excitation of electron 1 into higher p states, while s_1 and d_1 are s and d functions, respectively, which describe the excitation of electron 2. The first-order overlap $\Psi_0\Psi_1$ does not contribute to q' because $s_0(1)$ is orthogonal to $p_1(1)$ and $p'_1(1)$, and similarly $p_0(2)$ is orthogonal to $s_1(2)$ and $d_1(2)$. However, Ψ_1^2 contributes three second-order terms to q' which arise from $[p_1(1)]^2$, $[p'_1(1)]^2$, and $[d_1(2)]^2$. Second-order terms of the type Ψ_1^2 are also obtained from the simultaneous P_1^m excitation of a core electron in a p state and the valence electron. A similar class of terms is obtained using the P_2^m part of e^2/r_{12}. These terms were not evaluated because of the difficulty of determining the functions of type p_1, s_1, p'_1, and d_1. Thus p_1 and s_1 satisfy a set of two simultaneous differential equations. The same applies for p'_1 and d_1. The numerical solution of these sets would be much more complicated than the solution of Eqs. (5A) and (24A) which involve a single unknown function. However, there seems to be no reason to believe that the two-electron terms would be appreciably larger than the one-electron excitation terms which were shown to be very small for the case of Cl.

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Cross Sections for the Reactions $Ti^{48}(d,2n)V^{48}$; $Cr^{52}(d,2n)Mn^{52}$; and $Fe^{56}(d,2n)Co^{56}$†

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Measurements have been made of the $(d,2n)$ cross sections of the nuclear species Ti^{48}, Cr^{52}, and Fe^{56}. Results are given for incident deuterons in the energy region 1–20 Mev.

THE cross sections for the reactions $Ti^{48}(d,2n)V^{48}$, $Cr^{52}(d,2n)Mn^{52}$, and $Fe^{56}(d,2n)Co^{56}$ have been measured as functions of energy of the bombarding deuterons, using the conventional stacked foil method, for energies of 1 to 20 Mev. A beam of deuterons was provided by the 60-inch cyclotron of the Crocker Laboratory of the University of California.

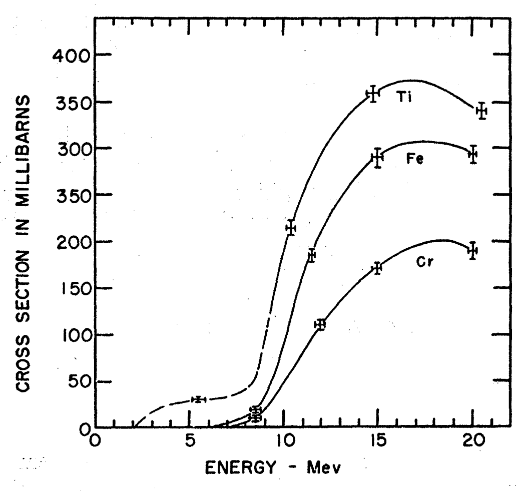

FIG. 1. Cross sections for the reactions $Fe^{56}(d,2n)Co^{56}$, $Cr^{52}(d,2n)Mn^{52}$, and $Ti^{48}(d,2n)V^{48}$.

The range distribution of deuterons in the beam, which was collected in a Faraday cup, was measured before each run by placing absorber foils of known thickness of aluminum in the beam and measuring the charge I_f collected on the foils, and the charge I_c passing through the foils and collected by the Faraday cup. These charges were measured by two electrometers and recorded. The ratio $I_c/(I_c+I_f)$ was determined as a function of thickness of aluminum absorber, giving the range distribution of deuterons. The target foils of Ti metal, Fe metal, and stainless steel were then placed in the beam and bombarded. The beam current was monitored by reading both I_c and I_f. The equivalent Al thickness of the target foils was determined by placing Al foils of varying thickness behind the target foil in the beam and again measuring $I_c/(I_c+I_f)$. Comparison of this measurement with that for the Al absorber foils determined the equivalent aluminum thickness of the stack of target foils and thereby the energies of the deuterons that struck each foil in the target stack.

Absolute cross-section measurements were made by chemical separation of the end products, with subsequent absolute β^+ counting. The absolute counting was done using a thin-window methane-flow proportional counter and correcting for scattering and absorption. The results for V^{48} and Mn^{52} were checked by 4π counting of very thin samples, and good agreement was obtained.

The absolute cross-section values depend on the fact that the end products of the bombardment decay

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partly by β^+ emission and partly by electron capture. It was assumed for V^{48} that 58 percent of the disintegrations were by β^+ emission and 42 percent by electron capture.[1] For Mn^{52}, 35 percent of the disintegrations were taken to be β^+ emission.[1] No effort was made to measure the 23-minute Mn^{52} isomer. For Co^{56} the disintegration rate was arbitrarily multiplied by four, since it is reported that K capture is at least three times as abundant as positron emission.[2] Thus the Fe cross section is a lower limit.

Corrections were made for the energy spread in the incident beam, as determined from the range distribution. The β^+ activities were corrected for the fact that the momentum of the incident deuteron sometimes carried the resultant struck nucleus out of the target foil.

The excitation functions are shown in Fig. 1. Individual experimental points could not be presented, as their identity was lost in the process of making corrections for the energy distribution of the deuteron beam. This process consisted of an inverse folding operation, carried out numerically on an IBM Card-Programmed Calculator. The vertical errors shown on the excitation function curves were estimated from the reproducibility of the shape of the excitation function. The horizontal errors represent the uncertainty in the energy of the incident deuterons. The uncertainty in the absolute cross-section scale, deriving principally from uncertainties in absolute β^+ counting efficiency, is estimated at ± 10 percent. No estimate is included for the possible errors in the values taken for β^+/K-capture.

The shelf at the low-energy end of the titanium curve is thought to represent a contribution from the $Ti^{47}(d,n)$-V^{48} reaction, which could not be avoided without the use of targets depleted in Ti^{47}.

Half-lives measured during the course of this experiment were:

$$T_{\frac{1}{2}} \text{ of } Mn^{52} = 5.60 \pm 0.01 \text{ days},$$

$$T_{\frac{1}{2}} \text{ of } V^{48} = 16.25 \pm 0.17 \text{ days},$$

$$T_{\frac{1}{2}} \text{ of } Co^{56} = 77.2 \pm 0.80 \text{ days}.$$

Some indications were given by the form of the experimental data that a small dip in the excitation function for the $Ti^{48}(d,2n)V^{48}$ reaction may be present at about 16 Mev. The evidence that has been accumulated is insufficient to settle this point at present, but it is hoped that further work may clear it up. We also plan to carry out a measurement of that part of the $Cr^{52}(d,2n)Mn^{52}$ excitation function leading to the 23-minute Mn^{52} isomer, in order to provide a Cr excitation function that will be more directly comparable to those given for Ti and Fe, which represent the total $(d,2n)$ cross section rather than just part of it.

[1] Good, Peaslee, and Deutsch, Phys. Rev. **69**, 313 (1946).
[2] L. G. Elliott and M. Deutsch, Phys. Rev. **64**, 321 (1943).

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n-γ Coincidences Produced by Inelastic Scattering of Neutrons

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Scintillation spectrometer analysis of the gamma-ray spectrum arising from interaction of 3.2-Mev neutrons with chromium shows several gamma rays including a very pronounced 1.43-Mev line. Coincidence observations indicate that there are a negligible number of gamma rays in cascade with the 1.43-Mev line. Thus the residual nucleus is left in the 1.43-Mev state by emission of a neutron which carries off the remaining portion of the energy. The energy distribution of this group of inelastically scattered neutrons as deduced from the coincidence pulse-height distribution of recoil protons in a stilbene detector has a maximum at 1.5 Mev.

THE particular level structure of chromium is such that inelastic scattering of neutrons yields relatively simple spectra that permit the spectrum of both scattered neutrons and gamma rays to be deduced. Spectral distribution of gamma rays shows several different energy lines and is in agreement with results of Peacock and Deutsch[1] on the decay of Mn^{52}. γ-γ coincidence observations[2] of Cr excited by 3.2-Mev neutron bombardment indicate that few gamma rays are in coincidence with the strong 1.43-Mev line. This indicates that chromium is left in the 1.43-Mev excited state by emission of a group of inelastically scattered neutrons of energy $E_n = [(52/53) \times 3.2 - 1.43] \cong 1.71$ Mev. To verify that this supposition is correct the spectral distribution of neutrons in coincidence with the 1.43-Mev gamma ray have been observed.

DESCRIPTION OF EXPERIMENTS

Figure 1 illustrates the basic experimental arrangement of which various modifications were made by substitution of one type of scintillation detector for

[1] W. C. Peacock and M. Deutsch, Phys. Rev. **69**, 306 (1946).
[2] Scherrer, Allison, and Faust, Phys. Rev. **94**, 791 (1954).