DETERMINATION OF THE EXISTENCE OF LOW LYING ROTATIONAL NUCLEAR ENERGY LEVELS

by

CLARENCE SAMUEL CLAY

B. S., Kansas State College
of Agriculture and Applied Science, 1947

A THESIS

Submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

Department of Physics

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1948

TABLE OF CONTENTS

INTRODUCTION

Early in the history of radioactivity it was observed that radiations emitted by various elements were characterized by having discrete energies. Later when through bombardment artificial radioactive elements were produced, these, too, were found to emit radiation in which the energies were fairly constant. Furthermore the absorption cross sections of the bombarded atoms showed definite resonance values for certain energies of the bombarding particles. All of these data indicate the probability of nuclear energy levels (1).

Early in 1942, Guggenheimer (2) presented a hypothesis in which he considered the nucleus as an entity which could rotate. He treated the nucleus as a sphere rotating about a central axis and, also, as a divided mass with one part revolving about the other.

Of particular interest was the case of the spherical rotor for which a nonrelativistic quantum mechanical treatment led to a solution only upon the assumption of discrete energy levels with eigenvalues given by

$E = BK(K + 1)$ in which - - - - - - - - - - - - - - - - - (I)

$B = h / 2 I$

$I = .4 m r^2$

$K = 0, 1, 2, 3, . . .$

$I =$ the moment of inertia of the spherical nucleus

$r =$ the radius of the spherical nucleus

By using the usual assumption that r is proportional to the cube root of the mass number and the mass is proportional to the mass number, it was possible to change the form of Eq. I to

$$E = 2.5\ B_0\ A^{-5/3}\ K\ (\ K + 1\ ) - - - - - - - - - - (II)$$

where A was the atomic mass number, E was the eigenvalue in million electron volts, and B_0 was a constant evaluated from experimental evidence to be 5.06 million electron volts.

Guggenheimer (2) was able to show fairly good correlation between theoretical and experimentally observed resonance levels in various atoms for high energy transitions. However, for the energy region existing between the lower limits attainable by a Van de Graff accelerator and the upper limits of K x-ray absorption, no data were available. Since in this region a number of atoms were predicted to absorb radiation, it was the purpose of this investigation to further test the rotational theory by observing the absorption of high energy x-rays by Ca, Ni, Fe, Zn, and Cu. These elements were selected for this experiment since their theoretical energy levels were in the region of 20 to 60 KEV which was accessible to available x-ray equipment.

APPARATUS

The apparatus used in this experiment is shown in Plate I. The x-ray machine was built by Pickering X-Ray Corporation for hospital use. The x-ray tube and its case were mounted on a table as shown. The De Broglie spectrometer was constructed on

EXPLANATION OF PLATE I

Photograph of the apparatus

A - The x-ray tube housing and the x-ray tube

B - Position of the absorber

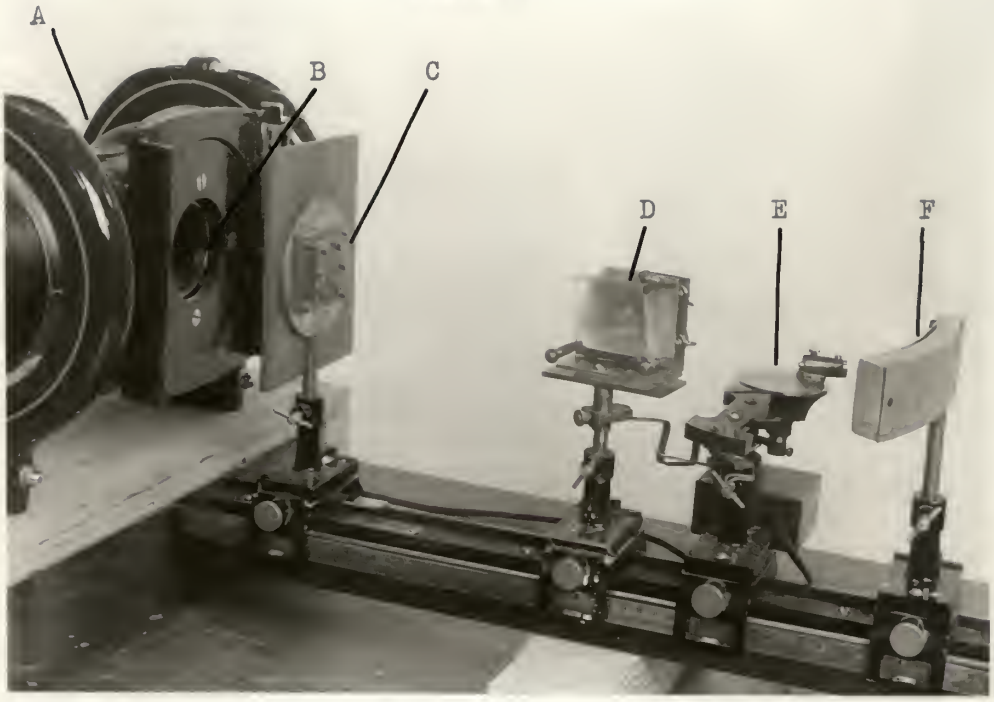
C - The lead slit

D - Calcite crystal

E - Crystal rocking assembly

F - Film holder

PLATE I



an optical bench which was bolted to the table (3, 4).

The distance from the slit to the axis of crystal rotation and the distrace from the axis of crystal rotation to the film were chosen to be 20 centimeters.

The crystal was rocked through an angle of about four degrees by the rocking assembly. The rocking assembly changed the angle of the crystal at a uniform rate of eight degrees per minute.

With a slit width of .1 mm the exposure necessary, using Eastman no-screen x-ray film, was about 10 to 15 millampere hours.

The wave lengths of the lines were calculated from the Bragg Law after the position of the lines were measured by the micro-comparator (4). After the tungsten $K\alpha_1$, and α_2 lines had been identified, they were used as the calibration point; and all other wave lengths were measured from the known tungsten $K\alpha_1$, and α_2 wave lengths (4).

The resolving power, $\frac{d\lambda}{\lambda}$, for this instrument measured at the tungsten K lines was approximately .005.

EXPERIMENTAL PROCEDURE

Two films were exposed with each element as the absorber in position B of Plate I. Two additional films were exposed, one at the beginning and one at the end of the experiment, without an absorber for control purposes.

Three densitometer traces were made for each film, and all

traces for a particular absorber averaged together. The traces for control (no absorber) were also averaged. All of these average traces were shown on Plate II.

The exposures were adjusted so that all films had nearly the same density.

The absorption curves on Plate III were drawn by taking the difference between the ordinates of the averaged densitometer traces for the particular absorber and the ordinates of the averaged trace for the control. These differences were plotted against energy.

The differences had no quantative meaning because the sensitivity of the film to different energies of the x-rays was not known.

EXPERIMENTAL RESULTS

The absorption curves found in Plate III for each of the elements showed that the absorption was not a smooth function of the energy of x-rays. The maxima of the broad absorption lines which appeared on these curves were listed for each element in Table 1.

Table 1. The positions of absorptions for each element tested.

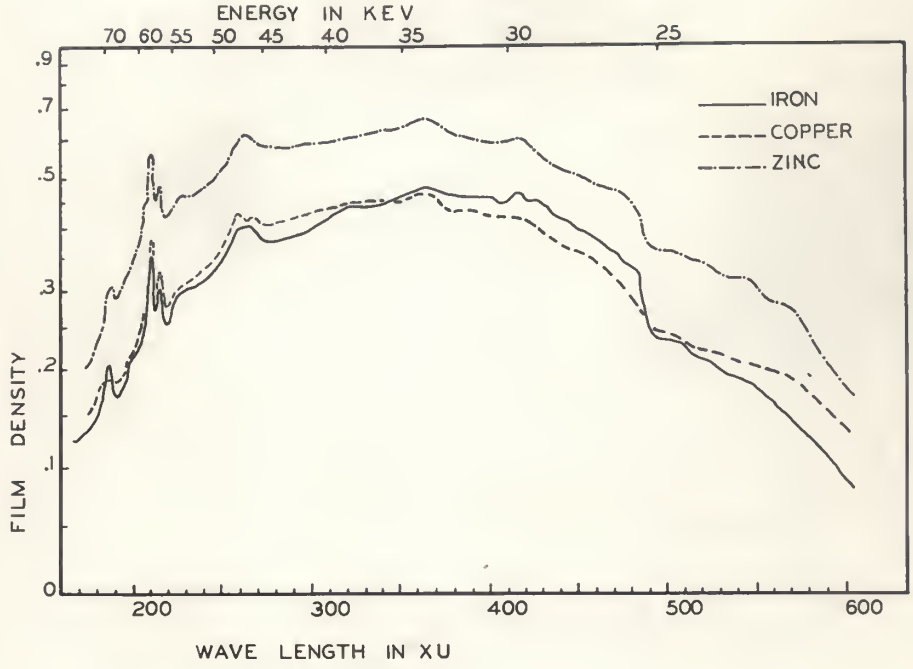
Element	:	Observed absorption (KEV)
Ca		26 49 to 58
Ni		30 43 49 57
Fe		31 56
Cu		25 50 to 56
Zn		25 48 55

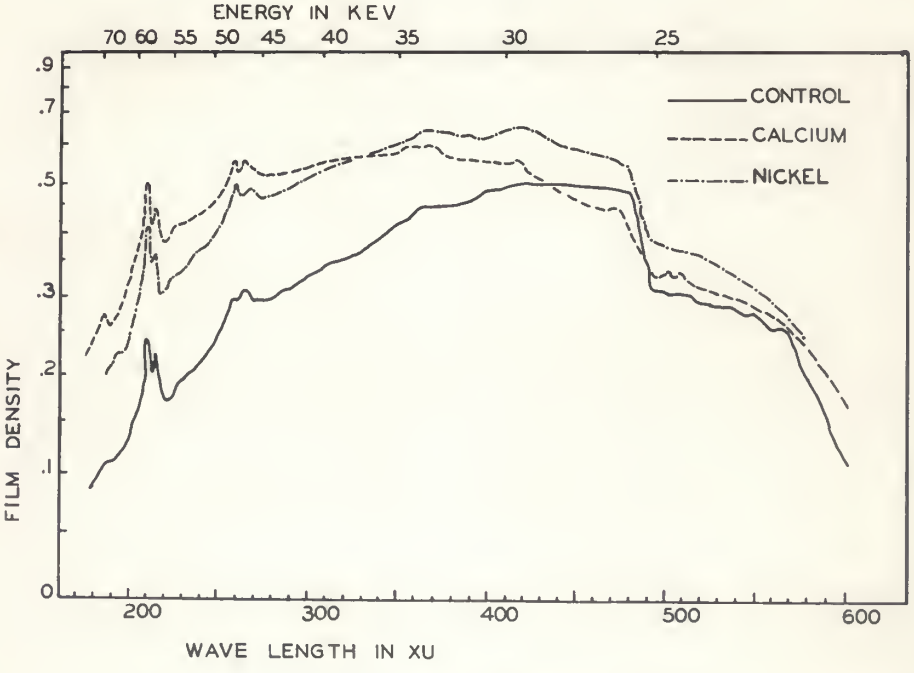
EXPLANATION OF PLATE II

Averaged densitometer traces of the films exposed with Ca, Ni, Fe, Cu, and Zn absorbers and also without an absorber.

All of the curves were drawn from averaged densitometer traces of two films exposed for each element as an absorber. Two films were exposed without an absorber for the control. Three densitometer traces were made for each film and the average of the six traces for the two films was used to make each trace shown on the plate.

PLATE II





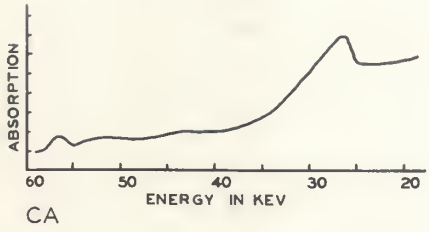
EXPLANATION OF PLATE III

Relative absorption versus energy for Ca, Ni, Fe, and Cu.

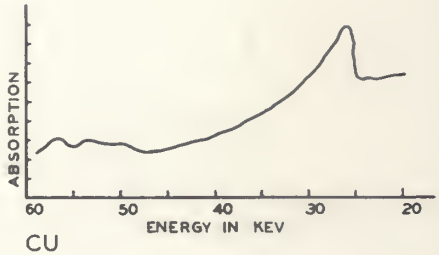
The differences of relative absorption shown, were plotted against energy. The absorption curves were obtained by taking the differences of the ordinates of the averaged densitometer trace for the control and the average trace for the particular element as the absorber (Plate II).

These differences had no quantative meaning in as much as the sensitivity of the film at different energies of x-ray was not known.

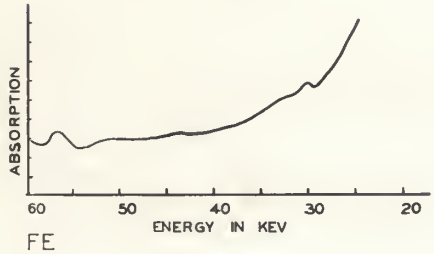
PLATE III



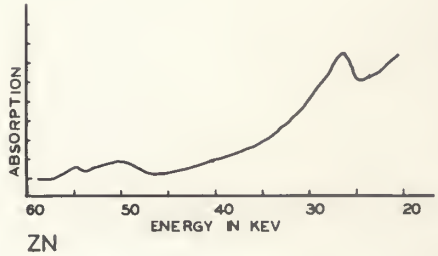
CA



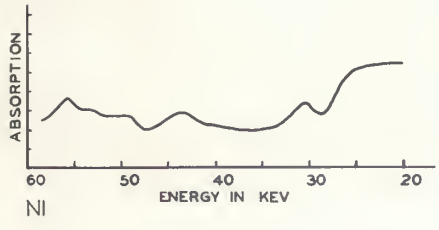
CU



FE



ZN



NI

Table 2. Calculated energy levels and calculated energy level differences compared to the observed absorptions.

Element	Energy level (KEV)	Differences (KEV)	Observed absorption (KEV)
Ca	$E_1 = 53.8$	$E_1-E_o = 53.8$	26 (52) * 49 to 58
Ni	$E_1 = 28.6$ $E_2 = 85.8$ $E_3 = 171.6$	$E_1-E_o = 28.6$ $E_2-E_1 = 57.2$ $E_3-E_2 = 85.8$ $E_4-E_3 = 85.6$	30 49 ** 57 43 (86) *
Fe	$E_1 = 31.0$ $E_2 = 93.1$	$E_1-E_o = 31.0$ $E_2-E_1 = 61.2$	31 56
Cu	$E_1 = 25.2$ $E_2 = 76.5$	$E_1-E_o = 25.2$ $E_2-E_1 = 50.4$	25 50 to 56
Zn	$E_1 = 23.8$ $E_2 = 74.1$	$E_1-E_o = 23.8$ $E_2-E_1 = 47.6$	25 48 55 **

* Values assumed to be in the second order. The value of energy in the parenthesis is the energy that does appear at that place on the film from the second order.

** Values not predicted by the Guggenheimer theory.

DISCUSSION OF RESULTS

The observed energies of absorption for each element were compared in Table 2 with the theoretical values. From this table it may be seen that most of the observed absorptions agreed with the theoretical values. Some of the values which did not agree may be explained on the basis of second order effects.

Calcium

The results in this experiment for calcium were a 49 to 58 KEV and 26 KEV absorption maxima. If the 26 KEV absorption were actually a second order effect, it would have been equivalent to 52 KEV absorption. Thus, both absorptions corresponded to an absorption at approximately 52 KEV which appeared in the first and second order. This agreed reasonably well with the Guggenheimer predicted value for the lowest absorption level for calcium, 53.8 KEV.

Nickel

Of the absorptions which did not apparently agree with the Guggenheimer theory, nickel had absorptions appearing at the 43 and 49 KEV. Since second order reflections were present on the film, the 43 KEV absorption could have been an absorption of 86 KEV x-rays appearing in the second order. The predicted value of

energy 85.8 KEV could have occurred for nickel by two methods, the E_0 to E_2 transition and the E_2 to E_3 transition. The absorption at this level was stronger because these two possible ways for the 85.8 KEV absorption existed. The absorption appearing at 49 KEV position, had no theoretical explanation in terms of the Guggenheimer theory. Future work may prove it to have been an absorption in which both electronic and nuclear energies were involved.

Zinc

The zinc absorption at 55 KEV did not have an explanation to resolve it completely with the rotational theory unless, it, too, was an absorption involving electronic and nuclear energies.

All absorptions observed with the exception of the Ni 49 KEV and Zn 55 KEV were identified with corresponding energy transitions predicted by the Guggenheimer rotational theory.

Conclusion

These results indicated that the absorption varied with the energy of x-rays and that there were maxima of absorption for particular energies of x-rays. The absorption curves were characteristic of the element. Most of the absorption maxima agreed with the theoretical values of energy levels calculated from the Guggenheimer theory. However, only five elements having

relatively close atomic mass numbers were tested and thus it was not possible to verify completely the rotational theory of nuclear energy levels. Further experiments involving more elements and quantitative measurement of absorption intensities must be performed before the nuclear rotational theory can be verified.

The experiment described in this paper, however, gave plausibility to such a theory.

ACKNOWLEDGMENT

Acknowledgment is made to Dr. R. H. McFarland, Department of Physics, for his advice and constructive criticism during this experiment and the preparation of this manuscript. Acknowledgment is also made to Professor E. V. Floyd, Department of Physics, for making the lead slit which was used in the spectrometer. Gratitude is also expressed to Dr. A. B. Cardwell, Head of the Department of Physics.

LITERATURE CITED

(1) Cork, James M.
Radioactivity and Nuclear physics. New York. D. Van Nostrand. 313 p. 1947.

(2) Guggenheimer, K. M.
On nuclear energy levels. Proc. Royal Soc. of London, 181 Series A : 169-181. 1942.

(3) Harnwell, G. P. and J. J. Livingood.
Experimental atomic physics. New York. McGraw-Hill. 472 p. 1933.

(4) Seigbahn, Manne.
The spectroscopy of x-ray. London. Oxford University Press. 287 p. 1925.