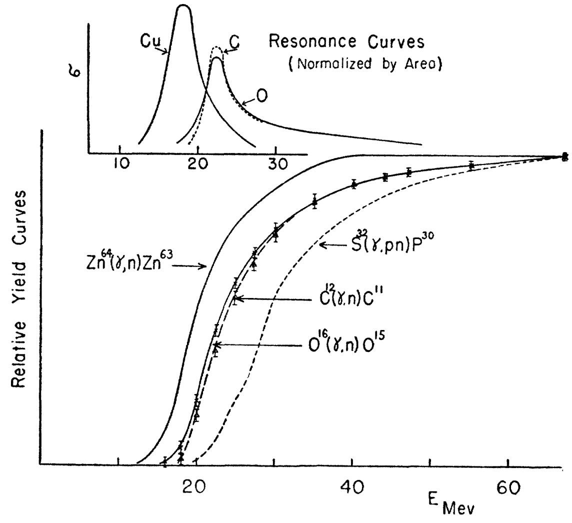

FIG. 1. Relative yield curves for C^{12} and O^{16}. Curves for S^{32} and Zn^{64} are also given for comparison.

several samples and monitors at normal incidence. The relative activity induced in the samples was thus independent of the dependence of geometrical beam-width upon energy.

The relative yield curves[3] for C^{11} and O^{15}, with C^{62} as a monitor, are given in Fig. 1. (In constructing these curves a correction has been made for the appreciable cross section possessed by copper at energies as high as the carbon and oxygen thresholds.)[4] The corresponding cross-section curves, computed by the method previously reported,[2] are also shown in Fig. 1. It is noteworthy that these resonances are quite similar, each being markedly asymmetrical and exhibiting a prominent high energy "tail" which extends to over 60 Mev. The carbon and oxygen resonances may be contrasted with the more common type illustrated by the copper curve reproduced in Fig. 1.

The high energy cross sections for carbon and oxygen are roughly proportional to E^{-3}, which suggests that this portion of the curve may be interpreted in terms of the nuclear photoeffect.[5] Additional evidence for this process is found in the reported[6] 90° excess of neutrons from carbon. Similar high energy tails have been found and are now under further investigation for the reactions $S(\gamma, pn)$, $Pb(\gamma, p$ or $\gamma, pn)$, $Al(\gamma, 2p)$, $Zn(\gamma, n)$, $Mg(\gamma, p$ or $\gamma, pn)$, and $Fe(\gamma, n)$.

The resonance curves for the reaction $C^{12}(\gamma, n)C^{11}$ as determined in the present work and as reported by other workers,[7-9] may be compared in Fig. 2. The main peak of the resonance found here agrees well with that given in the recent report of Katz and Cameron[7] if the energy scale of the synchrotron is adjusted to an 18.8-Mev C^{12} threshold. The author wishes, however, to draw attention to the existence of the long tail appearing at high energies and to the support which this may provide for the nuclear photoeffect.

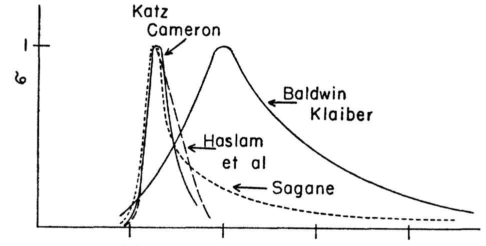

FIG. 2. Comparison of the resonance curves for $C^{12}(\gamma, n)C^{11}$ reported by different workers.

The author wishes to express his heartiest gratitude to Dr. L. J. Laslett and Dr. D. J. Zaffarano for their continued interest and help given during the course of the experiment.

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The Decay of Fe^{52}*

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A 7.8-HOUR iron activity emitting ~0.55 Mev positrons was found by Miller, Thompson, and Cunningham[1] as a product of the bombardment of copper with high energy deuterons. They identified this iron isotope as Fe^{52} through the growth of the well-known 21-minute Mn^{52}.

In order to measure yields of Fe^{52} in various spallation reactions, it is necessary to know what fraction of the Fe^{52} decays occur by electron capture. A search for manganese *K* x-rays resulting from electron capture in Fe^{52} was therefore undertaken by means of a proportional counter and pulse height analyzer.[2] Samples of Fe^{52} were prepared by bombardment of copper with 370-Mev protons in the circulating beam of the Columbia University Cyclotron at Nevis. The iron activity, with a fraction of a milligram of carrier, was purified by a procedure which involved carrying on $Al(OH)_3$, isopropyl ether extractions, and a separation from gallium by $Fe(OH)_3$ precipitation in 3*M* NaOH. The final samples were precipitated as $Fe(OH)_3$ from neutral solution on 0.1 mg/cm² Nylon.

Manganese *K* x-rays were found with a pulse height analyzer in conjunction with a proportional counter filled to one atmosphere with argon and methane. The decay of these x-rays could be analyzed into an 8-hour half-life and a very long-lived component, presumably due to Fe^{55}. The samples were rather weak and it was therefore not practical to obtain the total x-ray counting rate from the area under a pulse height distribution curve as previously described.[3] Instead, the peak counting rate was compared with that of an Fe^{55} standard sample whose total x-ray counting rate in turn was determined from the area under its pulse height distribution curve. With appropriate corrections[3] for geometry, counter efficiency, air and window absorption, fluorescence yield (0.27),[4] and *L* capture contribution (8.5 percent),[5] the absolute electron capture decay rate of Fe^{52} in the sample was calculated.

To determine the absolute positron disintegration rate of the Fe^{52} sample, counts were taken with an end-window GM tube, provided with a geometry-defining opening in front of the window. By means of beryllium and aluminum absorption measurements, the contributions of x- and γ-rays to the GM counting rate, and the attenuation of positrons by the air and mica window were determined. Small corrections were also made for long-lived activities (Fe^{59} and Fe^{55}). From the corrected counting rate and the calculated solid angle the sum of the absolute positron disintegration rates of Fe^{52} and of 21-minute Mn^{52} in equilibrium with it was determined. Decay curves of Fe^{52} showed no tail attributable to 5.8-day Mn^{52}. It was thus established that at least 95 percent of the Fe^{52} decays go to the 21-minute Mn^{52} isomer. From the electron capture and positron decay rates of the sample and the fact that

21-minute Mn^{52} decays 99.95 percent by positron emission,[6] the electron capture to positron ratio for Fe^{52} was found to be 1.6±0.4.

The Fe^{52} decay undoubtedly proceeds by an allowed transition ($\log ft \sim 4$). One can therefore deduce[7] a maximum positron energy of 640±40 kev for Fe^{52} from the measured electron capture to positron ratio of 1.6±0.4. Absorption measurements on sources of Fe^{52} in equilibrium with Mn^{52} gave an end point for the low energy β^+ component compatible with this energy. The presence of the 2.7-Mev positrons of Mn^{52} makes an accurate determination of the Fe^{52} end point difficult.

Scintillation spectrometer measurements of an Fe^{52} sample in equilibrium with Mn^{52} showed the presence of annihilation radiation and of a γ-ray of about 1.5 Mev. Immediately after a manganese-iron separation, the Fe^{52} exhibited only annihilation radiation. The subsequent growth of the 1.5-Mev γ-ray was observed. It may be concluded that Fe^{52} emits no γ-rays of energy greater than 0.5 Mev in appreciable abundance.

For intensity reasons, the γ-ray measurements just described were made with Fe^{52} samples produced by the bombardment of chromium with 30-Mev helium ions according to the reaction Cr$^{50}(\alpha, 2n)$. However, the Fe^{52} so obtained could not be used for the determination of the electron capture to positron ratio because of the preponderance of Fe^{55} produced by the Cr$^{52}(\alpha, n)$ reaction.

We are indebted to the operating staff of the Nevis Cyclotron Laboratory for the proton bombardment, and to Dr. P. Abelson of the Department of Terrestrial Magnetism who kindly performed the helium ion bombardment of chromium.

* Work performed under the auspices of the AEC.
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Yields of Iron Isotopes in High Energy Nuclear Reactions*

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The determination[1] of the electron capture to positron ratio in Fe^{52} has made it possible to obtain directly the relative disintegration rates of Fe^{52} and Fe^{55} in a sample by comparison of the 8-hour and long-lived Mn x-ray activities as measured with a proportional counter and pulse-height analyzer.[2] Such measurements have been carried out on iron samples separated from cobalt and copper targets bombarded with 370-Mev protons in the circulating beam of the Columbia University cyclotron at Nevis. With thin targets (~5-Mev energy loss) the ratios of formation cross sections (σ_{55}/σ_{52}) were 136±20 and 168±25 for cobalt and copper targets, respectively. With a thick copper target (energy loss ~60 Mev) a ratio of 206±30 for (σ_{55}/σ_{52}) was obtained. Although it is not certain that the difference between the results for the thick and thin copper targets is real, it is in the expected direction since the energy loss of the protons in the thick target would tend to reduce the Fe^{52} yield more than the Fe^{55} yield.[3]

The rather high cross section for the formation of Fe^{55} relative to that for Fe^{52} is of interest in connection with the results of Bartell *et al.*[4] They reported alternating high and low yields for successive atomic numbers among the products of the bombardment of copper with 190-Mev deuterons. Since they did not investigate the Fe^{55} yield, their observation that the yield of iron was low compared with that of manganese would be modified if the relative yields of Fe^{55} and Fe^{52} in their bombardment were similar to those found here. That this may be so is indicated by the fact that the ratio of formation cross sections for Fe^{59} and Fe^{52} was similar in the two cases; Bartell *et al.* reported $(\sigma_{59}/\sigma_{52})=20$ while, by absolute beta- and x-ray counting, we found $(\sigma_{59}/\sigma_{52}) = 45\pm 15$ in the bombardment of the thick copper target.

It is interesting to note that in our copper bombardment the yield of Fe^{55} is significantly higher than that of either Fe^{52} or Fe^{59}. This result is qualitatively consistent with the emission of nucleons by evaporation and "knock-on" processes.

It is a pleasure to express our gratitude to the operating staff of the Nevis Cyclotron Laboratory.

* Work performed under the auspices of the AEC.
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Coupling among Nuclear Magnetic Dipoles in Molecules*

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MULTIPLE nuclear magnetic resonance lines have been reported in several liquids, such as the Sb resonances[1] in aqueous NaSbF$_6$, and the P^{31} and F^{19} resonances[2] in POCl$_2$F, POClF$_2$, and CH$_3$OPF$_2$. Suggested interpretations of these effects include hindrance to molecular rotation[1-3] and second-order magnetic dipolar interactions.[4] We feel that new measurements of ours, together with the previously published results,[2] exclude both of the above suggestions, in general, and we would like to propose the hypothesis that the splittings come from a second-order interaction between the nuclear magnetic moments and some magnetic field internal to the molecule.

Significant experimental facts seem to be as follows. (1) The splitting is associated with the nuclear magnetic moments since $\delta H_A/\delta H_B=\mu_B/\mu_A$, where δH is the multiplet separation.[2] (2) Nuclei of the same species do not interact when they are in chemically equivalent positions in a molecule.[2] As an additional example, in HPF$_6$ we observe that P splits the F-resonance into two components and the F split the P into seven components, but there is no observable splitting of the F-resonances by the fluorines acting among themselves. (3) The relative intensities and number of components of a line A are determined by the statistical weights and the number of possible spin states of the B which cause the splitting.[2] Note that B have been in chemically equivalent positions in the twelve compounds we have observed thus far. (4) Our recent experiments show the splittings are independent of temperature and the strength of the static field H$_0$. The splittings remain the same in CH$_3$OPF$_2$ and POCl$_2$F from room temperature until the narrow components diminish in intensity and are lost in a broadening background line at about −80°C. (5) Although the splittings are several tenths of a gauss, we have found in almost all cases that the components are at least as narrow as the 0.01-gauss magnet inhomogeneity over the sample. (6) The P^{31}-resonances in PF$_3$ and PH$_3$ are quadruple with splittings of 0.82 and 0.10 gauss, respectively. The ratio of these splittings is 8.2 while the calculated ratio of the magnetic dipolar fields (μ/r^3) is about 0.7.

On the basis of these facts, we feel there are the following crucial objections to:

Rotational hindrance: In this case identical nuclei should interact, counter to observations. It is difficult also to reconcile any restriction of molecular tumbling with the observed narrow line widths or with the observed temperature independence of the splittings. Moreover, in the case of HPF$_6$, the phosphorus resonance has seven components, not nine as predicted by Andrew's analysis.[3] The evidence concerning NaSBF$_6$[1] is not conclusive al-