LOW-ENERGY EXCITED STATES OF ^{54}Mn

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The low-energy excited states of ^{54}Mn were investigated by means of the reaction ^{54}Cr$(p, n)^{54}$Mn at a proton energy of 2.7 MeV. The energy of the first two excited states, being (54.3 ± 0.5) keV and (156.9 ± 1) keV, respectively, were determined from the internal conversion electron spectrum. The ratio of internal conversion coefficients, $\alpha_K/(\alpha_L+\alpha_M)$, for the 54.3-keV transition was found to be 7.1 ± 1.

1. *Introduction*

The ^{54}Mn nucleus is unstable and cannot be obtained from the decay of neighbouring nuclides. The only way of investigating its excited states is to make use of one of the several possible nuclear reactions, sustained in a continuous beam of bombarding particles, which give ^{54}Mn as the final product.

The experimental data concerning the excited states of ^{54}Mn available hitherto had been obtained from the nuclear reactions: (p, n) [1], (p, d) [2], (p, α) [3,4], (d, t) [5, 6] and (d, α) [7].

The authors of the papers [1]–[7] dealt with the energies of the excited states and determined them with an accuracy worse than 12 keV. Johnsson *et al.* [8] were the first to examine the transitions between the excited states by utilizing the decay of 1209-keV resonance in the reaction ^{53}Cr (p, γ) ^{54}Mn. In this work the energy values of the low-energy gamma transitions are burdened with a large error.

The present study of the ^{54}Mn nucleus by beta spectroscopy was intended to give more complete characteristics of its excited states.

2. *Experimental*

^{54}Mn in the excited states was obtained by means of the reaction ^{54}Cr (p, n) ^{54}Mn sustained in a continuous beam of protons. Near the reaction threshold the cross section for the (p, n)

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reaction largely depends on the energy of the protons. For the utilized reaction the value of Q is -2.16 ± 0.07 MeV [9]. In this experiment the protons had an energy of 2.7 MeV.

Figure 1 shows a diagram of the experimental apparatus and geometry.

The internal conversion electron spectrum was measured with an adapted magnetic lens beta spectrometer, which is a part of a double Gerholm type spectrometer [10]. In the place of the source chamber a target chamber was substituted, and in it the target was set

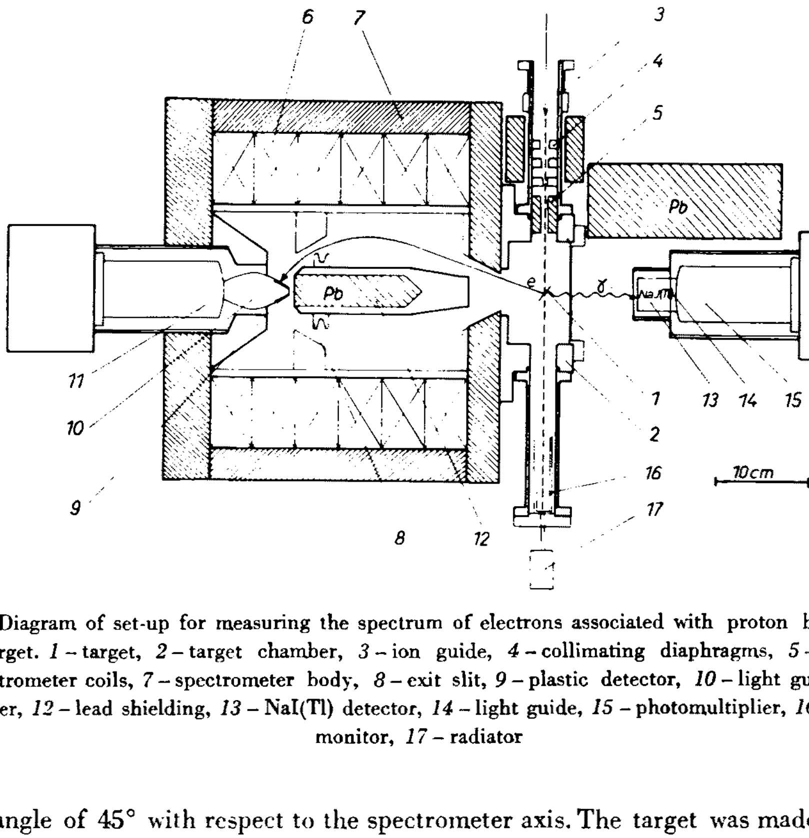

Fig. 1. Diagram of set-up for measuring the spectrum of electrons associated with proton bombardment of ^{54}Mn target. *1* – target, *2* – target chamber, *3* – ion guide, *4* – collimating diaphragms, *5* – lead shielding, *6* – spectrometer coils, *7* – spectrometer body, *8* – exit slit, *9* – plastic detector, *10* – light guide, *11* – photomultiplier, *12* – lead shielding, *13* – NaI(Tl) detector, *14* – light guide, *15* – photomultiplier, *16* – beam current monitor, *17* – radiator

at an angle of 45° with respect to the spectrometer axis. The target was made from Cr_2O_3, enriched in ^{54}Cr to 78%, deposited on thin Al or C backings. The effective thickness of the target was approx. 100 μg/cm^2. The beam was focussed on the target by means of a set of two quadrupole lenses. One monitor was placed in the prolonged path of the beam, which at the target was 3 mm in diameter at a current of approx. 2 μamp. The second beam monitoring was accomplished by measuring the gamma radiation from the (p, p') reaction that takes place in the thin aluminium backing. The gamma probe was encased in a layer of lead 10 cm thick. The electron detector in the spectrometer consisted of plastic scintillator glued to the light guide and an RCA 5819 photomultiplier. The beta spectrometer was powered by a stabilized, automatically controlled *d.c.* power unit. The electronic arrangement used enabled us to make $(e^- - \gamma)$ coincidence measurements.

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3. *Analysis of obtained results*

During bombardment of the ^{54}Cr target the reaction (p, n) took place, giving in result ^{54}Mn nuclei in excited states.

Figure 2 presents a spectrum, measured with a 1.5″×1.5″ NaI(Tl)detector, of the gamma radiation associated with various processes occuring in the target and collimating diaphragms during execution of the experiment. In the observed gamma spectrum a small part of this radiation is from transitions between the excited states of ^{54}Mn. A large part of the spectrum is due to proton bremsstrahlung and Pb X-radiation arising at the diaphragms. The strong 380-keV peak comes from a transition of ^{53}Mn, produced in the reaction ^{53}Cr$(p, n)^{53}$Mn (the target contained about 10% ^{53}Cr, whose cross section for the (p, n)

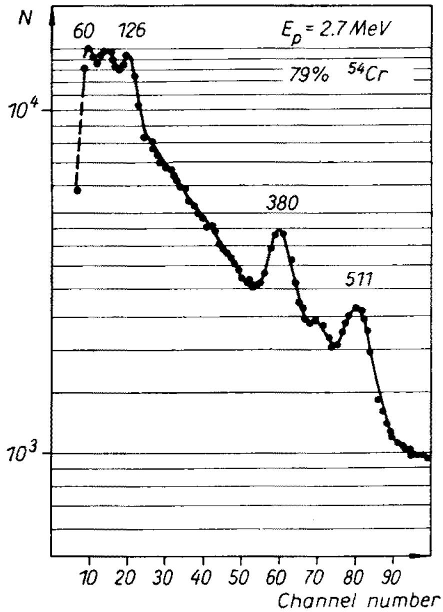

Fig. 2. Spectrum of gamma radiation associated with various processes during bombardment of ^{54}Cr enriched Cr_2O_3 target with 2.7-MeV protons

reaction for 2.7-MeV protons is much larger than for ^{54}Cr). The 511-keV peak corresponds to annihilation quanta accompanying most experiments made directly in a beam of bombarding particles. At higher energies there are peaks of energies of 1430 keV and 835 keV which come from the (p, p') reaction on the ^{52}Cr and ^{54}Cr isotopes. It is impossible to get any information about the excited states of ^{54}Mn by measuring the simple gamma spectrum because the transitions between these states are obscured by the strong radiation emitted during other processes.

The measured spectrum of internal conversion eletrons is depicted in Fig. 3. The obtained lines are interpreted as transitions from the first and second excited states to the ground state (the energy-level diagram is shown in Fig. 4). The results of the coincidence measurement (time resolution of coincidence arrangement was approx. 0.5 μs) of electrons corresponding

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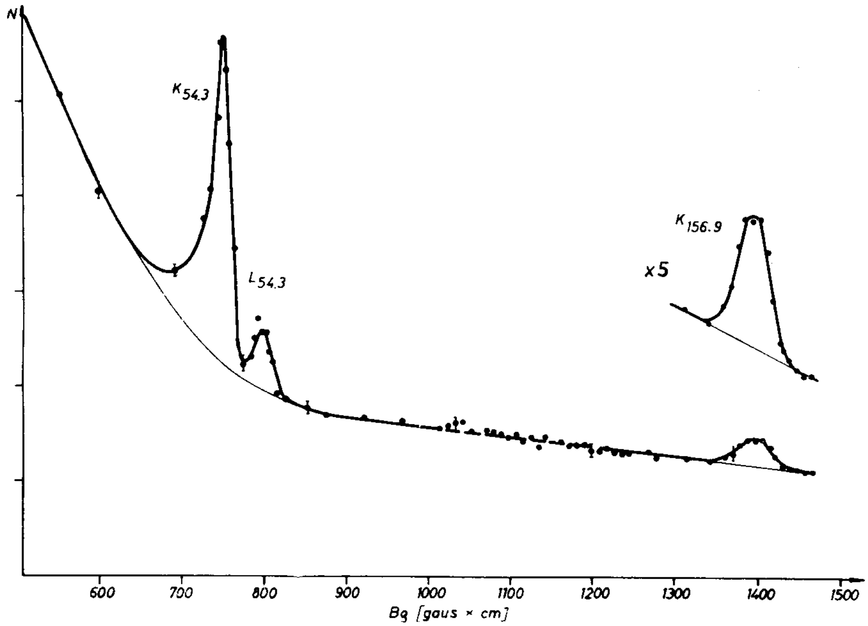

Fig. 3. Internal conversion electron spectrum of transitions in ^{54}Mn associated with the reaction ^{54}Cr(p, n)^{54}Mn

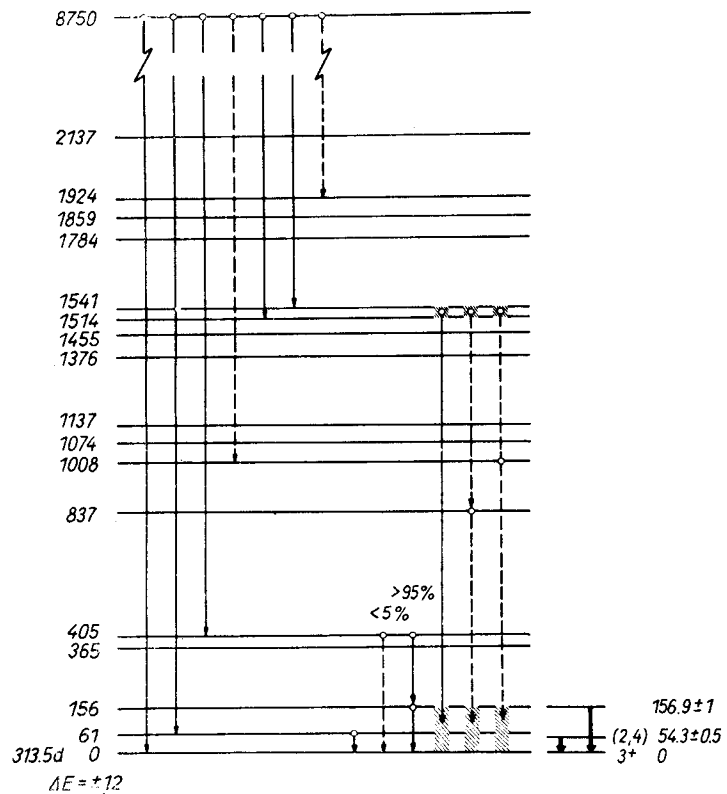

Fig. 4. Energy-level diagram of ^{54}Mn. Bold-face arrows are the observed transitions in the spectrum of internal conversion electrons

to the 54.3-keV transition and the low-energy part of the gamma spectrum are evidence against the 54.3-keV and 156.9-keV transitions being in a cascade. The obtained spectrum of electrons makes it possible to correct the scheme of excited states in the low-energy region by the accurately determined energies of the first two levels, (54.3 ± 0.5) keV and (156.9 ± 1) keV, respectively. The conversion electron spectrum is superimposed upon a heavy background of δ-electrons, scattered gamma quanta and neutrons. The background increasing in the low-energy range is due to δ-electrons, whose distribution is given by the formula $\sigma_\delta \sim Z^4/E_\delta^7$ [11]. The height of the background at a somewhat higher energy, being primarily due to scattered gamma quanta and neutrons, is proportional to the proton beam current and, therefore, the beam should be very stable.

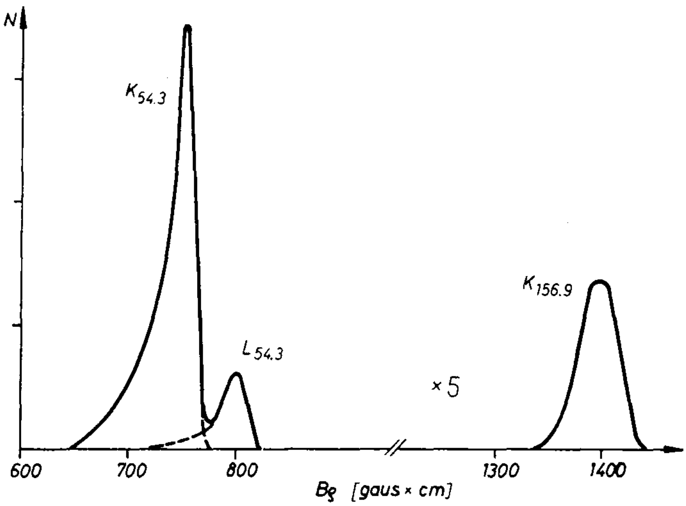

Fig. 5. Internal conversion electron spectrum after subtraction of background

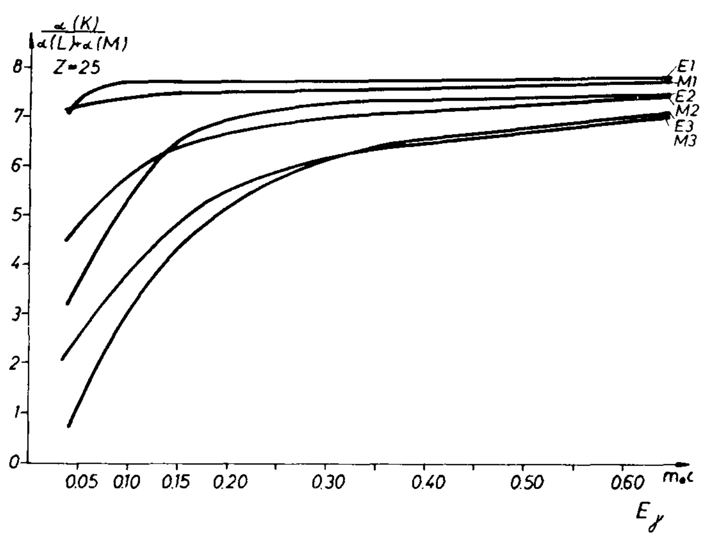

Fig. 6. $\alpha_K/(\alpha_L+\alpha_M)$ ratio for manganese, calculated on the basis of Rose's tables

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Figure 5 presents the internal conversion electron spectrum after subtraction of the background. For the 54.3-keV transition, after the efficiency of the detecting system is accounted for, the $\alpha_K/(\alpha_L+\alpha_M)$ ratio has a value of 7.1 ± 1. A comparison of this result with the value calculated on the basis of tables by Rose [12] (Fig. 6) enhances the presumption that the 54.3-keV transition is of dipole character and rather is a magnetic transition. The estimated $\alpha_K/(\alpha_L+\alpha_M)$ ratio for the 156.9-keV transitions is greater than seven, which also points to its dipole character.

Of the theoretical studies of the excited states of ^{54}Mn made to date, the best reproduction of the low-energy section of the level scheme is given by that of Vervier [13]. The anticipated spins for the first two excited states of this nucleus are in agreement with our results (2^+ and 4^+).

With higher proton energies the cross section for the (p, n) reaction increases and it will then be possible to investigate the higher excited states of ^{54}Mn by the method described here.

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