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THE SECONDARY AND TERTIARY RAYS FROM CHEMICAL ELEMENTS OF SMALL ATOMIC NUMBER DUE TO PRIMARY X-RAYS FROM A MOLYBDENUM TARGET

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Spectrometric experiments described by Clark and Duane in four notes[2] prove that the X-rays from a secondary radiator due to primary tungsten rays contain: (1) scattered rays with wave-lengths equal to those in the primary beam (both the *K* and the *L* series of tungsten); (2) fluorescent rays with wave-lengths equal to those in the primary spectra of the chemical elements in the radiator; and (3) tertiary rays, produced by the impact of *K* and *L* photo-electrons on neighboring atoms. According to these experiments the short wave-length limits of the tertiary rays from various radiators agree closely with the equation

$$\lambda = \frac{\lambda_1\lambda_2}{\lambda_2 - \lambda_1}, \qquad (1)$$

derived from the theory which gives the kinetic energy of the photo-electrons. In this equation, λ represents the short wave-length limit of the tertiary rays, λ_1, the primary wave-length and λ_2, a critical absorption wave-length characteristic of a chemical element in the secondary radiator.

Continuing these researches, we have used primary rays from a water-cooled molybdenum target tube and secondary radiators consisting of chemical elements of low atomic number—lithium, graphite, ice, rock-salt aluminium and sulfur. The wave-lengths of the *K* series lines of molybdenum lie in the neighborhood of .7 Ångström; whereas those in the *K* series of tungsten lie in the neighborhood of .2 Ångström. The notes referred to describe the experimental arrangement. The storage battery and the generator-transformer-kenotron system in parallel with each other supplied a current through the tube of 16 milliamperes at 38,000 volts. The weakness of the currents in the ionization chamber of the spectrometer necessitated the use of somewhat wider slits than in the previous experiments with a tungsten-target-tube. The widths of the two slits between the secondary radiator and the calcite analyzing crystal were measured in order to make proper corrections in estimating the dis-

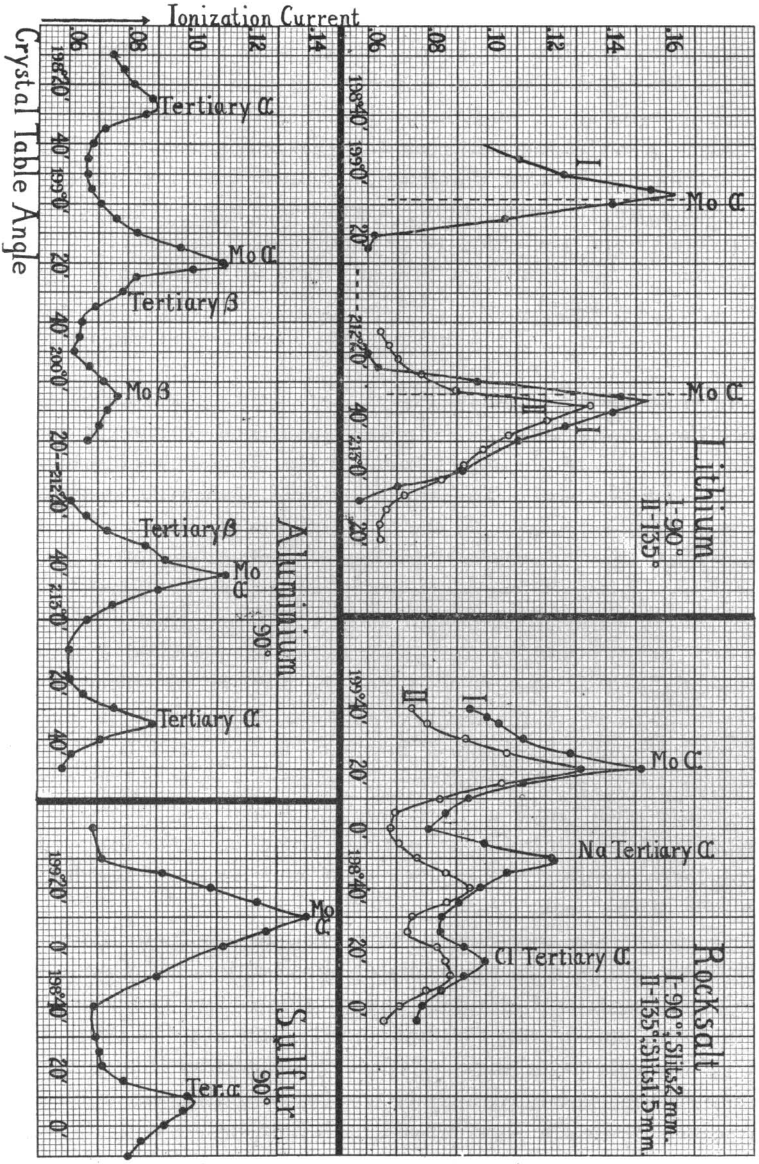

FIGURE 1

placement of the *limits* of the tertiary radiation. In order to estimate the true position of the limit of the tertiary radiation on the crystal table angle scale one must add a certain slit correction to the angle corresponding to the point where the curve begins to rise. This correction equals half the sum of the widths of the two slits divided by the distance between them, the ratio being expressed in angular measure. Similarly, in order to calculate where the tertiary hump ought to begin to rise, one should add to the angle corresponding to the top of the peak representing the undisplaced ray the angle $\Delta\theta$ corresponding to the wave-length difference $\Delta\lambda = \lambda - \lambda_1$ (from equation 1) and then subtract from this sum the above slit correction. The distance between the slits amounted to 500 mm. In some experiments (lithium, aluminium) each slit had a width of 1.5 mm., and in others (ice, rock-salt, sulfur), a width of 2 mm. The corresponding slit corrections are, therefore, 10′20″ and 13′45″, respectively. Figure 1 shows some of the results for lithium, rock-salt, aluminium and sulfur as secondary radiators.

We have performed the following experiments with the results mentioned:

1. *Lithium.*—Two complete experiments with angles of 90° and 135° between the primary and the secondary rays, each experiment with readings on both sides of the direct beam of the spectrometer, which establishes an accurate zero. The curves show a somewhat unsymmetrical *single peak* in every case. In the 90° experiments, the top of the peak lies at an angle about 2′ greater than that at which the unshifted line usually appears, and in the 135° experiments about 4′ larger. There is no evidence of peaks which, according to A. H. Compton's theory, should lie at about 14′ (at 90°) and 22′ (at 135°) from the unshifted α peaks. On the other hand, the value of $\lambda - \lambda_1$ for the tertiary radiation is so small for lithium as to merge the tertiary band completely with the unmodified $K\alpha$ peak. Its actual existence, however, is indicated by three facts: (1) comparatively great intensity; (2) apparent shift in the top of the peak, greater with larger angle between primary and secondary beams, analogously to the shift in the tertiary hump *maxima* observed in our tungsten experiments; (3) smaller slope and bulge on the long wave-length side of the peak.

2. *Graphite.*—One experiment with readings on both sides of zero, at 90°. Our results with this radiator agree with A. H. Compton's well known experiments with graphite and paraffin. Two peaks of about the same intensity appear, one the unmodified α line and the other displaced about 16′ towards larger angles. While this is greater than the 14′ found by Compton this experiment may be construed as being favorable to either theory, since $\Delta\lambda$ for the short wave-length limit agrees with its calculated value for tertiary radiation when proper correction for slit width is made, at least as to order of magnitude.

3. *Ice.*—An experiment at 90°. The second peak is displaced 19′ from

the first, 5′ more than expected upon the quantum theory; but here again $\Delta\theta$, for the short wave-length limit, agrees with the value 11′30″ calculated for the tertiary band, as nearly as can be estimated.

4. *Aluminium.*—Two complete experiments at 90° on both sides of zero and including also the β line. The tertiary radiation peak appears with a maximum about 50′ from the $K\alpha$ peak. The displacement of the limit corrected for slit widths agrees almost exactly with that calculated for tertiary radiation, about 40′. In addition, there is evidence of humps on the short wave-length sides of the α peaks produced by tertiary radiation due to the molybdenum $K\beta$ line.

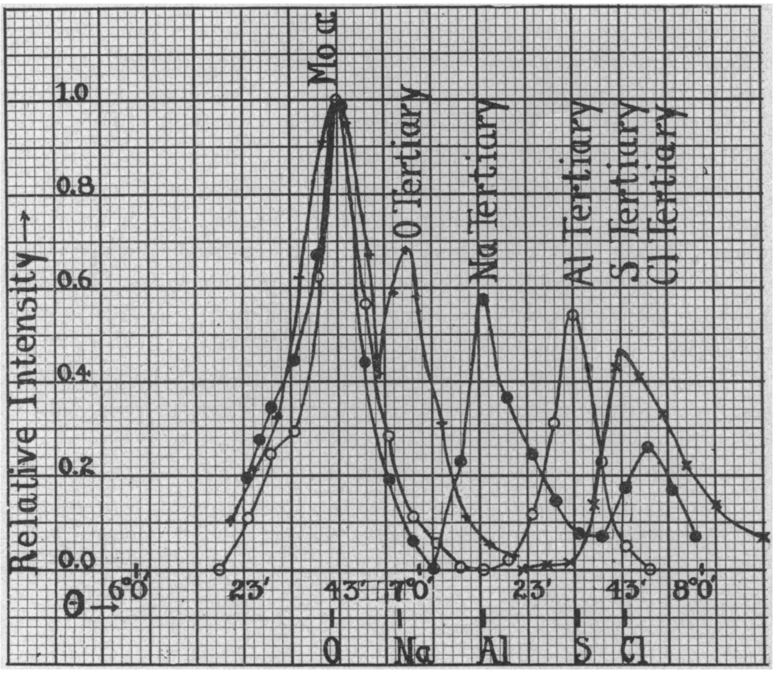

FIGURE 2

5. *Sulfur.*—An experiment at 90° in which the second hump is still further displaced than in the case of aluminium. $\Delta\theta$ is approximately 67′ and agrees with the value calculated from the tertiary radiation equation.

6. *Rock-salt.*—Two complete experiments at 90° and one at 135°. Here three peaks appear, one the $K\alpha$, the next the tertiary radiation from sodium and the third that from chlorine. There is no evidence of a line shifted in accordance with the theory of the transfer of quanta to single electrons. The short wave-length limits agree approximately with those calculated for sodium 26′ 20″, and for chlorine 76′ and these are the same

in the experiments at both 90° and 135°, though the maxima shift over in the latter case.

Figure 2 is a composite diagram showing the results for ice, rock-salt, aluminium and sulfur reduced to the same scale and with the $K\alpha$ line at the same point. The ordinates represent the heights of the peaks only. The theoretical positions for the points where the tertiary humps begin to rise are indicated at the bottom of the diagram. They do not differ from the positions estimated for the curves by more than about two per cent of λ. This is as close as can be reasonably expected in view of the size of the currents measured, the number of points plotted, the intermingling of the peaks, etc.

The following facts are at once apparent: (1) The *position of the modified peak is a function of the atomic number,* the displacement increasing with increase in atomic number; (2) the intensities of the shifted peaks decrease with increase in atomic number (proper allowance should be made in the case of ice and rock-salt for the fact that while all the atoms coöperate in producing the $K\alpha$ peak, only part produce a given modified peak, O in ice, and Na and Cl separately in rock-salt); (3) the position of the short wave-length limit of the modified peak is in approximate agreement in every case with that calculated for tertiary radiation.

These facts, together with the results of experiments previously reported with longer and shorter wave-lengths in the primary beam (K and L series of tungsten)[2] and with secondary radiators of chemical elements ranging in atomic number from 6 to 60 indicate that the rays with wave-lengths shifted toward larger values should be ascribed to tertiary radiation produced by the impacts of photoelectrons.

Experiments with longer primary rays are contemplated in an attempt to measure accurately the atomic energy levels of small magnitude.

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[2] These PROCEEDINGS, **9,** 413, 419 (Dec., 1923); **10,** 41 (Jan., 1924); **10,** 92 (March, 1924).