TRIPLE ISOMERISM IN Ir^{192}†

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About eight years ago we started a systematic program to search for long-lived isomers produced by pile neutron irradiation. Samples of most elements, weighing ~50 mg, were placed for one month inside the Brookhaven reactor and were then allowed to "cool." An analysis of the radiations from these samples carried out two years after the irradiation gave evidence only of well-known activities. A renewed study undertaken in the beginning of this year revealed a new activity induced in the Ir sample: Although the well-known 74.37-day ground-state activity[1] Ir^{192g} should have decayed to ~1 disintegration per sec, according to our computation, we observed a gamma spectrum, identical with that of Ir^{192g} (see Fig. 1), but corresponding to a source strength of 2820 ± 140 disintegrations per sec. As Ir^{192g} is known to have a 1.45-min isomer,[1] decaying mainly by a 58-kev isomeric ($E3$) transition to the 74-day ground state, we are forced to conclude that the activity observed stems from a third, longer lived isomer of Ir^{192}. This then constitutes a case of a nuclear isomeric triplet. Only one other case of triple isomerism is known, again in an odd-odd nucleus: Sb^{124}.[2] No definite spin assignments were possible so far for the metastable states in Sb^{124} because of the very low energies of the isomeric transitions. Hence, it seemed of particular interest to study the mode of decay of the new long-lived isomer of Ir^{192}.

We shall distinguish the two metastable states of Ir^{192} by naming the 1.45-min isomer Ir^{192m_1} and the new long-lived isomer Ir^{192m_2}. Measurements of the source intensity of Ir^{192m_2} through several weeks showed no decay within the statistical limits of error, allowing us to state a lower limit $T_{1/2} > 5$ yr.

The identity of the gamma-ray spectrum accompanying the decay of Ir^{192m_2} with that of Ir^{192g} indicates that Ir^{192m_2} decays by an isomeric transition. In order to determine the multipole order of this transition, we first studied the L x-rays emitted from a thin source of Ir^{192m_2}, using a 3-mm-thick NaI(Tl) crystal as detector. We found that the ratio I_L x-rays:I_{316} kev from this sample was ~16 times larger than that from an equally thin Ir^{192g} source, studied in the same geometry. There was no measurable difference, however, between the I_K x-rays:I_{316} kev ratios of the two sources. This implies that the isomeric transition is mainly converted in the L shell and is therefore a high electric multipole. Next we examined the conversion electrons from this transition by using a thin Ir^{192m_2} source placed on a 1-cm-thick anthracene scintillator, covered with a 0.2-mg/cm² Al foil. We found unresolved L and M conversion electron lines from a 161 ± 5 kev transition. (See Fig. 2, curve A.) The electron spectrum was compared with that of Ir^{192g} (see Fig. 2, curve B), which was quite flat in the same energy region. The energy calibration was carried out by means of the conversion lines of the isomeric transitions in Te^{125m} (See Fig. 2, curve C.)

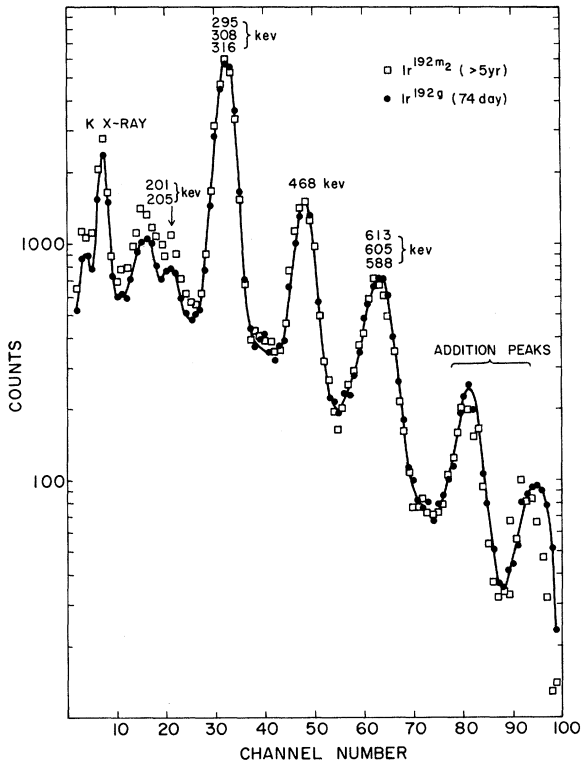

FIG. 1. Comparison of the scintillation spectra of the gamma rays from Ir^{192g} (●) and Ir^{192m_2} (>5 yr) (□). The slightly higher gamma-ray intensity in the low-energy region is due to increased backscattering in the thicker Ir^{192m_2} source. The peak between the K x-ray peak and the 201-205 kev photopeak is due to backscattering in the lead shield.

No unconverted 161-kev gamma rays were found. However, because of the weak Ir^{192m_2} activity at our disposal we can only say that $I_{161\text{ kev}}:I_{316\text{ kev}} < 0.1$. From the energy, the low K/L ratio, and the lower limit for the half-life of the isomeric transition, the most probable multipole assignment is $E5$, as follows from the values for the computed half-lives and activation cross sections given in Table I. For an $E5$ transition of 161 kev for $Z=77$, $\alpha_K=6.3$, $\alpha_L=568$ (Sliv),[3] $\alpha_M=238$ (Rose).[4] The theoretical half-life for a single proton $E5$ transition of this energy is 19.6 yr. Assuming that this is the actual half-life, we compute from the observed source strength an activation cross section $\sigma=5.2\times10^{-27}$ cm^2 for pile neutrons. Since natural Ir was used as the target, we estimate that a fraction of this cross section, $\leq 3\times10^{-27}$ cm^2, is due to an $(n, 2n)$ process in Ir^{193}.

As Fig. 2, curve A, shows, no conversion electrons from a 58-kev transition were observed in the electron spectrum of Ir^{192m_2}. Therefore, the $E5$ transition does not end in the 1.45-min state Ir^{192m_1}. Unless it is followed by a low-energy (< 30 kev) transition, which would have

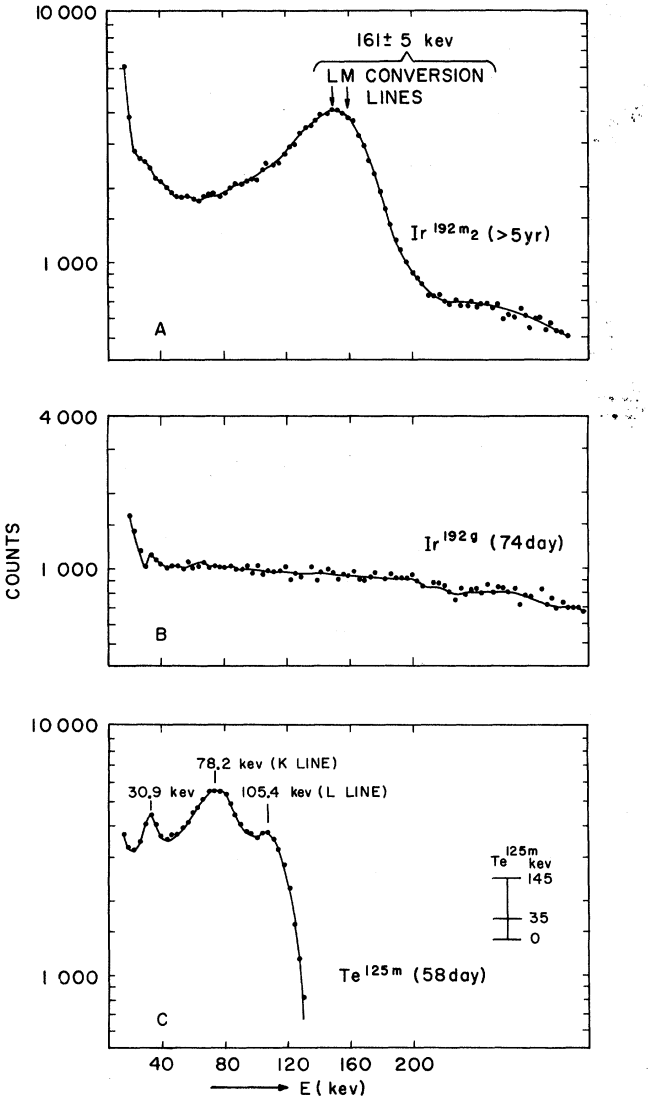

FIG. 2. Conversion electron spectra of Ir^{192m_2} (> 5 yr) (curve A) and Ir^{192g} (74 day) (curve B). The energy calibration was carried out by means of the K and L conversion electron lines of the 110-kev transition and of the L conversion electron line of the 35-kev transition in Te^{125m} (curve C). The positions of the L and M conversion lines of the isomeric transition in Ir^{192m_2} were determined by taking the theoretical conversion coefficients (see Table I) into account.

Table I. Relation between electric multipole order, half-life, and activation cross section computed for a 161-kev transition.

	$E4$	$E5$	$E6$ [a]
α_K	1.5	6.3	11.6
α_L [b]	122.2	568	5730
α_M [c,d]	21.4	238	3760
α_{tot}	145.1	912.3	9501.6
T_γ (sec) [e]	1.55×10^5	5.65×10^4	8.82×10^{19}
T (yr)	3.38×10^{-5}	19.6	2.79×10^8
σ_{act} (cm^2) [f]	...	5.2×10^{-27}	5.7×10^{20}

[a] The values for the $E6$ conversion coefficients were obtained by extrapolating logα versus electric multipole order.

[b] See reference 3.

[c] See reference 4.

[d] In order to take screening effects roughly into account, the M-shell conversion coefficients for $Z_{eff}=70$ were used.

[e] The gamma half-lives were computed using the formulas given by S. A. Moszkowski, in Beta- and Gamma-Ray Spectroscopy, edited by K. Siegbahn (Interscience Publishers, Inc., New York, 1955), p. 391.

[f] The activation cross sections σ_{act} were computed using the observed number of disintegrations/sec, the total neutron flux, and the computed half-life given in the line above. The following relation between half-life T (in years) and activation cross section (in cm^2) holds:

$$\sigma_{act}(Ir^{192m_2}) = 2.04\times10^{-28} Te^{5.06/T}$$

escaped detection, it may be assumed to go directly to the 74-day ground state which is known to have a character 4± or 5-.[1] From this it follows that if $I_{Ir^{192}g} = 4\pm$, then $I_{Ir^{192}m_2} = 9\mp$ and $I_{Ir^{192}m_1} = 1\mp$. On the other hand, if $I_{Ir^{192}g} = 5-$, then $I_{Ir^{192}m_2} = 10+$ or $0+$, and $I_{Ir^{192}m_1} = 2+$ or $8+$, respectively. Since a weak beta continuum had been reported for $Ir^{192}m_1$,[1] of unknown end-point energy, we decided to study which states in Pt^{192} are populated by beta decay of this isomer. Thus we hoped to be able to make a spin assignment for $Ir^{192}m_1$, from which the spins of the other two isomers would follow. The $Ir^{192}m_1$ sources consisted of enriched Ir^{191} (85.9%), irradiated for 10 sec by neutrons from our reactor. We measured the beta-spectrum of the 1.45-min activity and the beta-gamma coincidences, as well as the gamma spectrum and the gamma-gamma coincidences. From our results it follows that the Pt^{192} ground state (0+) and also the two lowest excited states at 316 kev (2+) and 611 kev (2+) are populated in the beta decay of $Ir^{192}m_1$. The branching ratios found were 7×10^{-5}, 8×10^{-5}, and 2.5×10^{-5} per disintegration, respectively.[5] Figure 3 shows the proposed disintegration scheme of the isomeric triplet. It contains the unique spin assignments for the three isomeric states derived from this work. (The assignment 2- for $Ir^{192}m_1$, although compatible with the beta branching, is excluded, because $Ir^{192}g$ would then be 5+.) Also, the previously established[1] spin assignments of the levels of Pt^{192}, which are fed in the beta decay of $Ir^{192}m_1$ and $Ir^{192}g$, are given. From these it follows that either all three beta branches of $Ir^{192}m_1$ are allowed and the three high-energy beta branches from $Ir^{192}g$ (representing ~99% of all beta decays) first forbidden, or vice versa, depending on which parities (upper or lower) are chosen. The logft values derived from our studies of the beta decay of $Ir^{192}m_1$ are almost the same as those for the beta branches of $Ir^{192}g$ reported previously. It is therefore not possible to make definite parity assignments for the three isomeric states.

By studying the 1.45-min growth of the intensity of the 468-kev gamma ray from the 4+ state of Pt^{192} which is not populated in the decay of $Ir^{192}m_1$, we obtained the ratio for the initial activation cross sections $\sigma_i(Ir^{192}m_1)$: $\sigma_i(Ir^{192}g) = 0.84$. Taking the total activation cross section from the literature,[6] $\sigma_t(Ir^{192}g) = (7.0\pm2.0)\times10^{-22}$ cm^2, we obtain $\sigma_i(Ir^{192}g) = (3.8\pm1.1)\times10^{-22}$ cm^2 and $\sigma_i(Ir^{192}m_1) = (3.2\pm0.9)\times10^{-22}$ cm^2. The latter value is to be compared with the value of $(2.6\pm1.0)\times10^{-22}$ given in the literature.[6]

The small cross section found for formation of $Ir^{192}m_2$ is in agreement with expectations from the rule[7] that σ_{act} decreases with increasing $|I - I_C|$, where I_C denotes the spin of the compound state. For $Ir^{191} + n$, $I_C = \frac{3}{2}\pm\frac{1}{2}$.

We wish to thank E. der Mateosian and G. Harbottle for their kind collaboration in various phases of this work.

†Work performed under the auspices of the U. S. Atomic Energy Commission.

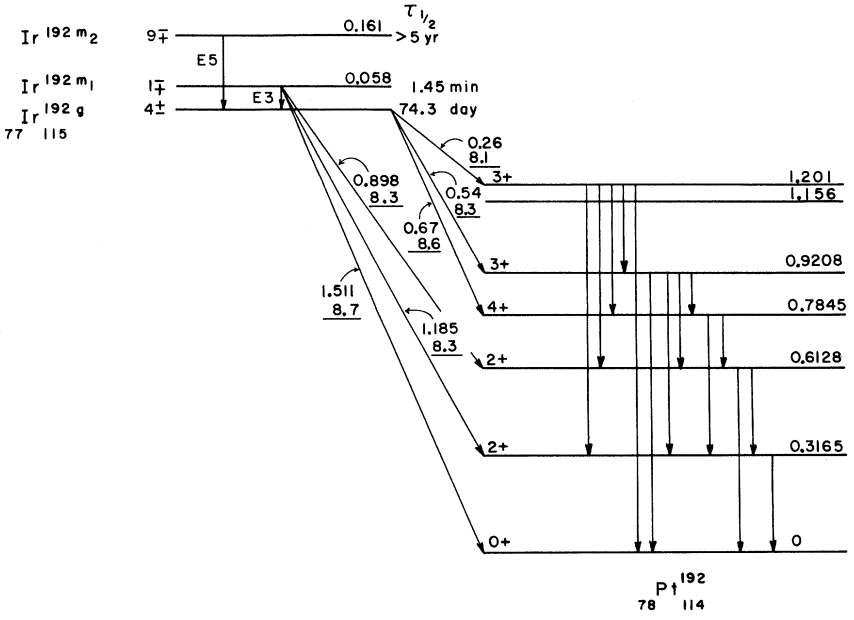

FIG. 3. Disintegration scheme of the triple isomers of Ir^{192}. The decay of $Ir^{192}m_2$ and the analysis of the beta decay of $Ir^{192}m_1$, as well as the spin assignments for the three isomers, result from the present work. Because the logft values for the beta transitions from $Ir^{192}g$ and from $Ir^{192}m_1$ are comparable, it is not possible to decide which set of the beta transitions is allowed and which is first forbidden. Hence the ambiguity in the parities (upper or lower set) still persists. Only that part of the decay scheme of $Ir^{192}g$ which is relevant for the discussion is shown.

[1]Strominger, Hollander, and Seaborg, Revs. Modern Phys. 30, 585 (1958); B. S. Dzelepow and L. K. Peker, Decay Schemes of Radioactive Nuclei [Academy of Sciences of the U.S.S.R. Press, Moscow, 1958)].

[2]der Mateosian, Goldhaber, Muehlhause, and McKeown, Phys. Rev. 72, 1271 (1947).

[3]L. A. Sliv and I. M. Band, Tables of Internal Conversion Coefficients (Academy of Sciences of the U.S.S.R. Press, Moscow, 1958), Part II.

[4]M. E. Rose, Internal Conversion Coefficients (North Holland Publishing Company, Amsterdam, 1958).

[5]A weak β-branch (~8.5%) of 2.6-Mev end-point energy, decaying with an effective half-life of approximately 1.5 min, seems to be due to an impurity (Rh^{104} and Rh^{104m} ?).

[6]Neutron Cross Sections, compiled by D. J. Hughes and R. B. Schwartz, Brookhaven National Laboratory Report BNL-325 (Superintendent of Documents, U. S. Government Printing Office, Washington, D. C., 1958), second edition.

[7]E. der Mateosian and M. Goldhaber, Phys. Rev. 108, 766 (1957).

OXYGEN-20*

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This is a preliminary report of the observation of the nuclide O^{20}, heretofore unknown. This isotope of oxygen is of interest because it is new, because it is a member of the group of nuclides with a closed shell of eight protons, and particularly because it is the lightest nucleus known with isotopic spin $T=2$.

We observed O^{20} by detecting the protons from the $O^{18}(t,p)O^{20}$ reaction. The experimental arrangement and equipment have been described in detail previously.[1] Briefly, 2.6-Mev tritons from an electrostatic accelerator bombard a gas target enriched in O^{18}. Reaction fragments are analyzed in a double-focussing magnetic spectrometer and are detected in a CsI crystal scintillation spectrometer. The varying sensitivity of the CsI to different particles and the momentum analysis of the fragments determine the mass and energy of these fragments. As an additional check that the fragments in the O^{20} reaction were protons, their behavior was observed when a thin aluminum foil was placed over the CsI crystal. Protons from targets of normal oxygen, 25% O^{18},[2] and 96% O^{18} were observed. Background runs were also taken with nitrogen and methane in the target to check on possible contaminant reactions. All target gases were analyzed with a mass spectrometer. To eliminate the possibility that the proton groups could have come from (He^3,p) reactions caused by the He^{3+} component of the beam, runs were taken using a HT^+ beam. It was shown that the results below were definitely from the $O^{18}(t,p)O^{20}$ reaction.

Two proton groups associated with O^{20} were observed. These are assumed to be due to the ground state and first excited state of O^{20}. The Q for the reaction $O^{18}(t,p)O^{20}$ is 3.12 ± 0.04 Mev. This then gives a preliminary value for the mass of O^{20} of 20.01036 ± 0.00004 amu or a mass excess of 9.65 ± 0.04 Mev. The beta disintegration energy[3] for the O^{20}-F^{20} decay is calculated to be 3.75 Mev. The first excited state of O^{20} is found to be at an energy of 1.70 ± 0.05 Mev above the ground state. No other energy level was seen up to about 4.05 Mev. The errors stated are standard deviations.

This mass for O^{20} indicates a more stable nucleus than has been expected. For instance, Talmi and Thieberger[4] with a shell-model calculation predicted a mass excess of 11.4 Mev. The measured mass of O^{20} corresponds to a 6.5-Mev excited level in F^{20} and to a 16.7-Mev level in Ne^{20}. These levels should be the positions of the first $T=2$ state in these nuclei.

More precise values on O^{20}, as well as information on the energy levels of O^{18}, N^{16}, and N^{17}, will be reported in a complete paper.

Our thanks go to Eugene Haddad for some helpful advice on this experiment.

*Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]Nelson Jarmie and Robert C. Allen, Phys. Rev. 111, 1121 (1958).

[2]The 25% O^{18} was kindly furnished by A. O. Nier, University of Minnesota.

[3]See S. Katcoff and J. Hudis, J. Inorg. Nuclear Chem. 3, 253 (1956), for an attempt to measure the O^{20} half-life.

[4]I. Talmi and R. Thieberger, Phys. Rev. 103, 718 (1956).