experiments, on which we are now working by both photographic and ionization methods, will suggest some way to clear up this puzzling situation.

Note: Since this paper was written we have built another spectrograph, of quite a different design, in a different part of the room, using a different molybdenum tube and a scatterer of a different element, aluminum. The photographs are even better than those with sulfur, and show the \( \alpha \) and \( \beta \) lines, in both the first and second orders, each with its Compton-shifted line about equal in strength to the unshifted line. The continuous spectrum shows also, at least in the first order, but there is not the slightest trace of a tertiary line.

1 Calculated from Bragg's \( N^4 \) law on the basis of Barkla's value of the absorption coefficient of aluminum.
2 B. A. Wooten, Physic. Rev., 13, 71–87, Jan., 1919. This ratio is for the rays after emergence from his tube.
3 D. L. Webster, these PROCEEDINGS, 10, 186–190, May, 1924.

COMPTON EFFECT: EVIDENCE ON ITS RELATION TO DUANE'S BOX EFFECT

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In the September number of these PROCEEDINGS, Duane\(^1\) and several of his collaborators published two papers describing experiments on secondary X-rays, with a wooden box which could be put around the tube and secondary radiator and removed again without disturbing the rest of the apparatus. They find in these experiments that with the box in place they obtain a peak in the spectrum similar to the peaks found by other observers and explained by the Compton theory, but when the box is removed, the peak disappears. This effect they explain as a result of tertiary rays from the wood, and they draw the conclusion: "These experiments indicate that, if we look at X-radiation from the point of view of the emission of radiation quanta, having a certain amount of energy and momentum, we must assume that the momentum and energy are transferred not to single electrons but to atoms and groups of atoms, substantially as represented in a theory recently published on the transfer of radiation momentum to matter in quanta."

The purpose of this paper is to discuss further evidence on this matter, leading us to doubt this conclusion. Some of this evidence is obtained from
calculations from Barkla's data on scattering. The rest is from certain aspects of Ross' experiments which were not discussed in his earlier papers, but which have taken on a new importance because of the paper quoted on preceding page.

With regard to the cause of their "box effect," Duane and his collaborators make the statement; "No one can doubt that a considerable amount of X-radiation must be passing in all directions through a box of the kind described, containing an X-ray tube in action. This radiation must have the wave-lengths characteristic of the secondary and tertiary radiation belonging to the chemical elements composing the walls of the box and whatever there is inside of it." Without at this point discussing such doubts although we have them for the cases in question, we must note the fact that if such secondary and tertiary rays from one part of the box strike another part, they will give rise to quaternary rays, and rays of still higher order, with wave-lengths shifted from the primary, not only by the amount given by a single application of Duane's tertiary wave-length equation, but by a second such shift, and more. Consequently if such rays are to be considered, such doubly and triply shifted peaks must be looked for in the spectra. On one of their published spectra, for molybdenum rays scattered from sulfur, the singly shifted peak is slightly stronger than the unshifted, even after a deduction for their β-line and sulfur L series effects. This would indicate that the singly shifted rays from the box are actually slightly stronger than the primary at the scatterer, and presumably also at almost any part of the box. The doubly shifted rays therefore should arise from a source as powerful as that of the singly shifted rays, and should be equally strong. But the doubly shifted peak does not appear at all.

This in itself contradicts their theory when carried to this logical conclusion. Moreover, it permits us to calculate the box effect without making any allowance for more than one scattering of any one quantum by the box.

An exact calculation of the amount of radiation returned by the box, even with only single scattering or single tertiary re-emission, is complicated by many minor factors which, so far as questions of order of magnitude are concerned, may as well be neglected. For a rough calculation, then, we may assume Barkla's well known mass-scattering coefficient, 0.2 cm.²/gm., to represent the strength of all re-emitted rays, scattered and tertiary, and neglect all non-uniformity of their space distribution and all increase of absorption by obliquity of incidence and emergence in the walls of the box. With these simplifications, it appears that the radiation returned by the wall on the side of incidence is the same as that emitted by a new source of rays whose total emission bears a ratio to the total flux of energy striking the wall, equal to \((\sigma/2\mu) (1 - e^{-2\mu T})\), where \(\sigma\) and \(\mu\) have the usual meanings and \(T\) is the thickness of the wall. This formula, applied to the case of the human
body subjected to very penetrating rays, gives results of the order of magnitude to account for the experimental evidence quoted by Duane and his collaborators in support of the quoted statement about scattered rays; and calculations on a similar basis account readily for the scattered rays on the emergent side, also mentioned in this connection. Applied to the present case, however, with a box of thickness $T = 2$ cm. (an estimate from their diagram) and with $\sigma/\rho = 0.2$ cm.$^2$/gm. and $\mu/\rho = 0.86$ cm.$^2$/gm. (the latter being the mean of values given by Olson, Dershem and Storch$^3$ for carbon and oxygen), the fraction in question is only 0.10. Moreover, since rays can leave the target only on the forward side, the flux of energy to be multiplied by this factor is only half the radiation produced in the target. Consequently, if these data are correct, the box as a whole should act as a source not more than 0.05 as strong as the target.

As the walls of the box are on the average considerably further from the block under examination (the "scatterer") than the target is, and most of the illuminated part of the walls is back of the scatterer, the rays received from the box by its front face should be very considerably less than 0.05 of those received from the target, and the box-effect peak in the spectrum of its rays should be correspondingly weak as compared to the peak of the primary wave-length. As the observed box-effect peak is actually at least as strong as the other, this leads us to believe that Duane's experiments demand some other explanation.

The experiments of Compton and Woo$^4$ likewise, show peaks of the same order of intensity in the Compton-shift position, which cannot be explained on such a basis and for which Compton's theory seems to be the only explanation yet at hand.

In Ross' experiments with the exception of one case, fig. 8 of his paper in these PROCEEDINGS, July, 1924,$^2$ there is still another factor in the situation. For in all but this one of his numerous experiments, he used the box shown in fig. 1, containing no wood. The only materials in this box containing any light elements were the tube itself, the lead-glass top and bottom plates, the hard-rubber plate holding the tube, the scatterer and its paraffin supporting post. Of these, the lead-glass plates were in the shadows of the target and the cathode, respectively; and all the others except the tube itself were back of the scatterer, which was opaque to these
rays, and therefore they could not send any rays to the surface under examination, except by a second scattering. As the combined strength of the rays from the two pieces in question, the hard-rubber plate and the paraffin post, was only about 0.02 of the strength of the primary rays, and the lead walls would return only about 0.0005 of the rays of this frequency striking them, the maximum strength of tertiary rays from light elements that could be directed in this way toward the top of the scatterer is 0.00001 of the radiation from the source, even without any allowance for the effect of increased distance. Ross' experiments must therefore be free from any detectable trace of the "box effect."

The only light atoms that might conceivably influence his experiments are the oxygen atoms in the glass of the tube. Approximate calculations show that their effect might possibly amount to a few per cent if the scatterer was in direct contact with the tube. The calculations are complicated by the phenomena of excess scattering, and the best way to determine the influence of the glass is by experiment. Fortunately the data are readily available, in Ross' photographs with graphite, in the paper quoted above. If the glass sent any appreciable tertiary rays to the scatterer, there would be the same doubly shifted peak discussed above. Careful examination of Ross' original negatives, even ones with strong Compton lines, such as fig. 8 of that paper, fails to reveal any such doubly shifted lines.

Finally there is one more line of evidence, namely the fact that in Ross' photographs of the carbon-scattered rays at various angles, the shifted line changes its position exactly according to Compton's theory, and much more than could be explained by Duane's hypothesis of filtering; and that for rays scattered at 30° it is actually on the short-wave side of Duane's theoretical short-wave limit.

Altogether, the evidence reviewed here seems to us definitely contrary to Duane's box-effect theory as an explanation of the Compton peaks, either in his experiments or in those of Compton and Ross, and leaves Compton's theory of the scattering of quanta by single electrons as the only theory advanced yet that will explain them.

4 A. H. Compton and Y. H. Woo, these PROCEEDINGS, 10, 271–273, June, 1924.