STUDIES OF NUCLEAR RESONANT
ABSORPTION OF GAMMA RAYS

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U. S. Atomic Energy Commission
Argonne, Illinois

Contract No. AT(11-1)-578
Project Agreement No. 6

"AEC Research and Development Report"

25 years of research
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STUDIES OF NUCLEAR RESONANT
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Contract No. AT(11-1)-578
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to

U. S. Atomic Energy Commission
Chicago Operations Office
9800 South Cass Avenue
Argonne, Illinois

Attn: Fred C. Mattmueller, Director
Contracts Division

(Covering the Period from June 1, 1961, to August 31, 1961)

February 23, 1962
I. INTRODUCTION

This report describes the work performed under contract No. AT (11-1)-578, entitled "Studies of Nuclear Resonant Absorption of Gamma Rays," during the period June 1 to August 31, 1961. Initial studies of the effects of magnetic fields on nuclear resonant absorption were continued and extended to include the variation in resonant absorption as a function of field strength. Two 2mc Co$^{57}$ sources were purchased and one of these sources was plated onto an Armco iron foil while the other was plated onto a No. 316 stainless steel foil. It was found that the stainless steel foil exhibited a mono-energetic resonant absorption line. This latter source, in conjunction with a No. 316 stainless steel absorbing foil, was determined to have a 40 per cent absorption, which is higher than any of our other sources. Consequently, this source will be used in future pressure and acoustical experiments. Calculations were also made to determine the feasibility of utilizing nuclear resonant absorption techniques to determine gravitational fields and to measure altitudes from space vehicles.

II. EFFECTS OF MAGNETIC FIELDS ON NUCLEAR RESONANT ABSORPTION

To determine the effect of polarizing magnetic field intensities on the fraction of nuclear resonant absorptions, a simple electromagnet was constructed. The field strengths at the 1mc Co$^{57}$ source were varied between zero and 1000 gauss while the absorber was placed between the pole pieces of a magnet having a fixed field of 800 gauss. Measurements

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were made with both parallel and perpendicular polarizing fields between
the source and the absorber. In Figure 1 the variation of transmission
intensity as a function of field strength at the emitter is shown. The results
in Fig. 1 are of a preliminary nature; however, they indicate the qualitative
trend of the variation in resonant absorption as a function of field strength
and relative polarization. The principle errors in the measurements are
due to residual fields in the electromagnet and the uncertainty in the
measured field strength. From Figure 1 it can be seen that the rate of
change of resonance absorption with magnetic field strength is greatest in
the region between 300 and 1000 gauss. Therefore, it is in this region that
magnetic field strengths would be most easily measured using this technique.
The percentage of nuclear resonant absorptions at magnetic field intensities
of one kilogauss were approximately 8.5 per cent for perpendicular fields,
26 per cent for parallel fields, and 15 per cent for no fields. Further
refined measurements, and extrapolation of results to other source-absorber
combinations, should indicate the feasibility of using nuclear resonant
absorption techniques for magnetic field intensity measurements when stand-
ard methods cannot be applied.

III- SOURCES

Two 2 mc Co\(^{57}\) sources were purchased from Nuclear Science and
Engineering Co. One source was plated on \(\frac{1}{4}\) inch diameter by 5 mil thick
Armco iron foil, and the other on a \(\frac{1}{4}\) inch diameter by 3 mil No. 316
stainless steel foil. The sources were heat treated in a hydrogen atmosphere
for approximately one hour at 950 degrees centigrade to diffuse the cobalt
into the iron and steel lattices using the furnace and associated equipment
described in ARF 1166-12. Absorption measurements were made using a 0.7 mil Armco absorbing foil to determine the per cent of resonant absorptions. A 17.5 per cent resonant absorption was obtained with the 2 mc Co$^{57}$ source plated on the 5 mil Armco iron foil. However, the 2 mc Co$^{57}$ source plated on the 3 mil stainless steel foil exhibited only a 1 per cent resonant absorption with this absorber. These absorptions are to be compared to the 21.5 per cent resonant absorption obtained with the old 1 mc Co$^{57}$ source plated onto a 3 mil Armco iron foil. Using the equipment described in ARF 1166-12, the variation in resonant absorption as a function of the relative velocity between source and absorber was investigated for the three Co$^{57}$ sources using the 5 mil Armco iron absorber. The results showed that there was no absorption at zero velocity with the stainless steel source, but that the absorption peak was displaced in energy by approximately $\frac{1}{5}$ the energy difference between the central and first Zeeman peaks of the Armco iron Co$^{57}$ source and Armco iron absorber combination. A 1 mil No. 316 stainless steel absorber foil was procured, and absorption measurements with the stainless steel Co$^{57}$ source were undertaken. With zero relative velocity between the source and absorber a 40 per cent resonant absorption was obtained. This was the highest resonant absorption obtained in this laboratory, and consequently, this source-absorber combination will be used in those experiments which do not involve magnetic fields.

IV - MEASUREMENTS OF GRAVITATIONAL FIELDS USING NUCLEAR RESONANCE ABSORPTION

Because of the successful gravitational red-shift experiments by R. V. Pound and G. A. Rebka, it was suggested that nuclear resonant absorption
techniques could be used to measure gravitational fields and altitudes from space vehicles. Calculations were carried out based on a measurement technique described in Appendix II of Annual Report (ARF 1166-12). In Table I the results of these calculations are given. A brief summary of the theoretical basis for these calculations follows.

The shift in frequency of a photon emitted at some height to the absorber, due to the difference of gravitational potentials at source and absorber, is given by

\[ \Delta \nu_h = \frac{\nu_0 G M h}{c^2 r^2 (1 + \frac{h}{r})} \]  

(1)

where \( G \) is the gravitational constant, \( M \) is the mass of the attracting body, and \( r \) is the distance from the center of the body. If the measurements are made on the surface of the earth and \( h \) is small compared to \( r \), Eq. 1 becomes

\[ \Delta \nu_h = \frac{\nu_0 g h}{c^2} \]  

(2)

where \( g \) is the gravitational acceleration. Since the shift in frequency, \( \Delta \nu_h \), can be measured using the Mossbauer effect and the technique described in Appendix II (ARF 1166-12), the acceleration due to gravity and the distance \( r \) can be calculated from the following formulae:

\[ g = \frac{c^2 K}{h \nu_0} \int \frac{D}{\rho} \]  

(3)
and a fractional error of $\sqrt{S/D}$ in g and $\sqrt{S/20}$ in r,
where K is a constant associated with the method of measurement and depends upon the fraction of resonant absorption F, S and D are the sum and difference of the measured transmissions, and $\Gamma$ is the natural line width of the emission spectrum. Expected values of K, D and S are given by

$$K = \frac{8}{3\sqrt{3}} \left( \frac{1}{F} - \frac{3}{\nu} \right)$$

$$S = R^+ + R^- = \frac{1}{2} I_0 (\nu - 3F)$$

$$D = R^+ - R^- = \frac{3\sqrt{3}}{\nu} \frac{F I_0}{\Gamma} \Delta \nu_h$$

where $I_0$ is the transmission intensity when nuclear resonant absorption is destroyed.

In Table I the various fixed parameters and some representative values for the variable parameters used in the above equations are given for two sources, Fe$^{57}$ and Zn$^{67}$. These Mossbauer sources were chosen because the expect observable line widths are extremely small. Zn$^{67}$ has a line width two orders of magnitude smaller than Fe$^{57}$, but the small fraction of recoil free gamma emissions requires the use of cryogenic techniques in any measurements involving nuclear resonant absorption in Zn$^{67}$. The intensity, $I_0$ was calculated assuming $\frac{1}{3}$ of the gammas are lost due to scattering and that the detector is a 5 cm diameter scintillator. Also

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calculated are the counting times necessary to obtain 10 per cent and 1 per cent statistical accuracy in \( g \), which corresponds to 5 and 0.5 per cent statistics in \( r \), respectively, for experiments located at the earth's surface, two earth's radii and on the lunar surface. The results shown in Table I indicate that very long counting times are required with these two sources. Consequently, the use of this technique for measurements of gravitational fields in space and space vehicles altitudes does not appear too promising. One possible improvement would be to use Zn\(^{65}\) at cryogenic temperatures, thereby increasing \( f \).

V. FUTURE WORK

With the acquisition of the new Co\(^{57}\) sources, we are now in the process of assembling the pressure equipment to determine any experimental changes in the nuclear resonant absorption due to pressure effects on the host lattice. The Co\(^{57}\)-stainless steel source will be mounted in the pressure bomb, and measurements of the fraction of nuclear resonant absorption will be made from 0 to 40,000 psi. Experimental apparatus will be constructed and assembled to carry on acoustical power measurements utilizing nuclear resonant techniques. The magnet field experiments will be refined and continued to determine the range and sensitivity of such measurements.
Fig. 1. *Transmission intensity vs. magnetic flux density about a Co$^{57}$ nuclear resonant gamma source.*
# Table I

## List of Parameters Used in Measurements of G and R, and Counting Times Necessary to Obtain Statistics in G and R

<table>
<thead>
<tr>
<th></th>
<th>Fe(^{57})</th>
<th>Zn(^{67})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\nu_0)</td>
<td>(3.48 \times 10^8) cycles/sec</td>
<td>(2.24 \times 10^9) cycles/sec</td>
</tr>
<tr>
<td>(r)</td>
<td>(1.1 \times 10^6) cycles/sec</td>
<td>(1.18 \times 10^4) cycles/sec</td>
</tr>
<tr>
<td>(F)</td>
<td>0.3</td>
<td>0.01</td>
</tr>
<tr>
<td>(h)</td>
<td>20 meters</td>
<td>2 meters</td>
</tr>
<tr>
<td>Source Strength</td>
<td>16.5 curies*</td>
<td>0.2 curies*</td>
</tr>
<tr>
<td>(I_0)</td>
<td>(5 \times 10^4) counts/sec</td>
<td>(5 \times 10^4) counts/sec</td>
</tr>
<tr>
<td>(D)</td>
<td>(1.77 \times 10^{-2}\ \nu_h) counts/sec (cps)</td>
<td>(5.5 \times 10^{-2}\ \nu_h) counts/sec (cps)</td>
</tr>
<tr>
<td>(S)</td>
<td>(7.75 \times 10^4) counts/sec</td>
<td>(9.9 \times 10^4) counts/sec</td>
</tr>
<tr>
<td>(r)</td>
<td>earth's surface</td>
<td>2 earth's radius</td>
</tr>
<tr>
<td>(\Delta \nu_h)</td>
<td>(7.6 \times 10^3) cps</td>
<td>(1.9 \times 10^3) cps</td>
</tr>
<tr>
<td>time for 10% in g, 5% in r</td>
<td>(\sim 7.1) min</td>
<td>(\sim 114) min</td>
</tr>
<tr>
<td>time for 1% in g, (\frac{1}{2})% in r</td>
<td>(\sim 12) hours</td>
<td>(\sim 8) days</td>
</tr>
</tbody>
</table>

* The internal conversion coefficients were assumed to be 15 and \(\frac{1}{2}\) for Fe\(^{57}\) and Zn\(^{67}\) respectively.
VI- LOGBOOKS AND PERSONNEL

The following personnel have contributed to the work described in this report: J. J. Ezop, I. Filosofo and C. A. Stone. Data pertaining to this program can be found in ARF logbooks C 10519, C 11411, and C 11618.

Respectfully submitted,

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