Decay Scheme of Ni^{65}

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SWARTOUT, *et al.*,[1] and Conn, *et al.*,[2] have shown that the 2.6^h activity of Ni is due to the mass number 65 and not, as was previously thought, to 63. This isotope, which decays by β- and γ-emission has earlier been studied by absorption methods[3] and also β-spectroscopically.[4] The upper limit of the β-spectrum was determined (abs.) to be 1.9 Mev. The γ-radiation was shown to have an energy of 1.1 Mev according to abs. measurements, and spectrometrically three photo-lines (from a Pb converter) were obtained, corresponding to the γ-energies 0.280, 0.65 and 0.93 Mev.

We have recently studied the decay scheme of this isotope using spectrometer and coincidence technique.[5] The β-spectrum appears to consist of three components with upper limits 0.60 Mev, 1.01 Mev and 2.10 Mev and with relative abundances 29 percent, 14 percent, and 57 percent. The γ-ray energies were found to deviate rather widely from those reported before, and turned out to be 0.37 Mev, 1.12 Mev, and 1.49 Mev from spectrometric measurements. Additional $\beta\gamma$- and $\gamma\gamma$-coincidence measurements support the decay scheme given in Fig. 1. According to this scheme the highest excited level in Cu^{65} can be de-excited *either* by the direct emission of one quantum of 1.49 Mev *or* two of 0.37 Mev and 1.12 Mev in cascade. The fact that these two competing processes occur simultaneously and with roughly the same probability suggests that the very much higher transition probability of the high energy quantum (cross-over transition) gets reduced to almost the same probability as for the 0.37-Mev transition because of selection-rules. From the intensities and energies of the three β-components one would conclude, according to their "*ft*"-values[6] that the softest one is allowed while the other two are first forbidden.

Using GT selection rules for β-decay it is possible to assign a limited number of spin alternatives for the different levels. From the same selection rules the parities of the different states can be (starting with Ni^{65}): even (or odd), even (or odd), odd (or even), odd (or even).

Numerically one can compute that in order to give the same order of magnitude of transition probability for the 0.37- and 1.49-Mev γ-radiation their "effective" l-values have to differ by one unit, e.g., if the l-value of the 0.37-Mev γ-ray is 2 the l-value of the 1.49-Mev γ-ray should be 3. In that case the corresponding decay constants for the two transitions come out to be roughly equal according to Segré-Helmholz[7] formula. One consequence of the γ-selection rules by Dancoff and Morrison[8] is that if the parity changes at a transition, only odd effective l-values can occur (e.g., the l-value, which has to be put into the formula for the decay constant computation, which is the order of the minimum allowed electric multipole), and if the parity remains the same, only even effective l-values occur. In the present case this would mean that the parity of the ground state and the first excited state in Cu^{65} should be opposite, or that of the ground state and the second excited state should be the same, in contradiction to the conclusions drawn from β-selection rules.

If we, for instance, consider the simple case when the second and first excited level and the ground state of Cu^{65} have the spins and parities (7/2, *e*), (5/2, *e*), (3/2, *o*), the following predictions can be made. The 0.37-Mev γ-ray would be expected to consist of 2^2-pole electric and 2^1-pole magnetic radiation. The 1.49-Mev γ-ray would consist of 2^3-pole electric and 2^2-pole magnetic radiation. The effective l-value in the last case is then one unit higher than the former case which explains the simultaneous existence of both these γ-rays. A change of parity of the first excited level in Cu^{65} would, however, require that the β-component going to this level should be second forbidden or allowed which seems difficult to combine with the experimentally found *ft*-value ($8.4 \cdot 10^5$).

The other alternative is to investigate the parity sequence *e*, *o*, *e*. In that case the electric components of the two γ-rays, assuming

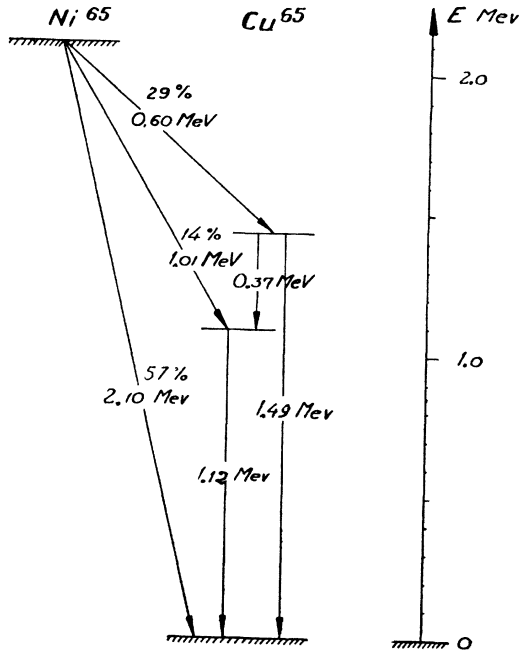

FIG. 1. Decay scheme of Cu^{65}.

the same spin values before, turn out to be 2^1-pole and 2^2-pole, effective l-values 1 and 2, respectively. This combination also fits the transition probability calculation since the difference in effective l-values is 1. In order to get this parity sequence we instead have to require that the β-component going to the ground state is second forbidden, which is only somewhat more probable than in the previous case since its *ft*-value is $3.9 \cdot 10^6$. This assignment is however still far from satisfactory.

If, however, one can allow a deviation of about a factor of 100 in the calculations of the relative radiation probabilities for competing transitions from the same level, then from our values the combination with $l=1$ for both 0.37-Mev and 1.49-Mev γ-rays would also be possible. In that case the β-selection rules regarding the parity would not have to be violated. The nature and multipole order, however, would be the same for both the γ-rays, namely electric dipole and magnetic quadrupole. The corresponding spins are then, starting from the ground state of Cu^{65} : 3/2, 7/2, 5/2. These spin values do not contradict G.T. selection rules.

It has been suggested to us by Professor Lamek Hulthén that selection rules concerning parity perhaps may be more complicated because of spin orbit coupling. If each state can consist of an admixture of *S*, *P*, *D*$\cdots$eigenfunctions (which is very probably the case in H^3 and He^3),[9] the parity has both odd and even character. It is still difficult to know what such parity admixtures can do to selection rules at heavier nuclei, such as Ni and Cu.

A fact of particular interest is that the first excited level in Cu^{65} of 1.12 Mev evidently also is obtained in the Zn^{65} ε+K disintegration, since this isotope is known to emit a γ-ray of just this energy when decaying to Cu^{65}. Hitherto only a few similar cases have been investigated but they can probably be expected to occur rather frequently when looked for. Especially in more complicated schemes such information can be useful to secure the order of emission of several γ-rays.

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[5] For a full account of the experiments, the reader is referred to Ark. f. Mat., Astr. o. Fysik **36A**, 19.
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[7] A. C. Helmholtz, Phys. Rev. **60**, 415 (1941).
[8] A. M. Dancoff and P. Morrison, Phys. Rev. **55**, 122 (1939).
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Experimental Corroboration of the Theory of Neutron Resonance Scattering

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DETAILED theoretical investigations have been made on the variations of the cross section with energy near a neutron scattering resonance.[1,2] In particular, the phenomenon of destructive inteference between resonance and potential scattering has been predicted. Until now, however, there has been no definite experimental evidence of this effect. While measuring the total cross section of sulfur, a resonance was observed which shows the effect predicted by theory particularly clearly.

Cross sections were determined from transmission measurements using monoenergetic neutrons from the Li(p,n) reaction. The width of the neutron energy distribution was estimated at 7 kev for measurements made at an angle of 115° with respect to the incident proton beam, and 11 kev for points taken in the forward direction. Measurements were made over an energy range from 16 kev to 250 kev using a procedure similar to that previously described.[3]

The cross section is assumed to represent almost entirely elastic scattering since it is improbable that inelastic scattering will be appreciable at the low energies involved. Further, measurements of the total cross section of sulfur at low energies[4] indicate that neutron capture will probably account for less than 0.1 b at the energies used here.

Figure 1 shows a sharp peak at 111 kev preceded by a dip which

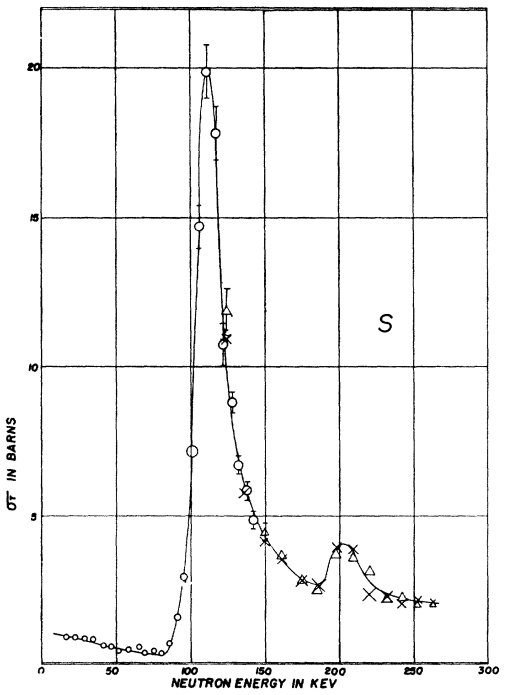

FIG. 1. The total cross section of sulfur as a function of neutron energy. The circles represent data taken at an angle of 115° with respect to the protons incident on the Li target. Other symbols show data taken in the forward direction. The height of the symbols is a measure of the statistical error.

is interpreted as caused by destructive interference between resonance and potential scattering. At this energy less than 2 percent of the potential scattering will be due to neutrons of more than zero angular momentum.[5] Therefore, it must be concluded that the resonance is caused by S-neutrons forming a state of S^{33} with spin $\frac{1}{2}$. This compound nucleus is formed from S^{32} which has an isotopic abundance of 95 percent and zero spin.

For S-neutrons interacting with a target nucleus of spin zero the Breit-Wigner single level formula, including potential scattering, is expressed by Feshbach, Peaslee and Weisskopf[6] as:

$$\sigma=\frac{4\pi}{k^2}\left|\frac{\Gamma_n/2}{E-E_r+i(\Gamma/2)}+e^{ika}\sin ka\right|^2,$$

where k is the neutron wave number in the center of mass system, a is the nuclear radius $1.4\cdot10^{-13}A^{\frac{1}{3}}$ cm,[7] E_r the resonance energy, and E the energy of the incident neutrons. Γ_n, the elastic scattering width, is taken to be equal to the total width Γ according to the preceding arguments.

The experimental width of the peak is about 19 kev which, by taking into account the effect of the neutron energy spread, yields a natural width of 18 kev. When this value is used for Γ, and E_r is taken as 108 kev, the experimental curve is found to be in good agreement with the theory. The correction for instrumental resolution increases the observed maximum cross section of 19.9±0.9 b at 111 kev to 21.5±1 b, which agrees with the theoretical value of 21.4 b at 111 kev. The theoretical minimum is zero at an energy of 82 kev. The position of the experimental minimum does not contradict this value, and the residual cross section of 0.3 b can be attributed to radiative capture and to the cross section of the other isotopes.

For 1-ev neutrons sulfur has a total cross section of 1.1 b, of which not more than 0.1 b is due to absorption.[4] Neglecting absorption, the potential scattering at low energies should be equal to $4\pi a^2$ or 2.4 b. The low value of the observed cross section can be explained by the effect of the resonance at 108 kev, since destructive interference reduces the theoretical value to 1.1 b at low energies.

There is evidence of a further resonance at 205 kev. The width of this peak is presumably quite small and its effect on the resonance at 108 kev should be negligible.

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Scintillations Produced by α-Particles in a Series of Structurally Related Organic Crystals

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WE are currently investigating the scintillation properties of a series of structurally related organic crystals, and in view of the fact that one of these crystals possesses a much higher conversion efficiency (number of photons per unit α-particle energy loss) than any other crystal previously reported, we considered it worth while to make a preliminary report of some of our results.

The series under investigation is 1,2-diphenylethane, 1,2-diphenylethylene (stilbene) and diphenylacetylene. The scintillation crystals were prepared by crystallization from a slowly cooling molten mass of the organic material. For purposes of comparison all crystals that were used were of approximately equal thicknesses