THE $^{58}Ni(n,p)^{58}Co$, $^{58}Ni(n,2n)^{57}Ni$, AND $^{58}Ni(n,np)^{57}Co$ CROSS SECTIONS AT 14·1 MeV*

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The energy spectrum of the protons which are emitted when nickel is bombarded with 14·1 MeV neutrons has been studied recently by several workers—Allan (1957), Colli, Facchini, *et al.* (1958), and Colli, Pignanelli, *et al.* (1958). The results of these experiments do not allow an accurate estimate of the relative importance of contributions from the (n,p) reaction and the (n,np) reaction. Such information is necessary when any reaction mechanism is postulated to account for the experimental results. In these experiments, therefore, activation techniques have been used to measure these two cross sections separately for the isotope ^{58}Ni at 14·1 MeV; in addition, the $^{58}Ni(n,2n)^{57}Ni$ cross section has been remeasured.

Reaction $^{58}Ni(n,p)^{58}Co$

Nickel foils were irradiated with monoenergetic neutrons produced by the $^{3}H(d,n)^{4}He$ reaction, the neutron flux being measured by counting the associated α-particles emitted into a known solid angle. During irradiation, the nickel foils were placed 3·5 cm from the centre of the target. However, because the deuteron beam wanders slightly over the surface of the tritium target during an irradiation, an estimate of the flux through the sample based on the distance from the centre of the beam is unreliable; for this reason, copper disks were placed on either side of the irradiated nickel foil and the induced $^{65}Cu(n,2n)^{64}Cu$ activity compared with the same activity in disks which were placed 15 cm from the neutron source. This technique allowed the integrated flux at the specimen to be measured with an accuracy better than ± 7 per cent.

^{58}Co formed by the (n,p) reaction during irradiation decays to an excited state of ^{58}Fe by positron emission and by the electron capture process. The k/β^{+} branching ratio has been measured accurately by Good, Peaslee, and Deutsch (1946), and their value of 5·89 was used here. The number of ^{58}Co atoms produced during the irradiation was estimated by counting the positron annihilation quanta with a scintillation spectrometer, allowance being made for self-absorption in the nickel foils. The geometry of the counter was eliminated by calibrating the spectrometer with a standardized ^{22}Na source, and the counting errors were estimated to be less than 12 per cent. Three independent measurements of the cross section were made, and the weighted mean of these gave

$$^{58}Ni(n,p)^{58}Co\ (14{\cdot}1\ \text{MeV}) = (560 \pm 110) \times 10^{-27}\ \text{cm}^2.$$

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Reaction ^{58}Ni(n,2n)^{57}Ni

The cross section of the reaction ^{58}Ni(n,2n)^{57}Ni has been measured previously by Paul and Clark (1953) using activation techniques, and they found a value of $(40{\cdot}6 \pm 10) \times 10^{-27}$ cm^2. The method described above, applied to the positron emitted when ^{57}Ni decays to ^{57}Co with a half-life of 36 hr, was used to measure this cross section. The value found was $(38 \pm 8) \times 10^{-27}$ cm^2—in good agreement with that of Paul and Clark.

Reaction ^{58}Ni(n,np)^{57}Co

The ratio of the cross sections for the two reactions ^{58}Ni(n,2n)^{57}Ni and ^{58}Ni(n,np)^{57}Co was measured by a method which depended upon the fact that the decay product from the 36-hr ^{57}Ni, produced by the (n,2n) reaction, is 270-day ^{57}Co—the same nucleus as is produced directly by the (n,np) reaction. In other words, the number of ^{57}Co atoms produced at the end of the irradiation is proportional to the ^{58}Ni(n,np) cross section, and the number present when the ^{57}Ni nuclei have decayed is proportional to the sum of the ^{58}Ni(n,np) plus ^{58}Ni(n,2n) cross sections.

A modified cobaltinitrite method (Mills and Vernon, personal communication) was used to separate the cobalt atoms from the nickel sample after irradiation, and the same separation technique was applied again to the nickel sample after one week had elapsed ; this removed all the ^{57}Co which had formed in the period due to the decay of ^{57}Ni. In both separations 5 mg cobalt carrier was used, and better than 99 per cent. recovery could be achieved in 45 min.

^{57}Co has a half-life of 270 days, decaying by electron capture to the 136 kV excited state of the stable isotope ^{57}Fe, while the ^{57}Fe decays to the ground state by emitting a 136 kV γ-ray. The ratio of the intensities of this γ-ray for the two separations is proportional to the ratio of the cross section ^{58}Ni(n,np)^{57}Co : ^{58}Ni(n,2n)^{57}Ni. The measured ratio was found to be 4·2, with a consistency of ± 10 per cent. between the individual determinations. The cross section for the ^{58}Ni(n,np)^{57}Co reaction derived from this ratio is $(160 \pm 40) \times 10^{-27}$ cm^2.

Discussion

There is evidence from experiments on the competitive modes of decay of ^{58}Ni bombarded by protons of 20 MeV energy for a preponderance of protons among the reaction products. Thus Cohen, Newman, and Handley (1955) find

$$\sigma(p,2p)/\sigma(p,pn)+\sigma(p,2n)=2{\cdot}8.$$

The results of the present experiment are somewhat similar in that they lead to the value

$$\sigma(n,np)/\sigma(n,2n)=4{\cdot}5 \pm 0{\cdot}9$$

for ^{58}Ni bombarded by 14·1 MeV neutrons. Thus, for proton and neutron bombardment of ^{58}Ni, proton emission from the excited nucleus appears to be favoured over neutron emission. Because of these facts a photonuclear experiment was carried out in this laboratory by Carver and Turchinetz (1959) to

determine the (γp) and (γn) yields. They find the ratio of the integrated cross sections to be

$$\int_0^{32} \sigma(\gamma p)\mathrm{d}E \int_0^{32} \sigma(\gamma n)\mathrm{d}E = 2 \cdot 35 \pm 0 \cdot 2,$$

and again there is the predominance of proton emission. Such results are difficult to explain in terms of the usual statistical theory but may be influenced by the rounding off of the potential barrier as proposed by Scott (1954), by a difference in the level densities of the residual nuclei ^{57}Co and ^{57}Ni, or by a combination of the two.

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