MLM-998

TRIP REPORT ON GORDON RESEARCH CONFERENCE
ON NUCLEAR CHEMISTRY

BY

GUSTAVE A. ESSIG

Date. August 12, 1954

INTERNAL DISTRIBUTION

1. Carroll A. Hochwalt

2. N. N. T. Samaras

3. J. J. Burbage

4. R. A. Staniforth

5. E. C. McCarthy

6. J. F. Eichelberger

7. D. L. Scott

8. J. W. Heyd

9. R. K. Davis

10. D. L. Timma

11. E. Orban

12. R. A. Miller

13. G. A. Essig

14. J. W. Wright

15. S. W. Scott, Patent Branch, Oak Ridge

16. Technical Information Service, Oak Ridge

17. Technical Information Service

18. Technical Information Service

19. Area Manager, AEC, Dayton

20. Area Manager

21. Area Manager

22-65. Central Files

Issued: AUG 19 1954

TABLE OF CONTENTS

INTRODUCTION

The annual Gordon Research Conference on Nuclear Chemistry was
held at the New Hampton School, New Hampton, New Hampshire from June 28,
1954, to July 2, 1954. Representatives from the United States and several
foreign countries attended. Many of these came from AEC-sponsored
national and university laboratories where nearly all the fundamental
research in this field is done. Under the rule adopted by the conference
none of the material presented at the conference can be published.

Most of the papers and discussion used highly technical terms,
equations, charts, and graphs. An attempt will be made to make this
report as comprehensive as possible.

A. Nuclear Structure and Radioactivity

1. Beta Rays

Considerable work is now being done to use beta-particle
decay as a tool in nuclear structure studies. This is done by
calculating the log (fτ) values which are dependent upon the
type of decay (beta-particle, positron-particle; or K-shell
electron capture); the maximum kinetic energy of the particles
or energy available for K-electron capture within the atomic
nucleus; and the half-life in seconds for the event to occur.

As a result a more clarified picture was presented which is
gradually and slowly resulting in a better understanding of
the nucleus of the atom. Selection rules (borrowed from
optical spectra theory) were discussed in an attempt to ex-
plain the various probabilities for different beta-particle
transitions. Most of the beta-emitting nuclei of light
isotopes have been studied. These have symmetry properties
in their wave functions so that the beta emission has "super-
allowed" or favored transitions, and here the matrix element
is large. Some "superallowed" transitions are produced in
"mirror nuclei" where the number of neutrons and protons are
nearly equal ($N = 2 \pm 1$). Such isotopes are hydrogen-3
(tritium), beryllium-7, and boron-9. The beta-particle or
positron decay is caused by the coulomb (electric charge)
difference between the nucleons in the nucleus. Further dis-
cussion touched on decay schemes of triads, where the number
of neutrons equals the number of protons in a nucleus in which
neutron excess is plus or minus two, or in even numbered atomic
weight nuclei, for example carbon-14, nitrogen-14, and oxygen-14.
The coupling between quantum numbers bore a distinct relation to
beta-ray transition schemes. While many decay schemes for the
light elements have been investigated, there is some question
if they can be worked out for atomic weights up to 65.

2. Long-Lived Radioactivities

The conference on long-lived radioactivities dealt with
isotopes with half-lives of approximately 30 million years.

Isotopes with half-lives shorter than this may be considered as extinct radioactive nuclides. Isotopes with half lives in the range from 300 million (3×10^8) to one million-billion (10^{16}) years are known as primary-nuclides. These nuclides are a group beginning with uranium-235 with a half-life of 710 million years to tellurium-131 with a half-life of approximately 10^{21} years. Decay schemes were discussed for potassium-40, lanthanum-138, rubidium-87, luticium-176, and rhenium-187. Some possible undetected primary natural radioactivities are vanadium-50 and calcium-48. Tellurium-130 has a possible double beta decay scheme as well as zirconium-90 and calcium-48. In general, by observing the selection rules, comparative lifetimes, and other quantum factors, it is possible to determine the probability of beta emission. The long-lived radioactivities are determined by observing the active daughter products of these materials.

3. <u>Nuclear Models and Energy Levels</u>

In the heavy element region, low-lying nuclear energy levels and the application of certain nuclear models were discussed. To form a better understanding of the nucleus, it is important to find the energy levels and the quantum numbers which depend upon the nuclear energy, momentum, parity, and isotopic spin for the light element region. Nuclear models have been postulated by many investigators and nearly all have had difficulties in explaining the experimental facts which are discovered as research continues. Some of these are: (1), the single particle

model with the potential energy well, spin and magnetic moment;
(2), the shell configuration, an improvement, which includes the
potential well; (3), the collective or liquid drop model with
its property of spherical deformation; and (4), which is per-
haps the best, the uniform or unified model of Bohr and Modell-
son with its strong coupling and large deformation approximation.
In the latter model, tests for quantum numbers K and J have shown
that K does not fit some examples very well; while J is good in
some cases, it gets worse with increasing distortion of the
sphere (nucleus), and in the low energy states is very poor.
Though J may be a good quantum number for light elements, it is
inapplicable with the heavy elements. Alpha decay was discussed
briefly. The decay scheme for americium showed alpha decay
with no change in the spin of the nucleus, but the nucleus
retained a hindrance factor. Hill and Wheeler of Prince Univer-
sity have postulated that the nucleus of the radioactive atom
took the shape of a football during its excited state and ejected
an alpha particle from an end.

4. Recent Nuclear Research on Heavier Elements at Argonne National
   Laboratory

Plutonium was used as a starting material in the Arco reactor.
The neutron bombardment and successive decays produced heavier
isotopes of plutonium, americium, and curium. By beta decay
elements atomic number 99 and 100 were produced. A new mass
spectrometer with a sensitivity of 10^{-13} grams was used to detect
a large group of newly formed isotopes and their decay schemes

were evaluated. Studies were made on the alpha-particle decays
and half-lives of several isotopes of curium. The isotopes of
californium were also studied to determine alpha-particle decay
and spontaneous fission. The possibility of creating or detecting
elements whose atomic numbers are greater than 100 appears remote
because the half-lives theoretically become exceedingly short.

5. Recent Chemical Research on Heaviest Elements at the University
   of California

In carrier experiments it was found that the hydroxides of
elements 99 and 100 are like lanthanum and the other rare earths.
Element 99 did not oxidize very readily and element 100 had a
half-life too short for oxidation to occur. Ion exchange columns
were used for the separation of these actinide elements. The rare
earth elements were removed before separating the actinide groups.
Considerable study was made of the "drop numbers" of the columns
with respect to the sequence of separating out the heavy element
from elements of atomic numbers 95 to 100. Different eluates
were tried and it was found that ammonium lactate was most effective
and the elements would separate in sequence according to atomic
number. In the plot of the log of drop number vs the atomic
number a curious break in the curves occurred for various ion
elements and an attempt was made to explain the break as "Stark
Effect" caused by the ion electric field.

B. High-Energy Nuclear Reactions

1. Photographic Emulsion Data on High-Energy Reactions and their
   Relation to Radiochemical Evidence

Photographic emulsions are a powerful tool in the field of
high-energy nuclear reactions. Studies were made of 10 to 100
Mev nucleons penetrating nuclear structure by two stages; (1),
"knock-on" nucleons; and (2), by nuclear de-excitation or phase
evaporation. These are known as Heisenberg nucleons and evapor-
ation nucleons, respectively. These particles were produced by
using a cyclotron with a five-mil scatterer and a target probe
containing the emulsion. Studies were made of the yields of
spallation (splitting or splintering of nuclei) reactions in
which copper was bombarded with 340 Mev neutrons. The careful
study of "stars" (produced by nuclear splintering) is a tedious,
eye-straining, and time-consuming art. The microscopic work
was estimated to cost about $10,000 per square centimeter and
it takes about one year to carefully scan one-third of a square
centimeter of film. One clever development was the construction
of a probe containing the target material in the form of a
closely-wound fine copper wires which were covered with a photo-
graphic emulsion. Although the construction was difficult, the
probe could be used more easily within the cyclotron. This probe
will be used for future studies. In the studies of the protons
evaporated or emitted by cyclotron-irradiated molybdenum, an
anisotropic distribution of protons vs emission angle was ob-
tained. This was described as the effect of nuclear surface
waves and, possibly, of a volume effect. Additional theory
explains this as follows. A neutron entering a nucleus con-
taining more neutrons than protons knocks out more neutrons than

protons, making the nucleus neutron-deficient. The protons decay which affect the angular distribution of the proton emission. This explanation was rejected by an experimenter who suggested that something goes on within the nucleus to excite the protons and to lower the barrier for emission. Further argument offered the Bohr-Wheeler oscillating droplet mechanism, in which a proton, like a drop of water forming on a spigot, oscillates until it drops, as an explanation for the proton angular distribution.

2.   The Evaporation Phase of High-Energy Reactions

When a primary cosmic ray or a high-energy particle punches a hole through the nucleus of an atom, the nuclear surface increases and the size of the hole can be calculated according to Heitler. The nucleus is left in an excited state and the energy within the nucleus may be distributed in many ways. This energy may be considered as distributed throughout the nucleus in the form of heat and a correlation can be made of nuclear energy and temperature. If the temperature is sufficient to reduce the potential barrier, an effect similar to that of evaporation occurs with the emission of one or more nuclear particles. It is assumed that the potential barrier falls rapidly as the excitation energy (from the incoming particle) increases. An attempt was made to explain how the excited nucleus emits a proton. This was discussed in the previous topic, Photographic Emulsion Data. The neutron-deficient nucleus was assumed to be a contributing factor and the binding energy of the nucleons with respect to the potential barrier was considered most important.

When high-energy cosmic rays (protons) strike matter,
approximately one and one-half neutrons are emitted per proton.
From a plot of the relative number of particles vs the exci-
tation energies of protons (up to 700 Mev) bombarding lithium,
it was found that both the yield and number of particles in-
crease with an increase in excitation energy. More neutrons
than protons are emitted, and in decreasing relative numbers
there are alpha particles, tritons, deuterons and helium-3
atoms (decayed tritons).

3. Excitation Functions (Cross Section vs Energy Curves) of
High-Energy Nuclear Reactions

This topic concerned primarily the "knock-on" stage of
the nuclear process in high-energy reactions having a range
of 100 to 500 Mev. It was noted that with nuclear reactions
involving energies greater than 60 Mev, the compound nucleus
theory is not applicable. With these high energies the
incident particle either is captured or penetrates the nucleus.
This is readily seen, because at these energies a fast moving
proton uses a very short time to go thru a nucleus. The wave
length of the proton is short with respect to the nuclear
diameter. The individual proton-neutron cross-sections are
small enough for the proton either to go through a nucleus or
have a collision. Considerable work was done in getting data of
cross-section values vs proton energies in the range of 100 to 1,000
Mev. Various proton-nucleon reactions were discussed. It was found
that as the energy of the incident particle is increased there

is a greater possibility that a particle will be released from
the nucleus; and that the cross-section required for a proton
to knock out a proton and a neutron increases with energy above
50 Mev. But as the proton energies increase beyond 100 to about
1,000 Mev the cross-section decreases rapidly. It appears that
evaporation is contributing materially to the cross-section
data on the "knock-on" reactions. At higher energies there
is evidence that mesons are produced.

4. Cross-Sections for Proton-Induced Reactions in the 0.5 to 3 Bev
   Energy Range

The cosmotron at Brookhaven was used to accelerate protons
to these high (cosmic ray) energies. Until recently the maximum
energy produced by the cosmotron was 2.2 Bev. As improvements
were made this was stepped up to 3 Bev and it is hoped to in-
crease this value still higher. Studies were made on the bom-
bardment of aluminum and copper by this instrument. Some data
were obtained for lead and bismuth. The yield-distribution data
for aluminum and copper spallation were presented. Curves of
cross-sections vs proton energies in Bev were shown for sodium,
fluorine, carbon, nitrogen, and beryllium. Excitation functions
were shown for lead and bismuth spallations. The interesting
thing was that for lead spallations the curve took a dip in the
rare earth region where A (atomic mass) is about 150. Some
isotopes were formed by the fissioning of the materials as well
by the spallation process. When tantalum, gold and bismuth were
bombarded with protons at energies from 1,100 to 2,050 peak Mev,

many nucleons were ejected, yet the energy used per particle emitted was constant. Pi plus and pi minus mesons were produced from the bombardment of beryllium and pi plus mesons from bombarded hydrogen. It was concluded that large energy transfers take place with these nuclear reactions.

C. Nuclear Geochemistry and Cosmochemistry

1. Radiocarbon Dating

Radiocarbon (C^{14}) dating is being done with a proportional counter which uses acetylene gas. The counting is done by anti-coincidence methods. Considerable care is required to keep the gas free of any contamination. The background count must be low, in the region of 2 to 3 counts per minute. The tube operates at 5,000 volts direct current. It takes about 28 hours of counting to verify radio-active decay to 40,000 years ago. Specially selected old wood and leaves found under the till (gravel) left by glaciers are the best samples, because they were deposited before the glaciers came and are more likely to be untouched - an important factor. One result of this work is that a temperature record of a particular region going back to over 20,000 years is obtained. An attempt has been made to correlate the glacial periods in Europe with those in the United States. From present knowledge the climates in Europe and America about 10,000 years ago were out of synchronization by about 200 years.

Glacial rocks may be dated by counting carefully selected speci-mens of chlorine-36 which was formed prior to glaciation by cosmic ray neutron bombardment of chlorine-35. Chlorine-36 is a gamma emitter and its radioactive decay may be used to date events 400,000 years ago.

Considerable work is being done in dating of deep-sea sediments.
Samples of radium are counted in the presence of ionium which is a
parent of radium. By plotting the decay of ionium and radium with
respect to time the era of sediment deposits may be determined.

2. <u>Dating of Radioactive and Lead Minerals</u>

By measuring the amount of radioactive decay end products of
uranium and thorium which are isotopes of lead mixed with helium,
minerals may be dated from 500 million to 3,000 million years ago.
Galena crystal minerals were investigated from several section of
the United States, Canada, and Africa. Ratios of the decayed lead
isotopes from these locations were carefully measured and the
particular mineral source was dated. Generally the lead-207 to
lead-206 ratio was found to be the best method for determining the
ages of old minerals. According to the geologist, common lead pipe
contains about 30 per cent radiogenic lead. However, lead obtained
from different regions contains varying amounts of radiogenic lead.
Galena from Rhodesia, Africa, was found to be 2,800 million years
old, from Northwest Territory in Canada, 2,300 million years old.
The Colorado pitchblendes are considered to be fairly young minerals.

3. <u>Dating of Common Types of Rock</u>

Rocks containing thorium-230 and thorium-232, strontium-87, and
rubidium-87 are obtained from geologically interesting locations.
Small samples of these elements are removed from the rocks by ion
exchange separation, deposited in microgram quantities on a special
holder, and the magnitude of the isotopes of each of these elements
are compared by using a mass spectrometer. The age of a sample of

the mineral lepidolite was found to be 1,610 million years by measuring the rate of decay of rubidium to strontium. Strontium-87 has a half-life of 6×10^{10} years. A sample of the mineral muscovite was determined to be 1,540 million years old. This topic was concluded with the observation that rock types can be dated but the interpretation is very difficult.

4. <u>Cosmic-Ray-Induced Radioactivities</u>

Investigations of radioactivities induced in the atmosphere by cosmic rays producing carbon-14, tritium and beryllium-7 are being conducted. Cosmic rays may be considered as ion cores ranging up to iron, however, they consist mostly of hydrogen and helium. By atom percentages they consist of approximately 80 per cent protons, 20 per cent alpha particles and 1 per cent CNO. The intensities of cosmic rays vary with latitude in the billion electron volt range and are bent by the magnetic field of the earth. The vertical cosmic ray flux varies from 0.07 particles per square centimeter per second at 40° north latitude to 0.21 at 56° north latitude and 0.025 at the equator, all in the same units. The east-west asymmetry is due to the magnetic field of the earth. The integrated flux density of cosmic rays at sea level is about 0.5 primaries (protons) per square centimeter per second. Including all effects the best estimate of rays reaching the surface of the earth is about 0.4 rays per square centimeter per second.

Primary cosmic rays produce protons, deuterons, tritons, neutrons, helium-3 atoms, alpha particles, about twenty-five known

mesons and about seventy-five unknown mesons. The secondary protons
require energies in hundreds of Mev to produce "stars". The general
effects of cosmic rays are: (1), to produce high-energy stars; and
(2), to produce low-energy events, especially neutrons.

Neutron flux determinations were made, using enriched boron-10
detector tubes and the cadmium difference method. The neutron flux
from cosmic rays is about 2.3 neutrons per square centimeter per
second. This is about six neutrons produced by each primary particle.
When cosmic ray neutrons bombard nitrogen-14 in the atmosphere, carbon-
14 is produced. Cosmic neutrons striking atoms in the atmosphere pro-
duce stars from which tritium is formed. The ratio of the number of
neutrons to the number of tritium atoms produced was determined to be
as approximately six to one. Production of beryllium-7 directly from
primary cosmic ray particles was very low. Most tritium is made at
the high altitudes and becomes water (and vapor) at an altitude of
50,000 feet. A study of the mixing of tritium at high altitudes was
presented. In general the tritium content varies with each rainfall.
In the Chicago area rain has contained approximately 6×10^{-18} mole
fraction of tritium. Integrated over all latitudes the tritium
content in the surface of sea water was found to be 0.25×10^{-18} mole
fraction. One-half of the beryllium-7 produced by cosmic rays decays
in the atmosphere. Beryllium-10, which has a half life of 2×10^{6} years,
goes primarily by means of rainfall into the sea. Since it is not
soluble in water, nearly all beryllium-10 will eventually be deposited
on the bottom of the sea. Tritium has been suggested (by Libby) as a
means of dating of excellent wines.

5. Radioactivity and the History of the Earth's Crust

The earth's mantle is estimated to be 3,000 kilometers thick.
The inner core of the earth is assumed to be liquid iron and nickel.
The thickness of the mantle was determined by studying the change of
velocity of seismic waves with respect to density inside the earth.
Mean density and moment of inertia measurements were used to deter-
mine the composition of the earth and this composition was compared
to that of meteorites. The composition of the earth is considered
to be similar to that of a stony meteorite. This assumption is borne
out by comparison of the quantity of uranium and thorium in meteorites
and rock samples from the earth. The nature of the surface layer of
the earth was studied by means of seismic wave velocities to obtain
a picture of its gravitational equilibrium with respect to the core.
There is strong evidence that the continents have grown with passage
of time. Mountain belts are building continuously by an inner pushing-
up and spreading-out process which adds to the area of the continents.
Studies have been made on the radioactive heat generated in different
types of rocks. Under a mountain area the heat gradient from the
depth of the mantle to its surface is about 700°C and in non-mountain
areas it is approximately 300°C. From the best evidence available
thorium and uranium are located in the earth's mantle under a layer
of aluminas, silicas, and alkali-earth material. The heat flow at
the bottom of the ocean was found to be higher than was expected.
This is probably due to heat generated by uranium and thorium below
the bottom of the sea. A big unanswered question is: How does the
uranium and thorium get to the surface of the earth without bringing

up other materials? A question was raised as to whether the earth
was heating or cooling and the conclusion was that the temperature
is constant. A suggestion was made that iron-60 with a guessed
half-life of 10^8 years might have contributed to the high temperature
of the earth if this event is extrapolated back in time three to four
billion years ago.

D.   Roundtable Discussion on Techniques of Absolute Counting

   1.   Absolute Counting

A roundtable discussion was held on techniques of absolute
counting. The characteristics of the 4π proportional counter were
presented. Hydrogen sulphide gas was used as the ionization medium
for the absolute counting of radioactive sulfur-35. Some investi-
gations using sulfur dioxide as a counting gas have been made.
Methods of preparing the gas were discussed. The principal method
was thermal decomposition of copper sulphate. At the National
Bureau of Standards the best 4π tube operation plateau obtained
during counting of carbon-14 was 600 volts in length. Many radio-
isotopes have been counted by National Bureau of Standards including
phosphorus-32, iodine-131, cobalt-60, carbon-14, radium-D, radium-E,
thallium-204, strontium-90, yttrium-90, gold-198, sodium-22 and sodium-24.
Within the next six months work will be done with helium-3, carbon-14,
cesium-137 and sulfur-35.

Several methods of counting are used at National Bureau of
Standards including: (1), internal gas counting; (2), radiation
balance which uses the Peltier heating effect, and which has been
used for counting tritium samples; (3), the 4π scintillation counter

with the sample held between two counters as in a sandwich, and (4),
the liquid scintillation method where the source or sample is intro-
duced into scintillation liquid to help eliminate self-absorption.
If the sample to be counted can be introduced properly, the best
methods to eliminate self-absorption are the internal gas counting
and the liquid scintillation methods.

Several terphenal mixtures and compounds were discussed for
improved scintillation counting. Attempts have been made to shift
the scintillation spectrum to a longer wave length which better matches
the sensitivity of the photoelectric multiplier tube. The National
Bureau of Standards counting accuracy for cobalt-60 is within ± 1
per cent, but difficulty has been encountered in trying to obtain
good counting accuracy for carbon-14 and sulfur-35.

Various methods of source preparation were discussed. One
method used a thin-film sample covering made from polyvinal-acetate
copolymer (VYNS). This material was dissolved in cyclohexanone (one
part VYNS to three parts of solvent), and a few drops of this solution
was spread over water to form a thin film. A wire loop was used to
remove the film from the water and to hold the film for drying. The
thickness of the film was determined by a light-reflection method.

Investigations are being made of the problems of thick-sample
source counting using 4π counters. Little had been done in this
field since 1910, probably because the effects are very complicated.
Absorption, back scattering, and other factors affect the distribution
pattern of the radiation. It was suggested that each laboratory
should evaluate the counting self-absorption and other conditions

so that corrected results will come within 5 to 10 per cent of absolute values.

Another method of counting was presented which consisted of non-electronic aluminum electrometer cells. The source of radiation is suspended inside of a large evacuated tank with a screen around the source. Ionization current is measured and calibrated in terms of source strength. Other variations of this type of counter were presented; some used magnetic fields to reduce electron scattering and preserve the counting geometry. Results of counting sulfur-35 and phosphorus-32 agreed well with results obtained at the National Bureau of Standards.

E. Extranuclear Effects on Nuclear Angular Correlations

1. Survey of the Field

A brief history of the field of extranuclear effects on nuclear angular correlations was presented. This field deals primarily with gamma-gamma cascade emissions and their relationship to the nucleus emitting them. Modern experimental methods are greatly improved. At one time it would have taken an experimenter using a Geiger-Mueller tube ten years to conduct one experiment in angular correlations.

The question of what happens to the nucleus during gamma-gamma cascade disintegration was discussed. Assume a nucleus having a spin (angular momentum) of four. It is in an excited state and it emits a gamma-ray in a definite direction. The nucleus adjusts itself and the spin becomes two. The still-excited nucleus emits a second gamma-ray at some angle theta (θ) in another plane with

respect to the direction of the first emitted gamma-ray. The nucleus
adjusts itself to the ground state and the spin is zero. What is the
probability that the nucleus will have rotated a certain angle theta
(θ) between the gamma-ray events? A radiation dipole pattern is set
up perpendicular to the direction of nuclear spin. Experiment and
theory shows that the probability may be expressed in terms of
Legendre polynomials which act like $\cos^2\theta$ functions. The experi-
mental technique utilizes two scintillation counters operated in
coincidence and adjustable radially. The decay scheme of indium-111
was used during these experiments and the angular correlations between
the first and second gamma-rays were studied. The constants required
for the probability equation were evaluated. Additional work was
done on investigation of what happened after K-electron capture by
the nucleus. It was found that as many as seven electrons may leave
their orbital shells during the stabilization of the atom. According
to theoretical assumptions, when the indium isotope is in an ion
crystal the atom is excited for a relatively long time and the electrons
are in a disturbed condition; hence the ionic sources had a correlation
that was perturbed. When indium-111 was in association with metallic
silver, the free electrons of silver would jump in the holes rapidly,
consequently the shell electrons could not act and no perturbation
occurred. The Zurich (Switzerland) group discovered an atom in a
metal crystal tetragonal lattice whose field gradient was such that
perturbation occurred. Studies were made of the characteristics of
nuclei that were perturbed and those that were not. Some perturbed
nuclei had very short half-lives in the order of 10^{-10} to 10^{-11} seconds.

They also had small magnetic and electric field gradients. Finally, the nuclear recoil energy for gamma emission was calculated to be about one electron volt with a possible maximum of 5 to 10 electron volts. The nuclear recoil energy from beta emission is about 10 to 20 electron volts.

2. Effects of Electric and Magnetic Fields

The theoretical and mathematical aspects of the angular correlation of gamma-gamma decay were discussed. Investigations have been made of the nuclear disturbances caused by application of magnetic fields during the gamma transition. The directional correlation of cadmium-111 was checked with different sources. If a crystal of this material was powdered, experiments were conducted more easily than with crystal solid. The alpha particle gamma ray transition of the thorium-230 was investigated for correlation and the disturbances of both levels of decay were studied. An attempt was made to explain why the radio-active isotopes in a liquid are more easily studied. Fluctuations apparently are much more rapid even with half-lived isotopes of 10^{-12} seconds, and no static directional effects are found in liquids. The mathematical expression was given for the transition probability that the nucleus (in liquid) is in a certain state. Finally it was concluded that the applications of these studies (effects of electric and magnetic fields) could be used for: (1), calculating interaction constants; and (2), making studies of the effects of radiation damage.

3. Quadrupole Effects

Experiments were discussed in which the object was to determine if nuclear attenuations are due to magnetic or electric interactions. It was found that magnetic fields did not affect the attentuations. The

electric fields from crystals were used to make this investigation.
Indium-111 was produced by cyclotron bombardment of cadmium. The
indium was separated and placed into a fine capillary tube. By heating
and centrifuging, the indium droplet was forced into the end of the tube
and a crystal was formed upon cooling. This source was properly mounted
on a goniometer head between two scintillation counters oriented rad-
ially and connected in coincidence. The crystal could be rotated in a
plane perpendicular to the counting tubes. From the counting data
calculations were made and curves were plotted with respect to the
rotation of the crystal in different planes. In rotating from 0 to 90
degrees the effect of the electric quadrupole interaction could be
plotted. An asymmetrical curve was shown for the gamma-gamma
correlation. Work is being done at Argonne National Laboratory on
the correlation of the alpha particle gamma ray decay of thorium-230,
and radium-226.

F. Effects of Radioactive Decay of an Atom on its Electron Shells

1. Theory and Experiments

This topic was the electronic quantum mechanics of the K and L
shells. The K-shell electron capture by the nucleus is primarily an
electromagnetic interaction. For example, when the nucleus of a
beryllium-7 atom captures a K-shell electron, a hole is left in the
K-shell and the atom becomes lithium-7 with release of a neutrino.
Or an L-shell electron may be captured and a hole left in the L-shell
of the lithium atom. Another possibility is that one electron in the
K-shell is captured by the nucleus and that the other K-shell electron
plus a neutrino is released from the lithium, thus leaving two holes
in the K-shell.

Some discussion followed on gamma-ray emission methods and the effect on electrons. When a gamma-ray is emitted from the nucleus of a radioactive atom, the nucleus may go to the ground state and it shrinks a little because a nuclear charge re-distribution occurs. The orbital electrons must readjust to the condition; however, sometimes they can not quite make the adjustment and so an electron is emitted from the atom. Electrons may be shaken off during the process of nuclear charge readjustment and nuclear recoil. The recoil process is more important with molecules than with individual atoms. For example, if emission occurs from the nucleus of an atom in a diatomic molecule and if the molecule sticks together, it will be rotated.

An electron may be emitted from an atom by direct coulomb interaction by a particle. A gamma-ray can interact with a shell electron and the electron can be released by the Compton effect, or by the Raman effect even though the probability for the latter effect is very small.

A mathematical expression was derived for the probability of forming a daughter atom or a daughter molecule in any final state of beta-ray decay or orbital capture. The relationship between the initial and final states of the atom depended upon the sum of the momenta of all emitted particles (electrons and neutrinos).

The probability was derived in the case of K-capture for a daughter atom in the ground state to have: (a), one hole in the K-shell; or (b), two holes in the K-shell. It was found that low and high limits of the probabilities were small and came close to experimental results. In the case of alpha-particle emission the probability of an electron shaking-off

is small. This is because the alpha-particle comes out of the nucleus
slowly and in the meanwhile electrons have time to readjust the radii
of their orbits.

Studies of beta-ray decay of molecular tritium show that the chances
of forming a helium-3 tritium molecule is about 50 to 60 per cent. This
is based upon spectroscopic data from infra-red experiments. The electron-
neutron correlation factor depends upon whether or not the beta-ray and
the neutrino are emitted in a parallel direction.

Ten papers have been published and two are in process of publication
on the effects of radioactive decay of an atom on its electron shells.
Nuclear decay processes and their effects can be studied and detected
in a number of ways. Some experimenters use Wilson cloud chambers and
photographs, others study the characteristic X-rays of the daughter
atoms by using critical absorbers to be quite certain as to the origin
of the photons. The easiest method is to experiment with alpha-particle
sources, since no beta-particle Bremsstrahlung peaks occur to affect
accurate evaluation of the data. Gamma-ray spectrometry experiments
were conducted with polonium-210. The data was evaluated to show the
number of electron ejections from the L-shell for each alpha-particle.
The experimental results were 17-1/2 times greater than the theoretical.
Other investigators obtained good results for K-shell electron inter-
actions, but poor results for L-shell interactions. An explanation
from the Bohr theory was: that if the velocity of the alpha-particle
with respect to the velocity of the electron is close, the electron can
jump to the bound state (latch on to the alpha-particle) and be carried
off into the continuum. Since the L-shell electron moves slower than

the K-shell electron, perhaps the alpha-particle is more likely to carry the L-shell electron with it.

An experiment was discussed which studied the orbital electron ejection in beta-ray decay. Sulfur-35 by giving off a beta-ray becomes chlorine-35. By a clever subtraction method on the plotted data, the effects of bremstrahlung were eliminated. It was found that the experimental results for K-shell electron ejection per beta-ray agreed very well with theory.

The writer wants to express his appreciation for the opportunity to attend this conference.