X-Rays Associated with U^{234}*

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WE should like to report the observation of x-rays associated with U^{234}. L and M x-rays were found to occur spontaneously, the yield of the former, per alpha-particle, being between one-third and two. Detection was accomplished by means of a thin-walled Geiger counter. The efficiency of the tube was between 0.25 and 1 percent, making the quantitative determination of yield uncertain as indicated. Absorption curves in aluminum were measured to determine the energy of the L radiation. Film and counter wall absorption made it impossible to obtain much information on the M x-rays.

The source of the x-rays was a thin film of U_3O_8 containing 0.245 mg of U^{234} plated on a 22 cm^2 disk. Other materials present contributed only 4 percent of the total alpha-activity. The U_3O_8 film was prepared and counted within four hours after the removal of the natural decay products (UX_1, UX_2, UY, UZ). Figure 1, curve A, shows the results of an aluminum absorption experiment run on this source. In addition to the points shown, one millimeter of lead as absorber gave less than three counts per minute above background. The chief component found shows an absorption characteristic of 15.0 ± 0.5 kev x-rays, resembling the L x-rays of thorium or uranium as closely as we were able to determine. The M x-ray has not been identified so decisively but the presence of a soft component with the appropriate absorption coefficient has been shown in this work (Fig. 1, curve A) and in earlier experiments done in cooperation with Mr. L. E. Glendenin of the Monsanto Chemical Company. The absence of detectable K radiation was particularly notable in this work.

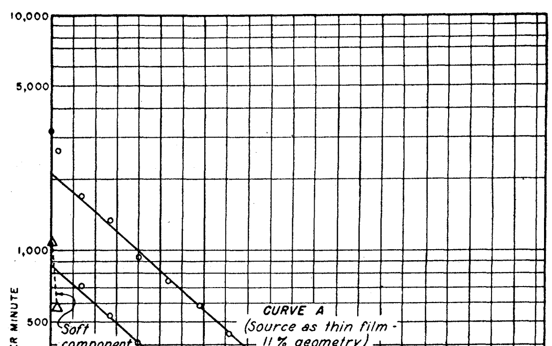

FIG. 1. Absorption of x-rays from U^{234} by aluminum.

A second set of aluminum absorption measurements was made using a solution of the same quantity of uranium as nitrate in 20 ml of solution contained in a shallow dish and of uniform depth, 0.78 cm. These measurements (Fig. 1, curve B) show no change in the absorption characteristics of the radiation. The intensity relative to curve A is 0.54. Calculating the effective intensity for 15-kev radiation from point sources distributed uniformly through the solution gives 0.51. This experiment together with the high yield of x-rays leads us to conclude that we are not dealing with a delta-ray effect.

Our interpretation is that the L and M x-rays observed arise from rearrangement of the electrons in the recoil atoms, after alpha-emission. The energy of these recoils is readily calculated to be about 82 kev by applying the law of conservation of momentum and the measured alpha-energy[1] of 4.76 Mev. This energy is insufficient to excite the K shell electrons (K limit = 100.4 kev),[2] but more than adequate to ionize the L and higher orbital electrons (L_{22} limit = 16.3 kev).[2] An adequate quantum-mechanical treatment of such excitation by recoil has not come to our attention.

Dr. S. DeBenedetti has pointed out the failure of I. Curie and F. Joliot[3] to observe K shell x-rays from polonium, though they did observe L and M x-rays. Other natural alpha-emitters are accompanied by interfering beta- and gamma-radiation to an extent sufficient to make observation of these recoil x-rays improbable.

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[1] G. T. Seaborg, Rev. Mod. Phys. **16**, 1 (1944).
[2] Int. Crit. Tab., Vol. **VI**, p. 39.
[3] I. Curie and F. Joliot, J. de phys. et rad. **7**, II, 20 (1931).

The Nucleus as a Crystalline Solid

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IN a previous letter,[1] it was pointed out that the relation between mass and charge for stable nuclei was that to be expected on the basis of a crystalline-solid model for the nucleus with the protons on the surface. On the basis of this model, it was proposed that nuclear fission might result from the splitting of a nearly perfect crystal along a cleavage plane by the entrance of a neutron. Davison and Watson[2] have raised an objection to this model and mechanism of fission on the grounds that the unequal mass fragments after fission should be expected to contain a different charge to mass ratio from each other, and from the charge to mass ratio for other elements. They point out that experimental observations of fission fragments show that these fragments possess the same charge to mass ratio. They therefore conclude that the mechanism of splitting a crystal will not account for fission, and that the charge cannot be considered as residing on the surface of the nucleus.

The objection raised by Davison and Watson on the grounds that fission fragments have equal charge to mass ratio seems not to be valid, since the fragments which are observed after fission are observed a long enough time after the splitting to permit a reorganization of fragments to obtain the charge to mass ratio corresponding to the resulting radioactive isotopes. The rearrangement of fragments may be considered to begin as the fragments start to separate. They can thus contribute their change in mass defect to the kinetic energy of the fragments.

The crystalline-solid model offers a ready explanation for the fact that splitting occurs into fragments of unequal mass. If a nucleus of uranium (235) or plutonium (239) is considered as made up of nuclear particles in spherical close packing, then a crystal so formed can be considered as consisting of a central plane of symmetry with nuclear particles above and below in equal numbers, and with protons above and below the plane as well as in the outside rim of the plane. A model for uranium or plutonium would provide approximately 20 or 22 protons around the edge of the central plane of symmetry.

If such a crystalline solid is split along a cleavage plane, it must be split above or below, but not through the middle of the plane of symmetry. This means that the fragments must have unequal rather than equal masses. The number of protons which would be required to be associated with the fragments is, for uranium (235), 36 and 56 for a clean split just above or below the plane of symmetry. This gives fission fragments krypton and barium. The number of neutrons in these two fragments would be such that the lighter fragment, krypton, would be left in a highly radioactive state and the heavier fragment, barium, would be left in a highly radioactive state after releasing about four neutrons. The various fission fragments observed could be associated with the splitting of the crystal with various parts of different planes going with the separate fragments.

Another aspect or property of nuclei which also indicates that the nucleus may be considered as a crystalline solid is illustrated in Table I. In this table are listed the atomic numbers of the elements which have a given number of stable isotopes. Many elements consist of only a single isotope. All of these elements have an odd atomic number and an odd mass number. The elements of odd atomic number never have more than two stable isotopes, while the elements of even atomic number may have several isotopes. In Table I it is shown that atoms may be arranged in periods, where in some periods the multiplicity of stable isotopes alternates between one and several. In other periods it alternates between two and several. The known stable isotopes then form a periodic system shown in Table I. In this periodic system there are five periods in which, with successively increasing atomic number, the number of stable isotopes alternates between one and several, and these periods are six atomic numbers long. There are four periods, also six atomic numbers long, in which the number of stable isotopes alternates between two and several. There are three periods, each eight atomic numbers long, in which the number of stable isotopes alternates between two and several. All the elements fit into this periodic system except atomic numbers 4, 71, 73, and 83. According to this table it is to be expected that these elements, which are listed as having only one stable isotope,[3] may be expected to have two stable isotopes.

TABLE I. Number of stable isotopes for a given atomic number. s=several—two or more.

1	s	1	s	1	s	1	s	2	s	2	s	1	2	s	2	s	2	s	2	s	1
													1	2	3	4?	5	6	7	8	9
9	10	11	12	13	14	15	16	17	18	19	20	21									
21	22	23	24	25	26	27	28	29	30	31	32	33									
						33	34	35	36	37	38	39									
39	40	41	42	43	44								45	46	47	48	49	50	51	52	53
53	54	55	56	57	58	59	60	61	62	63	64	65									
65	66	67	68	69	70								71?	72	73?	74	75	76	77	78	79
						79	80	81	82	83?											

The periodicity of six in atomic nuclei, as shown in Table I, as well as the existence of elements of odd atomic number with only one or at the most two stable isotopes is readily accounted for on the basis of a crystalline-solid model for the nucleus. We may consider that the plane of symmetry of the nucleus contains an odd number of protons. Those elements which consist of only a single stable isotope may be considered as the ones with perfect symmetry of both mass and charge about the plane of symmetry containing an odd number of particles. Elements which contain several stable isotopes may be considered as those which are not perfectly symmetrical in both mass and charge, and can contain, for a given number of protons, a variable number of neutrons.

[1] J. G. Winans, Phys. Rev. **71**, 379 (1947).
[2] B. Davison and W. H. Watson, Phys. Rev. **71**, 742 (1947).
[3] J. M. Cork, *Radioactivity and Nuclear Physics* (Edwards Brothers Inc., Ann Arbor, Michigan, 1946), Table of Isotopes.

X-Ray Wave-Length Standards

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X-RAY wave-lengths have been expressed in x units. The x unit is defined in terms of the calcite spacing and is nearly 10^{-11} cm, but is now known to differ from 10^{-11} cm by about 0.2 percent. During the last twenty-five years x-ray diffraction workers have expressed x-ray wave-lengths and crystal dimensions in terms of a unit which was $1000x$ units, but instead of calling it $1000x$ units have erroneously called it an Ångström unit. In recent years, the x-ray diffraction groups have agreed to use the term kilo x unit (abbreviated kx) in place of the incorrectly used Ångström unit, until agreement was reached on the