak over half the height of the 5 micron peak. This diamond also has a peak at 21 microns over half the height of the 8 micron peak. Since the 8 micron peak is smaller than the 5 micron peak the diamond probably contains a substantial amount of type II which could account for its high efficiency. About 67 per cent of the γ -rays scattered by this diamond are counted. Ultraviolet transmission patterns of diamond B-2 also indicate the diamond to be partly type II.

e. Proportional counting

The use of a diamond as a proportional counter depends upon the condition that the pulse height be proportional to the energy of the incident particle. If the diamond is to resolve maxima in the energy distribution of a nuclear source the pulse height must not depend upon what particular area of the diamond the particle enters.

Fig. 7. Ultraviolet Transmission Patterns of Diamonds

Fig. 8. The 3 to 23 micron infrared absorption spectra of two diamonds, one which shows large infrared absorption peaks and one which shows the absence of absorption peaks. Diamond B is a poor counter and diamond Q is a good counter.

Figure 9 shows theoretical curves, using Hecht's formula for pulse height, of the variation of pulse height with region of the crystal bombarded. The solid lines show that the pulse height depends strongly upon the region bombarded when electrons alone contribute to the conduction. Such is the case in silver chloride. Non-penetrating particles (such as alpha particles) bombarding through the negative electrode would be the only way to use such a crystal as an energy spectrometer. In diamond, according to McKay, (25) the average electron travels about 1.8 times as far as a hole before being trapped. Hence the dashed curves apply in this case. Unless the mean range of an electron is more than four times the electrode separation the region of the diamond bombarded must be restricted. This may require an electric field greater than breakdown. Hence the use of a diamond as a proportional counter for penetrating particles is not very promising. An attempt to obtain the 0.66 Mev internal conversion peak in the spectrum of Cs^{137} was unsuccessful.

f. Thermal effects

Using a cobalt 60 γ -source the effect of temperature upon the counting rate has been observed for several diamonds. The counting rate is unchanged as the temperature is decreased from 25°C to -78°C ; the counting rate is decreased to almost zero as the temperature is increased from 25°C to 150°C .

5.2 Sodium Wolfram Bronze

In the previous report some preliminary measurements on sodium wolfram bronze crystals received from, E. O. Brimm of the Linde Air Products Company were discussed. Without sodium this material is wolfram trioxide (WO_3), a ferroelectric insulator of perovskite structure like barium titanate. With addition of sodium the material exhibits metallic conductivity. An attempt was made to determine the sign and density of the charge carriers. The results reported must be rejected completely owing to spurious effects. In particular between -160°C and 40°C the temperature coefficient of resistance appears to be always positive and the Hall coefficient always negative. This problem has now been solved (26) and the results are given in the following discussion.

a. Crystal growth

Single crystals of sodium wolfram bronze were grown by a method suggested by the Linde Air Products Company. The method consists of mixing in a Vycor tube the proper proportions of Na_2WO_4 , WO_3 , and W; heating the mixture in an inert atmosphere

Fig. 9. Curves showing the variation of pulse height with region bombarded obtained from theoretical considerations. A uniform field throughout the crystal is assumed.

to 1000°C; and cooling the mixture slowly to 700°C. After rapid cooling to 25°C the crystals were removed from the Na_2WO_4 by leaching the mass in water. The excess Vycor, to which the crystals clung tenaciously, was dissolved in hydrofluoric acid. A few crystals had edges up to 5 mm but the majority of good crystals were 2 or 3 mm cubes.

The yellow, bronze appearing crystals were chemically analyzed and found to have 6.18 ± 0.14 per cent sodium by weight. Hence the crystals can be represented by the formula Na_xWO_3 where $x = 0.680 \pm 0.016$.

In attempting to grow single crystals with a lower sodium content a dark blue crystalline powder was obtained.

b. Electrical conductivity

The resistance of a sodium wolfram bronze crystal is a few milliohms. Hence the resistance of the lead wires can result in large errors and was responsible for the erroneous results reported previously. These first results were made with a Kelvin double bridge.

The final method used depended upon measurements of potential difference across the sample when a known current is flowing through it. The circuit is shown in Fig. 10 and the results in Fig. 11. The decrease in conductivity with increasing temperature is linear in the range -180°C to +40°C. This behavior is characteristic of metals.

The conductivity at 0°C is found to be $(5.3 \pm 0.7) 10^3 \text{ ohm}^{-1} \text{ cm}^{-1}$ and the temperature coefficient of conductivity in the range -180°C to -40°C is $(-2.1 \pm 0.4) 10^{-3}$ per degree centigrade.

c. Hall coefficient

The Hall voltage measurements were made with a constant magnetic field and an alternating current of ten cycles per second through the crystal. The Hall coefficient of sodium wolfram bronze yellow crystals at 30°C was found to be $(-5.3 \pm 0.8) 10^{-4} \text{ cm}^3/\text{coulomb}$. The temperature coefficient is small as for most metals. The Hall coefficient at -80°C decreased less than 25 per cent from the Hall coefficient obtained on the same crystal at 30°C. Confidence in the apparatus was obtained from measurements of the Hall coefficient of copper and magnesium which are known.

The sign of the Hall coefficient was determined by comparing the phase relations of the Hall voltage and crystal current with the corresponding two signals for antimony. The

Fig. 10. Electrical circuit and temperature controls used in conductivity measurements.

Fig. 11. Electrical conductivity of sodium wolfram bronze as a function of temperature.

Hall coefficient of antimony is so large that its sign could be determined easily by direct current methods. The sign of the Hall coefficient for antimony was definitely established as positive and the Hall coefficient for sodium wolfram bronze definitely established as negative. Hence conduction is by electrons, not by holes.

d. Density of charge carriers

From this value of Hall coefficient the density of charge carriers is calculated to be $1.18 (10^{22})$ electrons per cubic centimeter. From a quantitative chemical determination of the sodium content the sodium density is $1.20 (10^{22})$ sodium atoms per cubic centimeter--corresponding to $x = 0.68$ in the formula Na_xWO_3 . Hence we arrive at the important conclusion that each sodium atom added to the crystal WO_3 donates its valence electron to the conduction band.

e. Magnetic susceptibility

The energy of an electron (E'_0) at the surface of the Fermi distribution depends only upon the electron density (n_0). Using the above value for n_0 the value of E'_0 is 1.9 electron volts.

The magnetic susceptibility per unit volume $\chi = 1.28 (10^{-40}) n_0 / E'_0$ according to Pauli's simple theory of paramagnetism. Using the above values for n_0 and E'_0 , $\chi = 0.51(10^{-6})$.

The magnetic susceptibility of sodium wolfram bronze has been measured by Stubben and Mellor (27) who report a result of $(0.45 \pm 0.03) 10^{-6}$. This agreement with the calculated value is very good if the sodium concentration is the same in both cases. Stubben and Mellor claim a value of 0.9 for x in the formula Na_xWO_3 compared to our value of 0.68. It is doubtful if their value for x is correct, however, since investigators at Linde Air Products have not been able to grow crystals with x greater than 0.7.

f. Electron mobility and mean free path

The electron mobility (μ), drift velocity per unit field, is the product of the Hall coefficient and the electrical conductivity. The mobility of the electrons in sodium wolfram bronze is thus calculated to be $2.8 \text{ cm}^2/\text{volt-sec}$. This value of mobility is lower than that for most metals. Mobility of electrons in silver is $56 \text{ cm}^2/\text{volt-sec}$, in gold $30 \text{ cm}^2/\text{volt-sec}$, in zinc $5.8 \text{ cm}^2/\text{volt sec}$, in sodium $48 \text{ cm}^2/\text{volt-sec}$. A qualitative explanation of the low mobility may be the deep well in the periodic potential resulting from the highly ionized wolfram atom.

The mean free path of the electrons, $\ell = 2.02 (10^{-15}) n_0^{1/3} \mu$, is calculated to be 17 Å. This value is low compared to most metals which usually have mean free paths exceeding 100 angstroms.

g. Thermal conductivity and electronic specific heat

Using the Wiedemann-Franz law the thermal conductivity is calculated to be 0.0084 cal/cm-sec-degree at 0°C. This value indicates the crystals to be rather poor heat conductors compared to other metals such as copper (0.9 cal/cm-sec-degree) or even lead (0.08 cal/cm-sec-degree).

The electronic specific heat, as calculated from free electron theory, is $2.3 (10^{-4}) RT$ erg/mole-degree where R is the gas constant and T is the absolute temperature.

If the thermal conductivity and electronic specific heat were measured experimentally the validity of applying the free electron theory to these crystals could be ascertained. An experimental determination of the specific heat as a function of temperature below 10 K would allow one to calculate the effective mass of the electrons.

5.3 Piezoelectricity at Liquid Helium Temperatures

Pitt and McKinley (28) reported a sharp decrease in the piezoelectric response of quartz at room temperatures below 6°K. Using a Collins cryostat we have repeated their experiments with some additional precautions and have failed to find any effect at 4°K. The experiment will be repeated with more accurate equipment.

5.4 Apparatus for Growing Single Crystals of High Melting Point Metal

Apparatus is being built for growing single crystals of metals with melting points as high as 2000°C and for studying the properties of solids at high temperatures. The apparatus consists of a vertical furnace with provision for maintaining a thermal gradient in the vertical direction, a pumping system for evacuating the furnace, a means for lowering a metal sample through the thermal gradient, and associated temperature measuring and control equipment.

The furnace element of the apparatus is contained in a water-cooled Pyrex tube 90 mm in diameter and 30 cm in length. The radial direction has been intentionally kept small to permit the use of induction heating at high temperatures. The hot zone of the furnace is one inch in diameter and 6 inches in length. Molybdenum radiation shields are used to prevent

excessive heat loss. A resistance element will be used for heating the furnace up to the temperature at which difficulty is encountered with this method of heating. Above this temperature either induction heating or a combination of induction and resistance heating will be used. A power input of 5 kw is available to the resistance heating element.

Up to approximately 1600°C, thermocouples will be used for temperature determination and will also be used in conjunction with a Brown proportional controller for temperature control. Temperature regulation should be approximately ± 3 C at 1600°C with better regulation at lower temperatures. Above 1600°C an optical pyrometer will be used for temperature measurement. The type of control element for temperatures above 1600°C has not yet been determined.

The apparatus used for lowering the metal sample through the furnace described in ISC-73 will be modified so that it can also be used for the same purpose with this higher temperature furnace.

At the present time this apparatus is about 75% completed. The supporting structure, the vacuum system and the 5 kw power supply have been built and the furnace element is under construction.

5.5 Synchrotron Service Work

The synchrotron was used for the irradiation of a germanium crystal to permit the solid-state group to investigate the effect of irradiation, with the X-ray intensities available, upon the semi-conductive properties of this material. At the request of the Metallurgy Groups, the applicability of the synchrotron X-ray beam to radiographical examination of thorium billets was investigated. The results of a somewhat preliminary study led to a method which appeared satisfactory for revealing flaws in thorium billets 3-inches in diameter.

VI. SYNCHROTRON DEVELOPMENT*

In addition to routine operation and maintenance of the synchrotron, replacement oscillator equipment has been constructed and quantitative tests made of the beam-monitoring ionization chamber. The new oscillator equipment, for powering the R.F. cavity of the synchrotron, consists of a pair of 24-G tubes, serving as a driving oscillator, and a pair of UT-127A's as the R.F. amplifier. At present the 24-G oscillator is in use

*The 70 Mev synchrotron was erected with College funds as a facility of the Iowa State College Institute for Atomic Research. The synchrotron research program is currently supported in part by A. E. C. funds.

as a driver for the old amplifier employing 4 x 150A tubes, while the new amplifier is temporarily employed for testing new R.F. cavities being constructed from fused-silica sections (see below).

Analysis and experimental investigation of the behavior of the ionization chamber employed for monitoring the synchrotron beam strength has revealed the marked effect which the pulsed nature of the beam produces in the operation of the chamber and its associated amplifier. Thus, as the chamber voltage is raised, the resulting increased sharpness of the chamber-current wave-form evidently can render it more difficult to keep the amplifier operation within its linear range, whereas low chamber-voltages may permit excessive ion-recombination.

The foregoing effects were first observed in measuring "saturation curves" for the chamber, which exhibited in fact pronounced maxima at the higher radiation levels. A mathematical analysis of this phenomenon suggested suitable capacitance values which, when introduced ahead of the amplifier at the output of the chamber proper, should preclude overdriving of the amplifier. Following the addition of such capacitance to the instrument, the linearity was checked by measurements of the radioactivity induced in copper when the synchrotron was operated at various intensity levels. These tests showed no more than a small departure from linearity, although some further increase of capacitance would appear desirable.

The ionization-chamber has been employed to actuate an Esterline-Angus recording milliammeter, so that a record of individual irradiations can be provided. In addition, a means of readily testing and adjusting the amplifier sensitivity is being provided, so that, with the chamber in a standard position, a comparison can be made of the radiation intensities employed in separate runs.

The construction of gun structures and the assembly of ceramic sections* for the synchrotron vacuum chamber is continuing in a promising manner. The coating of the ceramic sections has been subjected to considerable study. Sections of fused silica have been acquired** to serve as the R.F. cavity and at present are being cut, coated, and tuned for operation at the correction frequency.

*The Laboratory is indebted to Dr. W. Hauth, of the Ceramic Engineering Department, for his invaluable contribution in fabrication of the ceramic sections.

**Custom-made by Amersil, Inc., of Hillside, New Jersey.

VII. PAPERS PUBLISHED

Jensen, E. N., L. Jackson Laslett and D. J. Zaffarano, "The Disintegration of Pr^{142} ." Phys. Rev. 80, 862-865 (1950).

Keller, Koenigsberg and Paskin "Ring Focus in a Thin Magnetic-Lens Beta-Ray Spectrometer." Review of Scientific Instruments 21, 713 (1950).

Knipp, J. K., R. B. Leachman and R. C. Ling, "Ionization Defects of Fission Fragments." Phys. Rev. 80, 478 (1950).

Laslett, Jensen and Paskin, "First-Forbidden Beta-Spectra and the Beta-Spectrum of Sr^{90} - Y^{90} ." Phys. Rev. 79, 412 (1950).

Ling, Rufus C. and Julian K. Knipp, "Ionization by Rec . . . Particles from Alpha-Decay." Phys. Rev. 80, 106 (1950).

Pratt, William W., "The Disintegration of Hf^{181} ." Phys. Rev. 80, 289 (1950).

VIII. LITERATURE CITED

1. Previously Rb^{86} had been investigated by D. J. Zaffarano, B. D. Kern, and A. C. G. Mitchell at Indiana University (Phys. Rev. 74, 6, 682 (1948)), who report that 80 per cent of the transitions go directly to the ground state of Sr^{86} , while the remaining 20 per cent of the cases involve a lower energy beta-ray component and a 1.081 Mev gamma-ray. Energies of 1.822 and 0.716 Mev were cited for the two beta-components.
2. E. N. Jensen and L. Jackson Laslett, Phys. Rev. 75, 1949 (1949).
3. L. Jackson Laslett, E. N. Jensen, and A. Paskin, Phys. Rev. 79, 412 (1950).
4. H. R. Muether and S. L. Ridgway, Phys. Rev. 80, 750 (1950).
5. P. A. Macklin, L. I. Lidofsky, and C. S. Wu, Report at the New York City meeting of The American Physical Society (Bull. Amer. Phys. Soc. 26, #1 Paper T13 (February, 1951)).
6. M. L. Pool, Phys. Rev. 53, 116 (1938).
7. J. A. Seiler, MDDC-614-DD (1949), Nat. Nucl. Energy Series, Div. IV, v. 9, paper 119 (McGraw-Hill, New York, in press).
8. R. B. Duffield and J. D. Knight, Phys. Rev. 75, 1613 (1949).
9. A. Turkevich, ANL-4010, sect. VII, p. 59 (1947).
10. DuMond, Lind, and Watson, Phys. Rev. 73, 1392 (1948).
11. A. H. Compton and S. K. Allison, X-Rays in Theory and Experiment (D. Van Nostrand Co., Inc.), second edition, p. 791.
12. L. M. Langer and R. D. Moffat, Phys. Rev. 78, 74 (1950).
13. H. M. Agnew, Phys. Rev. 77, 655 (1950).
14. Warsaw, Chen, and Appleton, Phys. Rev. 80, 288 (1950).
15. F. D. S. Butement, Proc. Roy Soc. (London) 63A, 775 (1950).
16. B. D. Kern, A. C. G. Mitchell, D. J. Zaffarano, Phys. Rev. 76, 94 (1949).
17. J. C. Bowe, G. Scharff-Goldhaber, Phys. Rev. 76, 437 (1949).

18. Knipp, Leachman, and Ling, Phys. Rev. 80, 478 (1950).
19. ISC-104. Ames Laboratory Progress Report in Physics for the period October 1, 1949 to June 30, 1950. (Sept. 25, 1950).
20. For the purposes of the analysis the average pulse height is assumed to be directly proportional to E. For experimental data bearing on this point and also on the variation of line-width with energy see J. I. Hopkins, Phys. Rev. 77 406 (1950).
21. N. Hole, Arkiv f. Mat., Astron., och Fysik, 34A #29, 9 (1947-); 36A, #9, 1-50 (esp. pp. 32-34) (1948).
22. Born, and Goeppert-Mayer in the Handbuch der Physik, Vol. 24, 2 p. 709. Springer, 1933.
23. Willardson, R. K.; "Characteristics of a Diamond Conduction Counter", MS thesis, Iowa State College, 1950.
24. C. C. Klick and R. J. Maurer, "Mobility of Electrons in Diamond", Phys. Rev. 81, 124 (1951).
25. K. G. McKay, Phys. Rev. 77, 816 (1950).
26. E. J. Huibregtse, "Electrical Properties of Sodium Wolfram Bronze", Ph.D. Thesis, Iowa State College, 1951
27. P. M. Stubben and D. P. Mellor, Journal Proc. Royal Soc. N. S. Wales 82, 225 (1948).
28. Pitt and McKinley, Can. Journal Res. 14, sec. A-B (1936).