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ON SECONDARY AND TERTIARY X-RAYS FROM GERMANIUM, ETC.

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In three previous notes we[2] have described experiments in which an X-ray beam, emergent from a secondary radiator at right angles to the primary beam from a tungsten target, was analyzed by means of a calcite crystal and an accurate ionization spectrometer with sensitive electrometer.

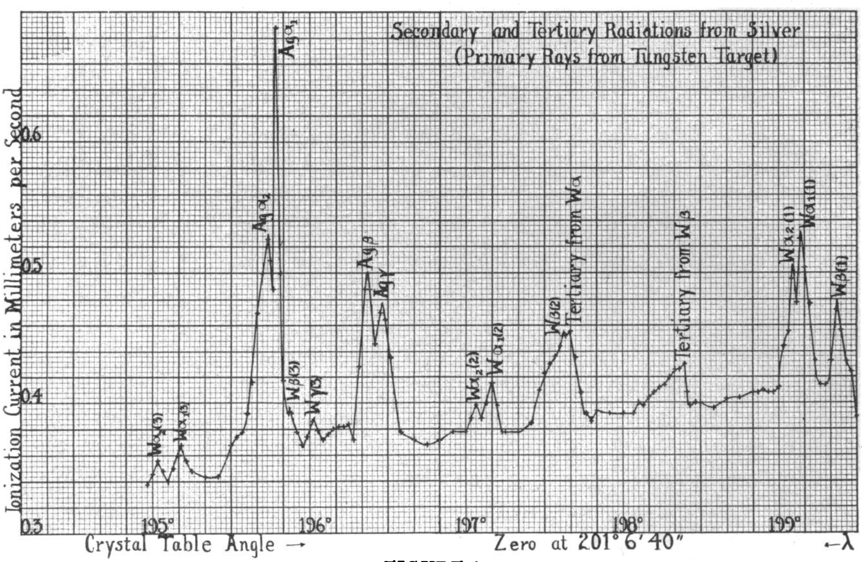

FIGURE 1

Results were given for 14 different chemical elements from carbon (atomic number 6) to neodymium (atomic number 60). We were able to identify and to measure the wave-lengths of three kinds of X-radiation in the secondary beam: (1) scattered rays with the same wave-lengths as the tungsten K series lines in the primary beam; there was no evidence of a softening of these rays as demanded by A. H. Compton's interesting theory of the scattering of radiation quanta by single electrons with recoil; (2) fluorescent secondary rays, characteristic of the element in the radiator; and (3) tertiary rays produced by the impact of secondary photo-electrons on atoms in the radiator. We showed that the short wave-length limit, λ, of the tertiary radiation (which appears as a broad band) is given by the expression $\lambda = \lambda_1\lambda_2/(\lambda_2 - \lambda_1)$, where λ_1 denotes a primary wave-length and λ_2, is a critical absorption wave-length of the chemical element in the radiator. The shift from the wave-length of the unmodified ray in the scattered beam is $\Delta\lambda = \lambda_1^2/(\lambda_2 - \lambda_1)$.

In this note we present additional experimental evidence bearing upon the phenomena just outlined.

1. Secondary and Tertiary Radiation from Silver.—The last of the three notes referred to (l. c.) contains the data for this experiment. The corresponding graph is now presented in Fig. 1 without further comment, since the tungsten peaks, the fluorescent silver peaks and the tertiary "humps" due to $WK\alpha$ and $WK\beta$ are all labelled on the diagram.

2. The Effect of the Angle between Primary and Scattered Beams on the Tertiary Rays from Molybdenum.—According to the theory, as represented by the equation $\lambda = \lambda_1\lambda_2/(\lambda_2 - \lambda_1)$, the short wave-length limit and the angle of its reflection by a calcite crystal should be independent of the angle between the scattered beam which is being analyzed and the primary beam striking the radiator. On the other hand the shape of the tertiary humps and the angular positions of their *maxima* might be expected to vary, for a variety of reasons, such as filtration.

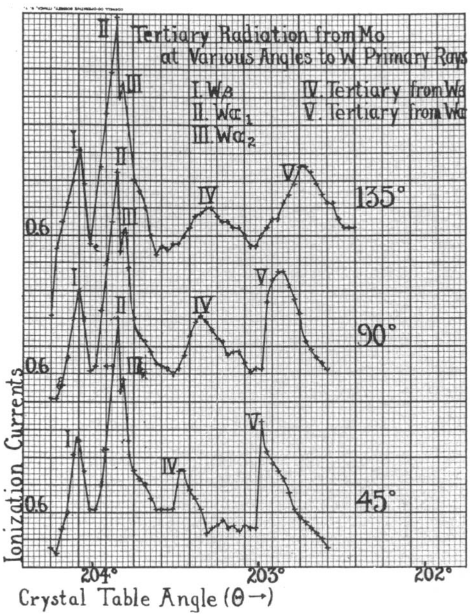

FIGURE 2

In order to test the effect of changing the angle, three experiments with a fixed molybdenum radiator were made under conditions identical except that the tungsten target tube was adjusted successively in such a way that the scattered beams passing through the spectrometer slits and reflected by the crystal made angles of approximately 135°, 90° and 45° with the primary beam. The results appear in Fig. 2. The three curves show the peaks due to unmodified Wβ and Wα rays at the same crystal table angles, and also tertiary humps due to Wβ and Wα. These differ considerably from each other in appearance. For the 45° experiment the humps are fairly narrow and quite sharp on the short wave-length side. At 90° they are somewhat more diffuse, and at 135° they appear as practically symmetrical, broad peaks. The tops of the tertiary humps clearly occur at quite different angles as shown by the following readings: (45°) 202° 55′; (90°) 202° 51′; (135°) 202° 45′. An important characteristic, however, is that in all three cases the corresponding tertiary humps have the *same short wave-length limit*, i. e., they start at the same angles, 30′ and 1°, from the beginning of the Wα peak for the tertiary radiations due to Wβ and Wα respectively. This experiment, therefore, contributes strong evidence in support of the existence of tertiary radiation and of the validity of the simple equation expressing its short wave-length limit. The shifts in the humps with the angle of incidence of the primary rays parallels the results of A. H. Compton's experiments with molybdenum primary rays and a carbon radiator.

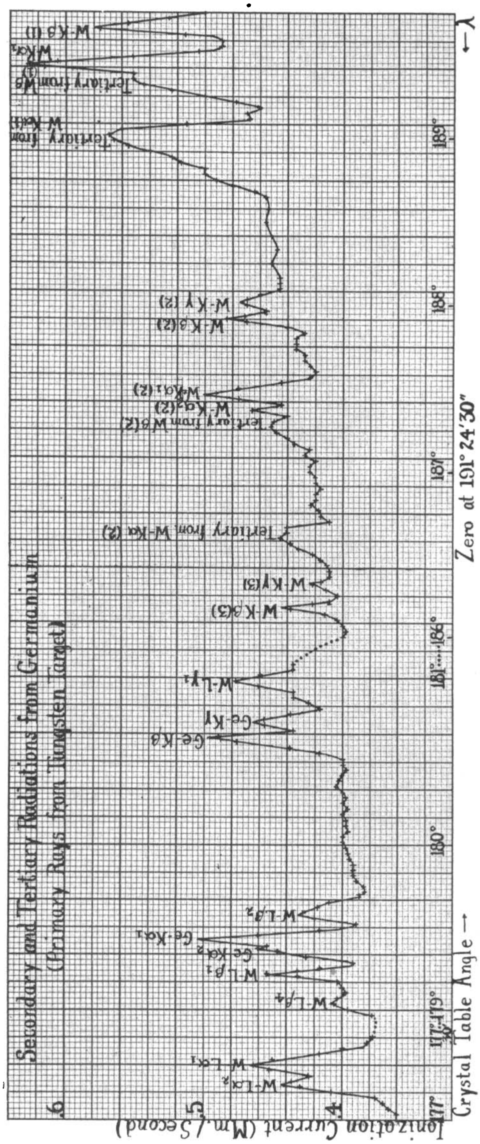

FIGURE 3

On a photographic record of the secondary radiation, with the proper time of exposure, the tops only of these tertiary humps would show. It would take a *very* much longer exposure to bring out the short wave-length limits.

3. Secondary and Tertiary Radiation from Germanium.—An experiment with metallic germanium as secondary radiator furnished some exceedingly interesting results. Professor L. M. Dennis of Cornell University kindly sent us a sample of the pure metal in the form of a quarter section of a large button-shaped melt with one edge highly polished. Considering that our previous work has been done with polished, fairly thin plates having comparatively large areas, strong radiation from this sample was not anticipated. However careful adjustment of the polished face (which had an area of only 2.5 cm.^{2}) so that the scattered beam grazing its surface might be analyzed, produced surprisingly large ionization currents. Fig. 3 and the following table I contain the results.

TABLE I

THE WAVE-LENGTHS OF SECONDARY AND TERTIARY RAYS FROM GERMANIUM

SPECTROMETER ANGLE	GLANCING ANGLE, θ 0	WAVE-LENGTH, λ	RADIATION	ORDER	KNOWN λ
191°–24′–30″					
189°–39′–20″	1°–45′–10″	0.1852	W-Kβ	1	0.1842
189°–25′–45″	1°–58′–45″	0.2091	W-Kα	1	0.2086
189°–22′– 0″			Top of tertiary due to W-Kβ	1	
189°– 0′– 0″	2°–24′–30″	0.2545	Tertiary due to W-Kα	1	0.2566 (calc.)
188°– 1′– 0″	3°–23′–30″	0.1791	W-Kγ	2	0.1790
187°–55′– 0″	3°–29′–30″	0.1844	W-Kβ	2	0.1842
187°–27′–30″	3°–57′– 0″	0.2086	W-Kα_1	2	0.2086
187°–22′– 0″	4°– 2′–30″	0.2134	W-Kα_2	2	0.2134
187°–20′– 0″			Limit tertiary due to W-Kβ	2	
186°–42′– 0″			Limit tertiary due to W-Kα	2	
186°–19′–10″	5°– 5′–20″	0.1791	W-Kγ	3	0.1790
186°–10′–20″	5°–14′–10″	0.1842	W-Kβ	3	0.1842
180°–59′– 0″	10°–25′–30″	1.0958	W-Lγ_1	1	1.0955
180°–44′– 0″	10°–40′–30″	1.1228	Ge-Kγ	1	1.121
180°–38′–30″	10°–46′– 0″	1.1314	Ge-Kβ	1	1.131
179°–34′–50″	11°–49′–40″	1.2413	W-Lβ_2	1	1.2417
179°–25′– 5″	11°–59′–25″	1.2581	Ge-Kα_1	1	1.257
179°–22′– 0″	12°– 2′–30″	1.2634	Ge-Kα_2	1	1.261
179°–13′– 0″	12°–11′–30″	1.2789	W-Lβ_1	1	1.2792
179°– 2′–30″	12°–22′–30″	1.2968	W-Lβ_4	1	1.2987
177°–20′– 0″	14°– 4′–30″	1.4728	W-Lα_1	1	1.4735
177°–13′– 0″	14°–11′–30″	1.4857	W-Lα_2	1	1.4845

The spectrum curve leads to the identification of the following kinds of radiation: (1) scattered K series tungsten rays with primary wave-lengths, through three orders: (2) scattered L series tungsten rays with unmodified wave-lengths (the intensities are surprisingly great. This portion of the spectrum was determined at a different time from the K series portion, under possibly more sensitive conditions); (3) fluorescent K series germanium rays, whose wave-lengths have here been measured more accurately than ever before; (4) tertiary rays due to W-Kβ and W-Kα *in two orders* (the first order tertiary hump due to W-Kβ is not separated from the W-Kα peak. The limit should come, by calculation, slightly less than 7′ from the beginning of the W-Kα peak); and (5) evidences of other tertiary radiation, as shown, for example, by the relatively great height of the W-Lα_2 peak. Calculation shows that tertiary rays produced by germanium L photo-electrons, which are removed from their orbits by impact of the W-Lβ rays, should appear at the angle of the W-Lα_2 peak. It appears, therefore, that tertiary rays from a multitude of sources and in intensities measurable by a sufficiently accurate and sensitive apparatus are present in the X-ray beams scattered by matter.

4. Scattering from a Paraffin Block.—In our previous experiments with carbon radiators and tungsten primary rays we used a polished graphite plate. The W-Kβ and W-Kα rays scattered by the graphite had wave-lengths identical with those of the primary rays, and there was no comparable radiation at an angle 14′ larger, as demanded by A. H. Compton's theory. We have repeated these experiments, this time using a paraffin block as radiator. The results are identical with those obtained with graphite, a diagram for which is shown in Fig. 1 of the second note referred to above (l. c.). This answers the possible objection that the failure to obtain the shifted rays might be due to the crystalline nature of the graphite as opposed to the amorphous state of paraffin.

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[2] These PROCEEDINGS, **9**, 413, 419 (Dec. 1923); **10**, 41, 47 (Jan. 1924).

EXHIBIT OF TELEPHONIC EXCITATION OF ACOUSTIC PRESSURE[1]

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1. In *Science* (**24**, p. 155, 1921), I described a series of simple experiments bearing on the nature of the acoustic forces observed in connection with telephone-blown pipes. Having occasion to test this work recently, I obtained a series of repulsions as well as the former attractions. This induced me to repeat the experiments with the bifilar suspension shown in figure 1. Here TT' are the telephones excited by a small inductor and