using this γ ray from Fe^{57}. With the line width we have found, a measurable shift of the line center is predicted by the principle of equivalence[9] for the height difference available to us inside this laboratory.

With a source of limited strength, statistical fluctuations decrease the definition of the line, owing to decreased counting rates, in a way that just compensates, assuming the inverse square law to apply over the path, the linear increase in shift as the height difference between source and absorber is increased. Use of very large vertical distances do not appear to offer much increase in precision.

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RECOILLESS RESONANCE ABSORPTION OF GAMMA RAYS IN Fe^{57}

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The recent observation that at low temperatures gamma-ray absorption and emission could take place without recoil,[1,2] has led to the suggestion that it might be of use in measuring hyperfine splittings of gamma-ray lines caused by effective magnetic fields acting on the magnetic moment of the nucleus.[2] This technique would be of particular interest in ferromagnets and antiferromagnets where other methods of measuring these fields are severely limited.

A particularly favorable case for recoilless emission or absorption is in the decay of the 14-kev first excited state of Fe^{57}. Here the Debye-Waller factor predicts that at room temperature 63% of the gamma rays should be emitted without recoil. A source of Co^{57} has been prepared by bombarding a 0.0005-in. Fe foil by 4-Mev deuterons from the Harwell Van de Graaff accelerator. An absorber of a similar Fe foil (containing 2.2% Fe^{57}) was used with a xenon-filled proportional counter to detect the 14-kev radiation. The source was mounted on the diaphragm of a loud speaker. The number of gamma rays emerging from the absorber with the source moving with a velocity large compared to the width of the line was approximately 20% larger than the number of gamma rays with the source stationary. This can be compared with the 1-2% absorption which has been reported at low temperatures previously.[1,2] This is approximately in agreement with the effect expected from the above Debye-Waller factor assuming the line to be split by the hyperfine interaction (if the latter were zero the effect would have been several times larger). The effect could be increased by using enriched Fe. Cooling the source to liquid air temperatures would increase the effect only by about 40%.

Since the magnetic field in Fe is expected to be approximately 200 kilogauss, one would expect the hyperfine splitting to be several times the line width of 4.5×10^{-9} ev even for the ground-state magnetic moment of 0.05 nuclear magneton. The excited state presumably will have a larger magnetic moment and thus give rise to even larger splittings. It should be very easy to introduce Fe^{57} into various alloys and compounds and obtain relative values of the hyperfine fields. These could also be measured easily as a function of temperature. Apparatus for such experiments is under construction.

It has been suggested by T. E. Cranshaw that the size of the absorption and the narrowness of the line makes this an ideal case for measuring

the gravitational red shift of a photon. At a height of 20 meters this would produce a shift in the energy of the gamma rays which would be 1% of the width. With a one-curie source of Co^{57}, this effect would be measured with 10% accuracy, in 20 hours of counting. An experiment to measure this is also under way in collaboration with Dr. Cranshaw and awaits the successful preparation of a source of sufficient intensity.[3]

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[3]After the conception of this last experiment it came to our attention that this application of recoilless resonance absorption has also been proposed by D. H. Wilkinson and by A. Boyle and S. Devons several months before us. It has also been suggested more recently by R. V. Pound and G. A. Rebka, Jr., Phys. Rev. Letters 3, 439 (1959).

NUCLEAR FRAGMENTS PRODUCED IN THE HEAVY ION BOMBARDMENT OF ALUMINUM*

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We have observed reaction products ranging from lithium to fluorine produced by bombarding aluminum with 160-Mev oxygen ions. The data were taken by means of a plotting oscilloscope which recorded the energy and rate of energy loss of each particle. The energy detector was a CsI scintillator and the dE/dx detector was a short proportional counter. A photographic record of 2000 particles is shown in Fig. 1. Each spot represents a detected particle. Its location on the photograph is determined by its energy and its rate of energy loss. Each curved line represents particles of the same Z, since dE/dx is approximately proportional to MZ^2/E. This simple relationship is modified by the dependence of the pulse-height response of CsI on the type and energy of particle[1] as well as by the dependence of the effective charge of the particle on energy. In principle each curve could be further separated into isotopes. The lack of separation may be due to insufficient detector resolution but also may be due in these photographs to the ratios of yields of different isotopes, i.e., an isotope in large yield may obscure small yields of adjacent isotopes.

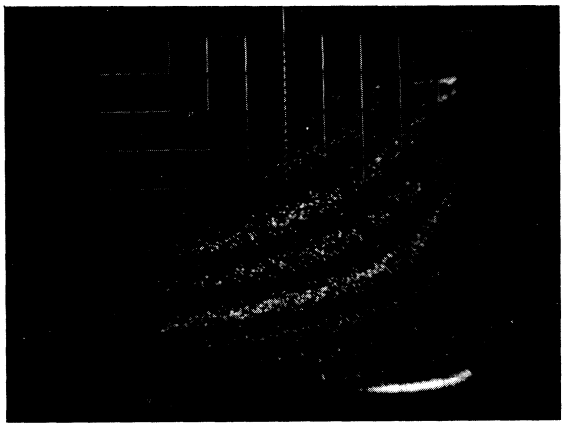

FIG. 1. Photographic record of nuclear fragments emitted at 15° in the bombardment of Al by 160-Mev oxygen ions. E increases to the left and dE/dx increases upward. The three most prominent lines in the center are due to oxygen, nitrogen, and carbon fragments; the solid line at the bottom is due to helium; also visible but less conspicuous are lines due to lithium, beryllium, boron, and fluorine and a few heavier fragments.

The energy spectrum and angular distribution in the laboratory for each element can be determined by counting and measuring the CsI pulse-height coordinates of spots on photographs. Photographs to be counted are limited to about 200 particles to reduce the possibility of overlapping spots.

Preliminary results obtained from 10 photographs at each angle of observation are shown in Figs. 2 and 3. Figure 2 shows the total number of particles emitted of each element (independent of energy) as a function of laboratory angle. Figure 3 shows the energy spectra of emitted carbon fragments in the center-of-mass system at various center-of-mass angles. The center-of-mass transformation was made assuming that the carbon fragments were of mass 12.

Table I gives the total cross section for the production of each element obtained by numerical integration of the yield as a function of the labor-