Scattering of 250 mev Photons by Free Electrons

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The paper reports measurements of the ratio of the scattering cross section for photons of 250 mev by free electrons in a Be target to the pair production cross section. The apparatus counted the recoil electrons and the pair electrons and positrons in the energy intervals 235-247 and 222-233 mev.

The observed ratios agree within the accuracy of the experiment with those deduced from the Bethe-Heitler formula for pair production and the Klein-Nishina-Tamm theory for Compton scattering.

IT is well known that the Klein-Nishina-Tamm formula for the differential cross section for the scattering of photons by free electrons has been verified by numerous experiments[1] in the region of incident photon energies up to 20 mev, with an accuracy of about 10%. Recently, measurements of the total cross section of Compton scattering at energies of the order of hundreds of mev have also been reported.[2] In the present paper we report on measurements of the Compton cross section using the photon beam of the 250 mev synchrotron, selecting particularly those scattering events in which the photon gave up nearly the whole of its energy to the recoil electron.

The pair electrons and positrons, as well as the Compton electrons emitted by the Be target passed through an analyzing magnet. The apparatus registered simultaneously the number of positrons, $N_+ = N_P$, and the total number of electrons (from pairs and recoil) $N_- = N_P + N_C$. The number of recoil electrons was then determined as the difference $N_C = N_- - N_+$. The ratio of this number to the number of pairs (i.e., the number of observed positrons) was compared with the theoretical value calculated from the formulas for pair creation and Compton scattering. The apparatus used for this experiment (Fig. 1) consisted of a collimator, cleaning magnets, the target, the analyzing magnet, and the counting devices.

The beam from the synchrotron was collimated by means of a lead block of 15 cm thickness, with an aperture of 5 mm diameter. The collimator was placed at a distance of 13 meters from the synchrotron. The measuring instruments were placed in a separate room, which was separated from the synchrotron by a 1.5 meter concrete wall. The whole passage of the beam from the collimator to the target was enclosed in a vacuum chamber. On entering the vacuum chamber the beam passed for 40 cm through a cleaning magnetic field of 7000 oersteds. This field removed all charged particles created in the beam on the way to the collimator and within the collimator. However, photons scattered in the collimator walls and traveling at an angle to the axis of the beam could also produce charged particles in the walls of the vacuum chamber, which could be recorded. For this reason a second cleaning field, of strength 3000 oersteds and 10 cm length was provided near the exit of the vacuum chamber.

The field of the analyzing magnet used in the apparatus had axial symmetry. The strength of the field could be varied over a wide range; in the center it could reach 13,200 oersteds over an aperture of 10 cm.

Electrons and positrons of high energy, traveling nearly in the direction of the beam, were deflected in such a way that on leaving the field they were moving along a straight line through the center of the magnet forming an angle α with the beam direction. This angle α depends on the strength and shape of the magnetic field, and the particle energy. From the knowledge of the variation of the field intensity with the distance from the axis one can calculate the orbit of an electron of given energy, and hence the final deflection α. Figure 2 shows the variation of this angle with the electron energy.

The electrons and positrons emitted by the target and deflected appropriately by the magnet were recorded in a counter telescope using twofold coincidences.

In the course of the measurements the field of the analyzing magnet was reversed systematically, so that each measurement was carried out with the field in both directions. This eliminated any inaccuracy in the alignment of the counter telescopes with the axis of the magnet and also any individual variation between the counters or the counting channels. The telescopes were placed in such a way as to count electrons and positrons of a high energy close to the maximum energy of the beam. In this way one therefore measures not the integral cross section, but the partial cross section for the production of a recoil electron with an energy in a fixed interval. Such a cross section,

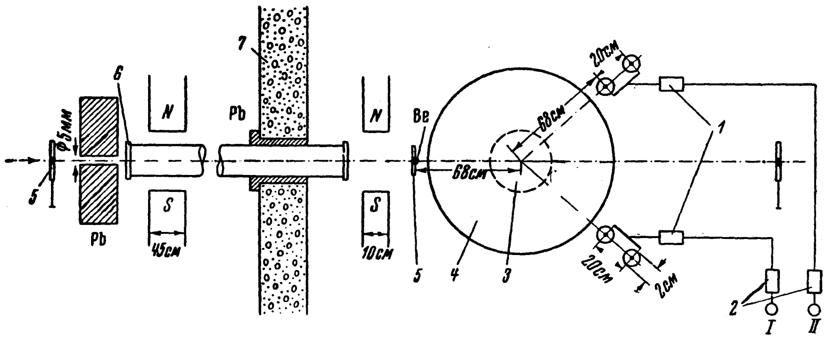

FIG. 1. Sketch of apparatus: 1-coincidence selectors, 2-output scalers, 3-pole pieces, 4-magnet coil, 5-X-ray films, 6-thin transparent window, 7-concrete wall of 1.5 meters.

in contrast to the total cross section which includes all final energies, will be called "semi-integral".

For a very small energy interval this "semi-integral" cross section goes over into the differential cross section. If we allow for the inhomogeneity of the incident photon beam, characterized by a function $f(\gamma)$ (where γ is the photon energy in units of mc^2) the measured cross section can therefore be expressed by the relation

$$\int_{\gamma_{20}}^{\gamma_{21}} \int_{\gamma_2+0.5}^{\gamma_{max}} f(\gamma)\, \sigma_C\, d\gamma_2\, d\gamma = \sigma_C^*,$$

where the upper limit of integration with respect to γ is the maximum energy of the photons in the incident spectrum, σ_C the differential cross section, γ_2 the energy of the recoil electron, and γ_{20} and γ_{21} the limits of the energy interval selected by the apparatus.

The "semi-integral" cross section for pair electrons can be expressed similarly:

$$\int_{\gamma_{20}}^{\gamma_{21}} \int_{\gamma_2+1}^{\gamma_{max}} f(\gamma)\, \sigma_p\, d\gamma_2\, d\gamma = \sigma_p^*,$$

where σ_P is the differential cross section for pair creation, γ_2 the energy of the electron (or positron) in the pair, and γ_{20} and γ_{21} have the same meaning as before.

The determination of the absolute value of this "semi-integral" cross section meets with difficulties which arise from the fact that both the number of incident photons and their spectrum are not sufficiently accurately known. We therefore

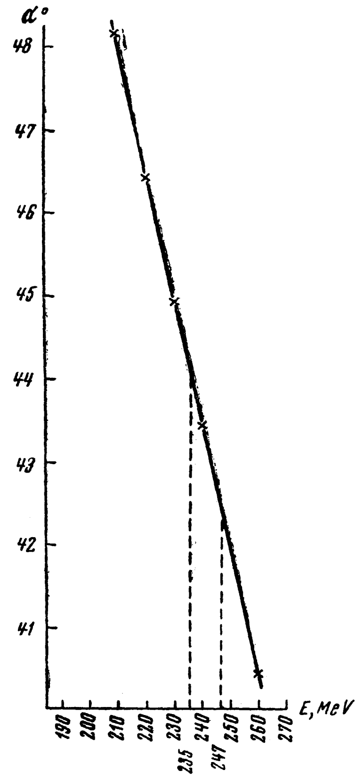

FIG. 2. Variation of the angle of deflection for particles in the magnetic field with energy.

chose to determine the ratio of the "semi-integral" cross section for Compton scattering to the "semi-integral" cross section for pair creation. This method is particularly effective if both the observed recoil electron and one of the pair electrons has an energy very close to the maximum energy of the incident photons. At high photon energies the total cross section for Compton scattering is much less than the cross section for pair creation. The

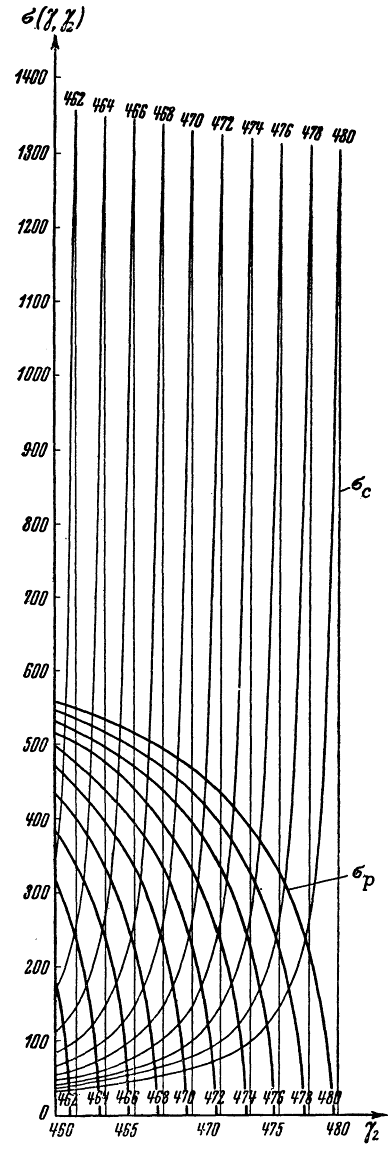

FIG. 3. Variation of the differential cross section σ_C for Compton scattering, and σ_P for pair creation with electron energy, for different values of the incident photon energy γ. The values of γ are indicated on the curves. The unit for the cross sections is 0.78×10^{-30} cm^2.

differential cross sections of the two processes are of the same order when the energy γ_2 of the observed electron or positron lies in a certain interval close to the energy of the incident photon. (Cf. Fig. 3). This fact makes it possible to obtain the number of recoil electrons by subtraction from the total number of electrons with energies

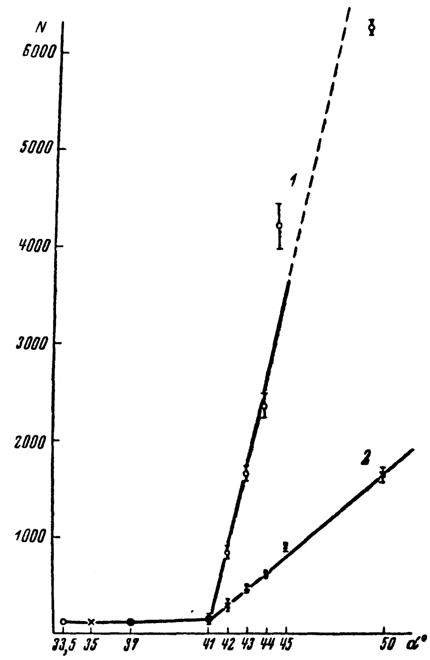

FIG. 4. Counting rate of electron telescope against angle of deflection in the magnetic field. Curve 1-with, Curve 2-without beryllium target.

close to the energy of the incident photons.

One of the main factors in setting up the cross section measurements was the accurate placing of the telescopes in space, and their adjustment for the selected electron and positron energy. If the target is removed from the photon beam,then ideally the counter should not record any particles at any angle. In practice, some charged particles are always produced in the air near the beam, and some scattered photons will create charged particles in parts of the apparatus; in addition, the beam may still contain some charged particles which have got through the cleaning fields. Therefore there will be a certain counting rate in the absence of a target. This background count of charged particles was always determined and subtracted. When the target was placed in the beam, the counting rate increased by a large factor. Figure 4 shows the counting rate N_- of the counter telescope as a function of the angle α, the deflection of the electrons in the magnetic field. The electrons and positrons of the maximum energy were deflected by a certain angle α_{max}. At telescope angles less than α_{max}, the counting rate diminished sharply. The break in the curve for the counting rate determines the maximum energy of the electrons and positrons, and hence also the maximum energy of the photons in the beam. The maximum photon energy in the beam was found by this method to lie between 249 and 254 mev, which agrees with the nominal value (250 mev) of the maximum energy of the photons from the synchrotron.

In order to check the performance of the apparatus, the ratio of the cross sections for pair creation and Compton scattering was measured for different target materials. The results obtained for targets of elements with low Z agree with the Z dependence of this ratio calculated from the Bethe-Heitler formula for pair creation. For high Z, when the Bethe-Heitler formula is not applicable, one has to use for the pair creation cross section formulas obtained in references,[3,4] and to allow for the fact that the pair occurrenceof an electron or a positron of given energy has different probability.

For the calculation of the ratio of the "semi-integral" cross sections for Compton scattering and pair creation from the theoretical formulas it turned out to be important to know the spectrum of the incident photons. The magnitude of this ratio is, however, not very sensitive to the shape of the spectrum (different calculations of the ratio for a Schiff spectrum and a $1/\gamma$ spectrum differed only by about 20%). In our case, when the synchrotron pulse is spread out in time, the spectrum is in the neighborhood of the maximum, in good approximation proportional to $1/\gamma$, as can be seen from the measured numbers of positrons in the intervals 222-233 and 235-247 mev.

Calculations of the required ratio between the cross sections for a spectrum of this form gave for the energy intervals 235-247 and 222-233, to which the measurements relate, the values 2.01 and 0.85, respectively.

The results of the measurements of the ratio between the "semi-integral" cross sections for the intervals 235-247 and 222-233 mev are 1.84 ± 0.18 and 0.71 ± 0.08, respectively. Thus we find a good agreement between the calculated and measured ratios of the "semi-integral" cross sections for Compton scattering and pair creation.

Since the validity of the formula for the pair production cross section (for low Z) in the energy region of 200 to 300 mev has been established experimentally,[5] our results may be taken as confirming the validity of the Klein-Nishina-Tamm formula at incident photon energies of 220 to 250 mev.*

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*In a short communication[6], measurements of the cross section for Compton scattering with photons of 250 mev have been reported. The results of these measurements are also in agreement with the theoretical formula for the scattering of photons by free electrons.

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