the effective single scattering cross section is given by

$$\bar{\sigma}/\sigma = 1 + (\sigma na/4)G(d/a), \quad (13)$$

where

$$G(d/a) = (a/d)(X - \sigma naY + \tfrac{1}{2}\sigma^2 n^2 a^2 Z) \quad (14)$$

and is written only as a function of d/a since it varies but slowly with σna, as may be seen in Fig. 4. By considering the mean curve to apply to all cases of interest, the function G becomes a function of d/a only.

To apply the calculations of the right circular cylinder to the case of the ring scatterer, we assume that except for multiplying factors which are angular functions, the geometrical variation of the single and double scattering ratios is given correctly after associating the radial thickness of the ring scatterer b with the radius of the cylinder a.

If, instead of isotropic scattering, one takes the other extreme of an angular distribution peaked strongly in the forward direction, one finds that the single scattering ratio in the ring scattering varies as $d\exp(-\sigma nd)$ whereas the double scattering ratio varies as $d^2\exp(-\sigma nd)$; thus leading to a linear variation of the apparent single scattering cross section with the thickness of the ring.

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The Radioactive Decay of Tungsten 181†

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Using tungsten enriched in mass 180, neutron capture produces a strong activity in W^{181} with a half-life of about 140 days. Using scintillation crystal and photographic magnetic spectrometers, two gamma rays of energy 136.5 and 152.5 kev are found to occur. Neither of these had been previously observed and conversely none of the previously reported gamma energies are found to exist. The main decay of W^{181} takes place by K capture directly to the ground state of Ta^{181}. Coincidence measurements are made with some evidence that the gamma rays are in sequence.

ON bombarding tantalum with high-energy (16-Mev) deuterons, Wilkinson found[1] that a radioactive tungsten of half-life 140 days could be chemically separated from the target. Since natural tantalum consists only of mass 181, the $(d,2n)$ reaction could produce W^{181}. The more common (d,n) process would result in W^{182}, which is stable in nature. A similar radioactive tungsten product was later produced[2] by bombarding tantalum with protons, thus inducing the reaction $Ta^{181}(p,n)W^{181}$. Since the natural relative abundance of W^{180} is only 0.13 percent, the neutron capture process in the pile with ordinary tungsten is not highly productive of W^{181}. Its presence, however, has been observed by this method and certain values ascribed[3] to the energies of its gamma rays.

In the present investigation a specimen of tungsten with a fifty-fold enrichment in mass 180 was kindly made available by the Oak Ridge National Laboratory. Samples were irradiated for a two-month period in both the Oak Ridge and the Argonne piles. In addition to the long-lived W^{181}, a rather strong yield of the well-known[4] short-lived W^{187} was obtained, as well as a certain amount of the 73-day W^{185}, which emits only beta radiation.

A study of the radiations from the long-lived W^{181} has been made, utilizing magnetic photographic spectrometers to observe conversion and photoelectrons and the scintillation crystal spectrometer for any unconverted gamma rays and coincidence events. In addition to several Auger electron lines, five conversion electron lines are found with energies of 69.0, 85.0, 125.0, 141.0, and 149.8 kev. These form a K-L and a K-L-M group for gamma energies of 136.5 and 152.5 kev. The K conversion lines for the two gamma rays are about of equal intensity and the K/L ratio for each is, by visual estimate, approximately 8 ± 2.

A survey of the high-energy gamma spectrum to detect the previously observed gamma energies was made with the scintillation crystal spectrometer. No evidence could be found for a gamma ray as reported[1] at 1.8 Mev nor for energies of 30, 600, and 800 kev as found[3] by Alburger *et al.* The peak due to the tantalum x-rays is extremely strong, and had any of the other unconverted gamma rays been as much as one-millionth as intense they could have been detected. A spectrographic analysis of the enriched tungsten specified a high purity, with zinc present to no greater than 0.01

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[1] G. Wilkinson, Nature **170**, 864 (1947).

[2] J. Burkig and J. Richardson, Phys. Rev. **76**, 586 (1949).

[3] Alburger, der Mateosian, Friedlander, Goldhaber, Mihelich, Scharff-Goldhaber, and Sunyar, Brookhaven National Laboratory Quarterly Progress Report, July 1–September 30, 1950, p. 2 (unpublished).

[4] Cork, Brice, Nester, LeBlanc, and Martin, Phys. Rev. **89**, 1291 (1953).

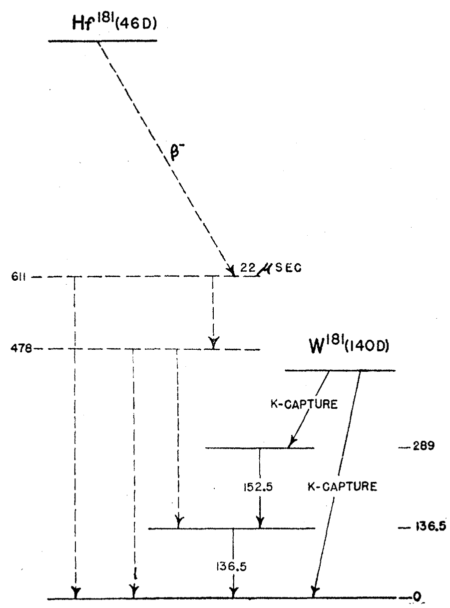

FIG. 1. A proposed nuclear level scheme for mass 181.

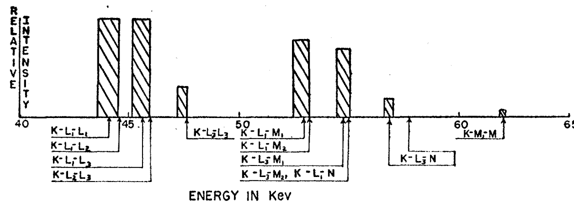

FIG. 2. The Auger electron energies from W^{181}.

percent. Peculiarly, however, evidence for the existence of Zn^{65} appeared in the scintillation spectrometer. The gamma ray at 1.114 Mev together with its associated Compton peak and the positron annihilation radiation at 0.51 Mev are there, though weak, in the same relative intensity as found in Zn^{65}.

The gamma ray of energy 136.5 kev is undoubtedly the same transition known to exist in Ta^{181}, following the beta decay of Hf^{181}. The 152.5-kev transition does not occur in the hafnium disintegration. There appears some evidence that the 136.5-kev and the 152.5-kev gamma rays are in coincidence. They are thus probably in sequence, with the 136.5-kev transition leading to the ground state.

NUCLEAR LEVEL SCHEME

It is possible to suggest a nuclear level scheme as shown in Fig. 1, which satisfactorily accommodates all of the observed data. The arrangement cannot be regarded as unique since other K-capture paths are possible. The very strong tantalum x-rays as compared with the intensities of the gamma rays suggest a strong K capture branching directly to the ground state. No evidence could be found for the existence of positrons from sources of W^{181} placed in the double-focusing magnetic spectrometer.

The ground state of Ta^{181}, with its 73 protons, from shell theory, is expected to be characterized as a $g_{7/2}$ level. The large K/L ratio for the 136.5-kev gamma ray, whose Z^2/W is 39, suggests that it is an $M1$ transition. The same conclusion could be applied to the 152.5-kev transition. The ground states of Hf^{181} and W^{181} have been thought to be either $p_{1/2}$ or $p_{3/2}$ levels. For the K capture to the ground state of Ta^{181}, the $\log ft$ value is of the order of 8.0, so that the process is perhaps first forbidden, with a spin change of two and a change in parity, thus favoring a $p_{3/2}$ state for W^{181}. It seems unlikely that the Hf^{181} could be similarly characterized, for in that case a beta transition directly to the ground state of Ta^{181} might be expected and no such beta ray is observed. The absence of the other known gamma transitions in Ta^{181}, shown as dotted lines in Fig. 1, probably follows from energy considerations. It is possible that the ground state of W^{181} is actually lower in energy than the 611-kev, 22-microsecond level in Ta^{181}. The absence of the 152.5-kev gamma transition in the Hf^{181} decay is more puzzling, but it is undoubtedly due to selection rules for the states involved.

AUGER ELECTRONS

Rather strong well-resolved Auger electron lines are observed in the photographic spectrometer set with a low magnetic field. The energies of the lines and their approximate widths expressed in kev as measured are shown graphically in Fig. 2. The estimated relative intensities are represented by the heights of the areas. The relation of each line to the known work-functions for the tantalum nucleus is indicated in the figure. It is evident that the resolution of the components is still not complete, but it also seems quite apparent that radiation corresponding to certain transitions such as K-L_2-L_2 and K-L_2-M_2 are not present.