



Collision of photons by the use of x-rays  
by Roy V Wiegand

A THESIS Submitted to the Graduate Committee in partial fulfillment of the requirements for the degree of Master of Science in Engineering Physics  
Montana State University  
© Copyright by Roy V Wiegand (1940)

Abstract:

An attempt was made to detect radiation formed by the collision of photons in two crossing X-ray beams by examining all possible directions from the crossing point. X-ray film was placed on the six sides of the collision point and long exposures taken to determine if radiation was given off in any direction. This radiation would probably be most intense near the bisector of the angle between the two beams and would have a wave-length given by  $\lambda = \lambda_0 / (1 + \cos \phi)$  where  $\lambda_0$  is the wave-length of the colliding photons and  $\phi$  is the angle between them.

The two separate beams coming from a single source were brought together by reflection from calcite crystals. The crystals also served to eliminate all but the desired wave-length in the final crossing beams. The Lal line of tungsten was used since its intensity and reflecting angle were most suitable. Many preliminary exposures were necessary to align the tube, slits and crystals and to locate sources of scattered radiation which were then eliminated by lead shielding.

No "collision" radiation of sufficient amount to register on the photographic film was found even though exposures of 25 hours were used.

COLLISION OF PHOTONS  
BY THE USE OF X-RAYS

by

ROY V. WIEGAND

A THESIS

Submitted to the Graduate Committee

in

partial fulfillment of the requirements

for the degree of


Master of Science in Engineering Physics

at

Montana State College

Approved:

  
Arthur J. M. Johnson  
In Charge of Major Work

  
Arthur J. M. Johnson  
Chairman, Examining Committee

  
J. B. Adams  
Chairman, Graduate Committee

Bozeman, Montana

June, 1940

RECEIVED  
LIBRARY  
MONTANA STATE COLLEGE  
BOZEMAN, MONTANA

N378

W635c

cop. 2

TABLE OF CONTENTS

	Page
ABSTRACT - - - - -	3
HISTORICAL BACKGROUND - - - - -	4
EXPERIMENTAL PROCEDURE - - - - -	6
THEORY - - - - -	14
RESULTS AND CONCLUSIONS - - - - -	17
BIBLIOGRAPHY - - - - -	18

S 9-40 Thesis - Grad. committee, cop. 2

64115

WATERMILL  
BOND  
MADE IN U.S.A.

ABSTRACT

An attempt was made to detect radiation formed by the collision of photons in two crossing X-ray beams by examining all possible directions from the crossing point. X-ray film was placed on the six sides of the collision point and long exposures taken to determine if radiation was given off in any direction. This radiation would probably be most intense near the bisector of the angle between the two beams and would have a wave-length given by  $\lambda = \lambda_0 / (1 + \cos \phi)$  where  $\lambda_0$  is the wave-length of the colliding photons and  $2\phi$  is the angle between them.

The two separate beams coming from a single source were brought together by reflection from calcite crystals. The crystals also served to eliminate all but the desired wave-length in the final crossing beams. The  $L_{\alpha 1}$  line of tungsten was used since its intensity and reflecting angle were most suitable. Many preliminary exposures were necessary to align the tube, slits and crystals and to locate sources of scattered radiation which were then eliminated by lead shielding.

No "collision" radiation of sufficient amount to register on the photographic film was found even though exposures of 25 hours were used.

### HISTORICAL BACKGROUND

This problem and method of attack was suggested by Dr. Arthur J. M. Johnson of the Physics Department at Montana State College. Dr. Johnson became interested in the X-ray method of approach after Jauncey and Hughes failed to detect any collisions of light quanta, as mentioned below.

The problem has been investigated by several persons using various methods of approach. In 1929 G. E. M. Jauncey and A. L. Hughes<sup>7</sup> conceived the idea that two photons should be able to collide forming two new photons having different frequencies. These men computed the frequencies of the "collision" radiation which should be expected, as a function of the frequency and angle of collision of the two original beams of photons. A short time later<sup>8</sup> the experiment was actually performed using the rays of the sun as a source of photons and using the human eye as an instrument for detection of the expected collision photons. It was reported that no "collision" radiation could be detected. G. J. Gorter<sup>6</sup> also attempted to combine light quanta from the sun by concentrating filtered rays in a liquid and observing the results with a photographic plate. He, too, reported negative results.

The problem was also investigated at about this same time by S. Vavilov<sup>14</sup>, a Russian scientist, who used a different kind of visible light as a source of photons. Instead of using the sun for photon beams, as did Jauncey and Hughes, light of

condensed sparks was used. This experiment also showed negative results. The problem was considered by A. K. Das<sup>5</sup> of Calcutta, India, and although no actual experimental work was performed, he expressed the desire to try X-rays or gamma rays as a source of photons and suggested that some one with the necessary equipment available perform it using this photon source.

The theory of this problem has also been quite thoroughly discussed in two articles written since these above mentioned experiments were performed. In the first J. L. Synge<sup>13</sup> discussed the subject from the standpoint of the conservation laws. In the second article G. Breit and J. A. Wheeler<sup>1</sup> considered the problem from the standpoint of the collision area and density of the photon.

### EXPERIMENTAL PROCEDURE

An RB-1-4 General Electric Coolidge X-ray tube was arranged as shown in Figures 1, 2a, and 2b. Radiation from the target of the tube was limited to two beams by the use of horizontal slits  $s_1$  and  $s_3$ , and vertical slits  $s_2$ . The crystals C are located so that the beams are reflected from them to cross at the point P. The crystals and slits are arranged so that the paths are approximately equal and the crossing point is the same distance from the crystals as is the target.

In selecting the wave-length best suited to this experiment it was necessary to get a wave-length as long as possible in order to obtain a fairly large collision angle and yet to choose a line that would not be too highly absorbed in the air path used. The  $L_{\alpha 1}$  line of tungsten was used since it had the greatest intensity of the various lines with the right order of reflecting angle from calcite crystals. According to Siegbahn<sup>12</sup> the  $L_{\alpha 1}$  line of tungsten has a wave-length of 1.473 Angstrom units. For this wave-length the same author gives a value of  $14^{\circ} 4.3'$  for the reflecting angle from a calcite crystal. Upon examining Figure 1 it can be seen that for symmetry the angle between the rays at the target and at the collision point must be  $28^{\circ} 8.6'$ .

Compton and Allison<sup>2</sup> gives the relation for this absorption as  $I = I_0 e^{-\mu_m x}$  where  $I$  is the transmitted intensity for an initial intensity  $I_0$  of a ray passing for a distance  $x$

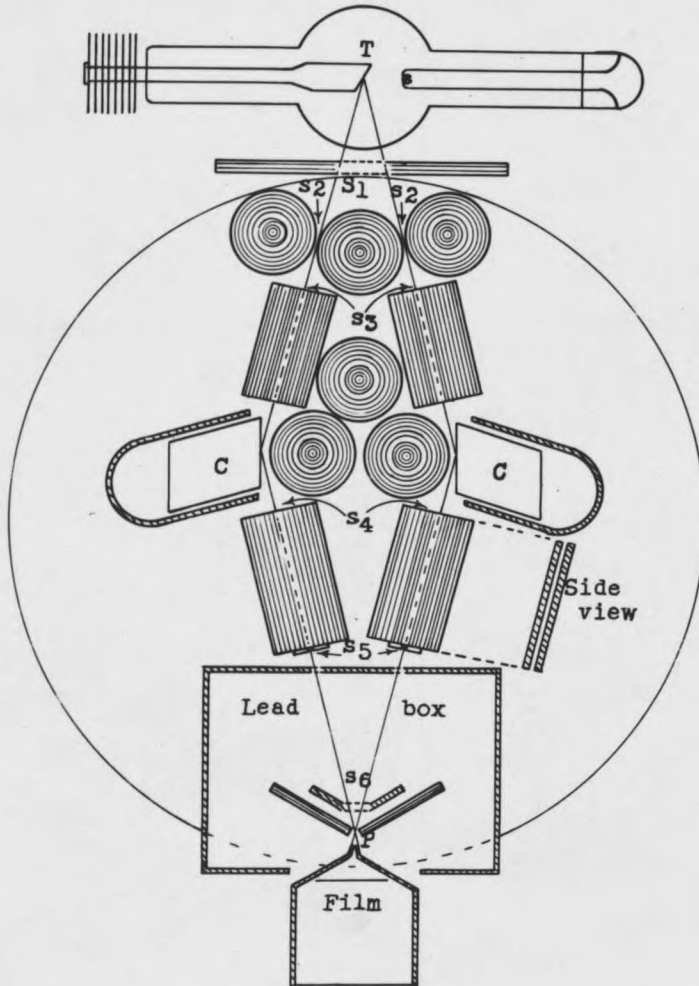


Fig. 1. ARRANGEMENT OF APPARATUS  
Shaded parts are lead.

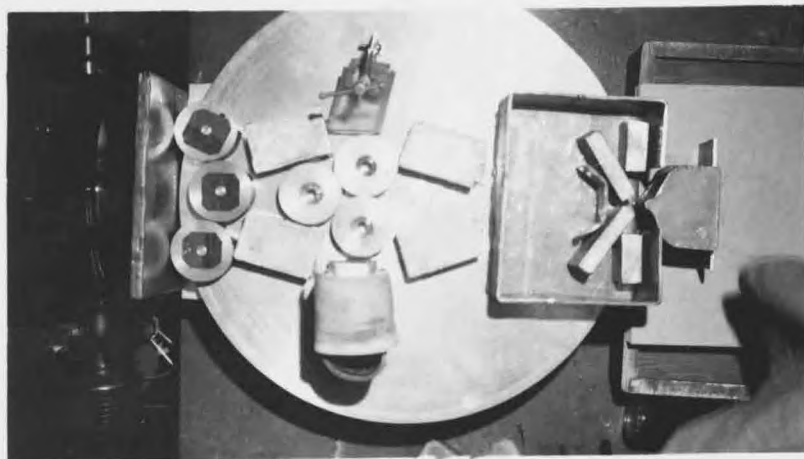


Figure 2a. TOP VIEW OF APPARATUS. Shielding removed from one crystal.



Figure 2b. SIDE VIEW OF APPARATUS. Shielding removed from one crystal.

through a substance having a mass absorption coefficient  $\mu_m$ . The value for  $\mu_m$  was taken as 8.3 from a table compiled by Compton and Allison<sup>3</sup>. Using the above information the ratio of intensities after passing through 50 cm. of air at an average pressure of 640 mm. of mercury and a temperature of 15° Centigrade was found to be:

$$\frac{I}{I_0} = 0.661$$

which shows that the beam has lost only about one third of its original intensity by absorption.

In operating the X-ray tube it was necessary to determine the most suitable operating potential because of limiting factors in the apparatus. Although the tube is a more efficient producer of  $L_{\alpha 1}$  lines at 70 kilovolts, it was found that better results could be obtained by using 40 kilovolts since the short K lines are eliminated at this low potential and therefore much scattered and secondary radiation is eliminated. This reduction of voltage was partially compensated by doubling the current through the tube. Compton and Allison<sup>4</sup> give for the relation of intensity of the given line to the potential  $I \sim \left(\frac{E}{E_q} - 1\right)^n$ , where the most reliable value of  $n$  is about 1.65.  $E$  is the potential across the tube and  $E_q$  is the potential required to remove the electron from its orbit. Using this empirical relation, the ratio of intensities is seen to be as follows:

$$\frac{I_{40}}{I_{70}} = \frac{\left(\frac{40}{8.4^*} - 1\right)^{1.65}}{\left(\frac{70}{8.4^*} - 1\right)^{1.65}} = 0.332$$

which shows that the intensity of the  $L_{\alpha 1}$  line is actually decreased to one third of its original value when the voltage is decreased to 40 kilovolts. This is a conservative value since the value of "n" becomes slightly smaller than 1.65 for values of  $\frac{E}{E_0}$  greater than four, making the actual loss not quite as great as it appears. If then the current through the tube is doubled, the intensity can be returned to two thirds of its original value without materially increasing the power used or increasing the working temperature of the tube.

The proper position for the X-ray tube was determined by passing a light beam in the reverse direction along the two paths and thereby casting an image of the slits on the target T (Figure 1). The correct angle for the calcite crystals was found by trial and error as was the position of the set of vertical slits  $s_5$ . Figure 3 shows exposures of the main X-ray beams on photographic film which were used to determine when the crystals and slits were in the proper positions to give beams well matched in intensity and size. The peculiar exposures obtained in numbers 3a and 3c were found to be due to secondary radiation from the iron clamps supporting the crystals. Much difficulty was encountered in determining the actual source of this radiation. This trouble was finally

\*Siegbahn<sup>11</sup>

eliminated by completely shielding the clamps with sheet lead. It was also found necessary to shield the photographic plate by the use of lead boxes shown in Figure 1, from scattered and secondary radiation coming from the walls and from various objects in the room.

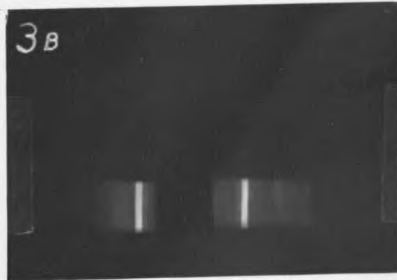
Numbers 3b and 3c show the  $L_{\alpha 1}$  line together with other reflected radiation. Since it was desirable to have only a single wave-length and have a narrow beam, the set of vertical slits  $s_5$  was inserted to limit the width of the beam and exclude all but the  $L_{\alpha 1}$  radiation. Numbers 3d and 3e were taken after the slits  $s_5$  were inserted.

The actual search for "collision" radiation was not started until test exposures showed that the colliding beams were approximately equal in size and intensity and until the exposures showed no blackening except the actual beams of  $L_{\alpha 1}$  radiation. Much more time was required for the adjustments and aligning exposures than for the actual search for "collision" radiation.

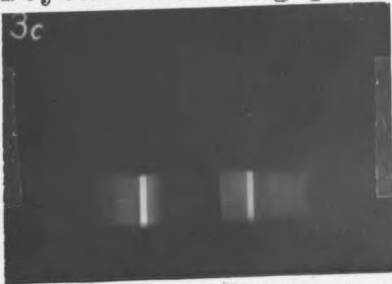
Exposure number 3e of Figure 3 was taken at the crossing point of the beams and number 3f was taken at a distance of about one eighth inch beyond the crossing point. These exposures were made to determine if any interference pattern could be observed in the region where the two beams were occupying the same space. Exposures 3g and 3h were taken beyond the crossing point. These were long exposures taken with the



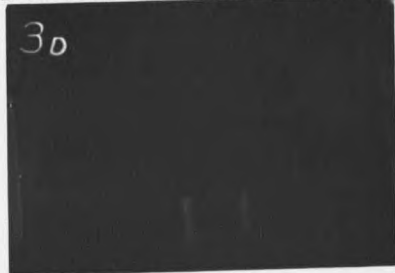
Aligning Exposure  
 $\frac{1}{2}$  hr. 70 K.V. 4 M.A.  
Beyond crossing point



Aligning Exposure  
1 hr. 45 K.V. 8 M.A.  
Before crossing point



Aligning Exposure  
1 hr. 45 K.V. 8 M.A.  
Before crossing point



Aligning Exposure  
1 hr. 45 K.V. 4 M.A.  
Slits  $s_5$  inserted



Test for Interference  
1 hr. 45 K.V. 4 M.A.  
At crossing point



Test for Interference  
1 hr. 45 K.V. 4 M.A.  
 $\frac{1}{8}$ " Past crossing pt.



Test for Collision  
Radiation in Box  
6 hrs. 45 K.V. 4 M.A.  
1" Past crossing pt.



Test for Collision  
Radiation in Box  
25 hrs. 45K.V. 4M.A.  
 $\frac{3}{4}$ " Past crossing pt.

Figure 3.

has been identified with a specimen that was given in the caption-  
letter to me in 1940.

As this type material is all in the collection of the  
Smithsonian Institution, it is possible that the specimens were given  
to me by the Smithsonian Institution. (It is also possible that the  
specimens were given to me by the Smithsonian Institution in the  
collection of the Smithsonian Institution.)

THEORY

Since light has definite corpuscular properties it would soon reasonable to expect that under properly controlled conditions these corpuscles might be caused to collide. The photons formed by such collisions might be expected to have frequencies different from those of the colliding photons since there might be a resulting new distribution of energy.

Using the generally accepted laws of conservation of energy and momentum the "collision" radiation should have definite frequencies which are easily computed for given directions. After deriving an expression for the frequency, as a function of angle, from these laws, it is only necessary to choose an angle and the frequency to be expected is determined. This relation of frequency to angle is shown in the following derivation:

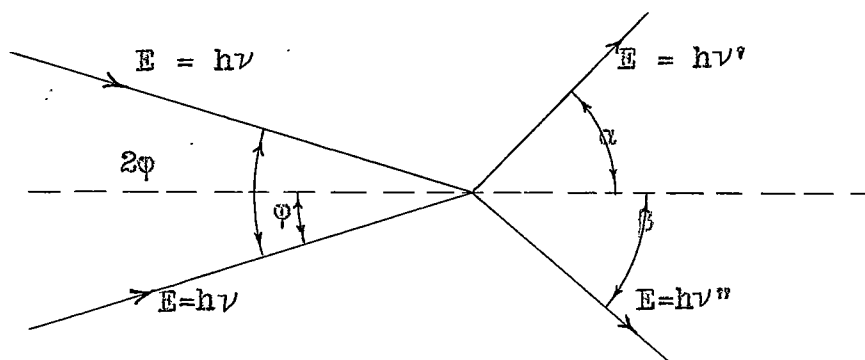


Figure 5.

Let two photons of equal energy from two beams of X-rays meet at an angle of  $2\phi$  as in Figure 5.

Assume that two new photons are formed by the collision and leave the point of intersection at angles  $\alpha$  and  $\beta$  with the bisector of the collision angle. Applying the law of conservation of energy we have:

$$(1) \quad 2h\nu = h\nu' + h\nu''$$

and from the law of conservation of momentum

$$(2) \quad h \frac{\nu'}{c} \sin\alpha = h \frac{\nu''}{c} \sin\beta$$

$$(3) \quad h \frac{\nu'}{c} \cos\alpha + h \frac{\nu''}{c} \cos\beta = 2h \frac{\nu}{c} \cos\varphi$$

Solving equation (3) for  $\cos\beta$

$$\cos\beta = \frac{-\nu' \cos\alpha + 2\nu \cos\varphi}{\nu''}$$

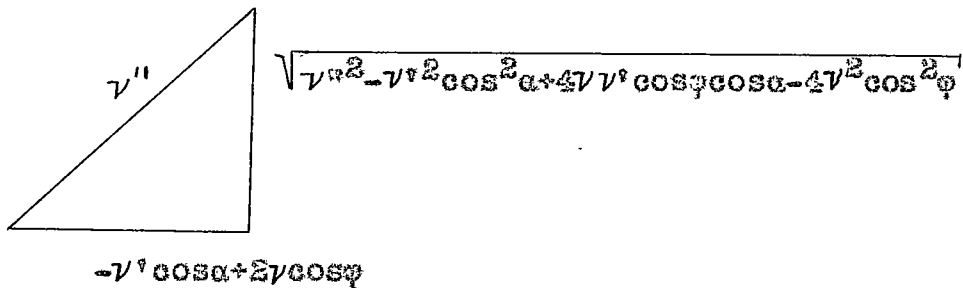


Figure 6.

Using the right triangle of Figure 6 to find  $\sin\beta$

$$\sin\beta = \frac{\sqrt{\nu''^2 - \nu'^2 \cos^2\alpha + 4\nu\nu' \cos\varphi \cos\alpha - 4\nu^2 \cos^2\varphi}}{\nu''}$$

Substituting in equation (2) and eliminating  $\nu''$  by use of equation (1)

$$\nu' \sin\alpha - \sqrt{4\nu^2 - 4\nu\nu' + \nu'^2 - \nu'^2 \cos^2\alpha + 4\nu\nu' \cos\varphi \cos\alpha - 4\nu^2 \cos^2\varphi} = 0$$

Simplifying:

$$-4\nu^2(1-\cos^2\varphi) + 4\nu\nu'(1 - \cos\varphi\cos\alpha) = 0$$

$$\nu' = \frac{\nu(1-\cos^2\varphi)}{(1-\cos\varphi\cos\alpha)}$$

is the expression for the "collision" radiation frequency as a function of the initial frequency, angle of collision, and angle of departure.

For the two angles  $\alpha = 0$  and  $\alpha = \pi$  this equation reduces to:

$$\nu' = \nu(1 + \cos\varphi) \quad \text{for } \alpha = 0$$

$$\nu'' = \nu(1 - \cos\varphi) \quad \text{for } \alpha = \pi.$$

Hughes and Jauncey<sup>9</sup> considered the radiation in these two directions only and obtained the expressions given above.

The absence of an interference pattern in exposure 3e and 3f can be understood quite easily for according to elementary interference theory the distance between interference fringes varies directly as the wave-length and inversely as the tangent of one-half the angle between the beams. Since the  $L_{\alpha 1}$  line of tungsten has an exceedingly short wave-length compared to that of visible light, the angle between the beams would necessarily have to be much smaller than the angle here used if these effects were to be made visible.

### RESULTS AND CONCLUSIONS

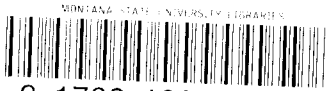
Exposures 3g and 3h of Figure 3 show prints of typical test films. On these, as on all test films, no "collision" radiation was observed. Negative results were also obtained from test films placed almost completely around the intersection of the two beams. No "collision" radiation was detected in any direction from the intersection of the beams. Since there was no trace of "collision" radiation with 25 hour exposures, it was not thought desirable to make longer exposures with the equipment available.

The Geiger-Müller counter was also used in an attempt to detect the "collision" radiation. Since the background count, however, was so great that it masked any effect which might have been present, the counting method was abandoned.

It can be concluded from these experiments that if X-rays are composed of photons and if these photons can collide, the number of collisions is too small to be detected by the present method of attack.

BIBLIOGRAPHY

1. Breit and Wheeler, Phys. Rev. 46, 1087-91 (1934)
2. Compton and Allison, X-rays in Theory and Experiment, 2nd Ed., Page 9, D. Van Nostrand, New York (1935)
3. Ibid. 2, Page 522.
4. Ibid. 2, Page 81.
5. Das, Phys. Rev. 57, 94-5 (1931)
6. Gorter, Physica I, 199-200 (1934)
7. Hughes and Jauncey, Phys. Rev. 33, 290 (1929)
8. Ibid. 7, Phys. Rev. 35, 1439, (1930)
9. Ibid. 7, Phys. Rev. 45, 217 (1934)
10. Ibid. 7, Phys. Rev. 45, 217 (1934)
11. Siegbahn, The Spectroscopy of X-rays, Lindsay Translation, Table II, page 247, Oxford University Press, London (1925)
12. Ibid. 11, Tables V, VI, Page 251, 257
13. Synge, Phys. Rev. 45, 500-1 (1934)
14. Vavilov, Phys. Rev. 36, 1590 (1930)



3 1762 10022687 5

N378

64115

W635c

cop.2

Wiegand, R.V.

Collision of photons by the  
use of x-rays.

DATE

01 10 72

N378

64115

W635c

cop.2